Advancing Pedagogical Methodologies through the Development of a Robotics Training Manual (RTM) for Mathematics

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***Abstract*—Robotics is a discipline intrinsically grounded on mathematics since the latter is the foundational framework for numerous aspects of robotics. This paper is a design and development research aimed at identifying the most difficult learning topics in grade 7 Mathematics and developing a training manual that integrates robotics technology in pedagogy. It generally aims to assist in improving Filipino learners' mathematics knowledge and skills through robotics. The study employed a researcher-made survey questionnaire and an evaluation form. The findings revealed that the ten most difficult topics include algebraic expressions, arithmetic and geometric sequences, simulator calculators, scientific calculators, protractors, and polygons. Following the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) Model, a Robotics Training Manual (RTM) was crafted, designed, and developed to introduce distinctly diverse pedagogical approaches to teaching these Mathematics topics. The results of the evaluation showed that the RTM is highly acceptable in terms of its objectives (M = 3.75), content and activities (M = 3.79), and assessment (M = 3.60). These results indicate that the RTM aligns well with the identified most difficult learning topics of the K to 12 Curriculum. It further implies that its content and activities are pertinent to learners' needs, and its assessments promote higher-order thinking skills. By incorporating robotics into mathematics instruction, educators can highlight the interconnectedness of various subject areas and demonstrate the application of mathematical concepts across different fields. This interdisciplinary approach fosters a comprehensive understanding of mathematics and underscores its relevance to other curricular endeavors in diverse contexts.**

***Keywords*—design and development research, mathematics education, robotics technology, training manual**

I. Introduction

Robotics and mathematics are essentially and technically intertwined, though independently directed, fields of endeavor, with mathematics much touted as the backbone for robotics technology. Robotics provides a tangible and engaging way for learners to apply and use theoretical mathematical concepts. For example, a teacher may engage learners_in activities like programming robots to navigate mazes. This teaches Cartesian coordinates and spatial reasoning [1]. Another example would be learning about ratio and rates by allowing learners to utilize robots and challenge them to test how fast a robot (e.g., rover) would hit an object on a coordinate plane [2]. Such practical applications are some examples of the many that exhibit how robotics foster deeper comprehension of complex topics in mathematics by allowing students to physically interact with the concepts they learn in the classroom.

Mathematics demands consistent practice to reinforce learning among learners and for them to develop problem-solving skills. Without regular practice, learners may struggle to apply mathematical concepts effectively [3]. Using ineffective study methods, like passive learning, or focusing solely on memorization can impede learners' understanding and retention of mathematical concepts. Learners who lack motivation or fail to see the relevance of math may disengage from learning, leading to poor performance [4]. Addressing these factors often requires a combination of targeted instruction, supportive learning environments, and a mindset that encourages learners to embrace challenges while learning from mistakes.

In the 2022 Program for International Student Assessment (PISA), the Philippines ranked 77th out of 81 countries globally. This was conducted by the Organization for Economic Co-operation and Development (OECD) for 15-year-old learners across the globe. The country scored approximately 120 points lower than the average: 355 in math, 347 in reading, and 373 in science. These results are considered as a school failure [5].

One of the main causes of school failure among learners is the lack of interest and boredom [6]. This may sometimes be caused by the usual strategies used by current education systems that usually do not focus on innovative activities; those that promote student active and meaningful participation. Considering the low retention level among learners, teachers are encouraged to enhance students' mastery of topics by incorporating games and manipulatives into their teaching.

Recently, the Philippines has been actively promoting initiatives in Science, Technology, Engineering, and Mathematics (STEM) education. This also include integrating robotics into the curriculum. By integrating robotics into the K to 12 Curriculum, the Philippines may enhance its educational system's capacity to prepare learners for the challenges and opportunities of the 21st century. This consequently fosters innovation, creativity, and resilience among its future workforce: today's learners [7].

The integration of robotics in mathematics education has garnered significant attention due to its potential to enhance students' attainment of learning outcomes, engagement, and

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problem-solving skills. The importance of tangible learning experiences in mathematics education is emphasized in robotics integration. Robotics provides learners hands-on opportunities to explore abstract mathematical concepts in a concrete, tangible manner; thereby, promoting deeper understanding and retention [8]. The academe seeks the significance of real-world applications in mathematics education, suggesting that robotics projects offer learners authentic contexts in applying mathematical concepts to make learning more relevant and meaningful [9].

As the need to discuss robotics integration in mathematics education rises, the challenge for learners to solve complex problems and practice critical thinking comes to the fore [10, 11]. The importance of preparing learners for the demands of the 21st-century workforce is also a factor to consider. This posits that robotics education may equip learners with essential skills such as critical thinking, creativity, and technological literacy, which are increasingly valuable in an evolving global economy [12].

Additionally, the potential of robotics in addressing diverse learning needs in mathematics education brings about an educational landscape to be explored. This suggests that robotics projects may be tailored to accommodate different learning styles and abilities, thereby providing inclusive learning experiences for all learners [13]. The interdisciplinary nature of robotics projects is a substantial matter to study as it has potential to integrate concepts from science, technology, engineering, and mathematics (STEM). Thus, it can help in promoting a holistic understanding of the said disciplines and fostering connections across curricular areas [14, 15].

In a nutshell, the highlighted research and literature underscore the significance of robotics in mathematics education. It can serve as a means of promoting meaningful learning experiences while fostering problem-solving skills, enhancing student engagement, and preparing learners for future success in a technology-driven world.

Bridging the gap in mathematics education through a robotics approach involves integrating hands-on, experiential learning opportunities with mathematical concepts. Research by Valera *et al*. [12] emphasizes that robotics provides a tangible context for learners to engage with mathematical concepts such as geometry, measurement, and algebra. Nam *et al*. [16] and Bento *et al*. [17] suggest that robotics challenges require learners to apply mathematical concepts in real-world contexts, leading to deeper understanding and improved problem-solving abilities. Alam *et al.* [13] investigated the potential of robotics in promoting inclusive mathematics education for learners with diverse learning needs. Their research suggested that robotics activities can provide accessible and engaging learning experiences that accommodate different learning styles and abilities. The study of Jahnes *et al*. [18] even demonstrated that an educational module highlighting the connection between robotics and mathematics significantly improved learners' enjoyment, appreciation, and understanding of mathematical concepts. Their findings perceived the introduction of educational modules to intensify the connection between robotics and mathematics in stimulating learners' enjoyment, appreciation, and understanding of the concepts of mathematics within the field of robotics.

All in all, these studies consistently demonstrate the potential of robotics as a powerful tool in boosting learners' knowledge, understanding, engagement and problem-solving skills in Mathematics.

By providing learners with highly interactive and hands-on learning experiences, robotics may be able to inspire a new generation of mathematical learners. Robotics projects often involve teamwork, allowing learners to collaborate with their peers in designing, building, and programming robots. Through collaboration, learners learn to communicate effectively, share ideas, and work together towards a common goal.

The link between robotics and mathematics and its usefulness in boosting the mathematical knowledge and skills of learners requires teachers' effort and action. Teachers play a fundamental role in the design and implementation of activities involving the robotic platform [19]. Teachers may design hands-on activities that require learners to use mathematics skills to solve problems and accomplish tasks with robotics technology. For example, learners can use geometry concepts to calculate angles for robot movements or algebra concepts to create equations for controlling robot speed and distance.

By integrating robotics into teaching mathematics, educators can create engaging and interactive learning experiences that help learners develop a deeper understanding of mathematical concepts and transform these concepts into real-world applications.

Despite all these, robotics projects and its history in mathematics education may not always target specific learning outcomes or targets. This paper presents a more systematic process of integrating robotics into mathematics education; that is, identifying specific targeted topics, designing activities or projects geared towards mastering the topics, and evaluating the activities manual to ensure its effectivity and functionality. Moreover, this paper is inspired by the overwhelming challenge seemingly posed among Filipino educators to improve the Filipino learners' competency level and knowledge in Mathematics.

With the background information discussed and research gap mentioned, the researchers aimed to develop a training manual that integrates robotics technology in teaching mathematics. Specifically, this study sought to:

1) Identify the most difficult learning topics in Grade 7 mathematics.
2) Develop a training manual integrating robotics technology based on the most difficult topics in Grade 7 mathematics.
3) Determine the level of acceptability of the developed training manual integrating robotics technology.

II. Literature Review

This paper highlights the utilization of design and development research in developing a training manual revolving around robotics in mathematics. Design and Development Research (DDR) studies generally focus on the design and evaluation of educational programs, materials, and practices. It combines both quantitative and qualitative research methods to improve instructional design by testing theories, models, and frameworks. This research is essential for instructional designers to validate their practices and enhance educational outcomes. At the core of instructional design and technology is the evaluation of instructional products, tools, programs, and models [20]. DDR not only supports the development of new educational artifacts but also facilitates the continuous improvement of existing frameworks and practices. This, in turn, contributes to the evolving landscape of instructional design. By focusing on real-world applications, DDR helps bridge the gap between theory and practice across all disciplines of education.

Similarly, this study also seeks to design, develop and evaluate an educational material: a robotics training manual. The use of DDR allowed the researchers to attain its objectives while following the appropriate theories and concepts surrounding the variables of the study. The variables include robotics, mathematics education and training manual development.

The integration of robotics into mathematics education has proven to be instrumental in enhancing student engagement and learning outcomes. Through the incorporation of robotics technology, learners experience notable improvements in various aspects of mathematical understanding, including utility, application, perceived utility, and comprehension of computational concepts [21]. Future primary education teachers recognize the extensive benefits of integrating educational robotics into mathematics lessons because of its ability to evoke diverse emotions and provide learners with newfound possibilities for exploration and learning [22]. Furthermore, educational robotics engages learners to think in critical and computational terms, to solve problems, and to collaborate; hence, it widens the scope of educational opportunities available to learners of varying learning styles and abilities [23].

However, the integration of robotics technology into formal mathematics education is as challenging as any strategy or technique in any field of study. One significant hurdle lies in aligning robotic learning activities with curriculum goals and effectively integrating them with traditional learning methods [24]. Additionally, the shortage of qualified teachers in educational robotics presents a notable barrier to the widespread adoption of robotics technology in both school and supplementary educational settings [25].

Despite these challenges, the cognitive benefits of incorporating robotics technology into mathematics education are profound [26]. Research indicates that educational robotics enhances learners' interdisciplinary knowledge and skills, with educators noting positive perceptions of student learning outcomes, including the development of critical 21st-century skills and proficiency in programming [27]. Moreover, the use of robotics in mathematics education has the potential to enhance accessibility, motivation, and engagement among learners. In particular, it benefits those with visual impairments by providing enhanced engagement, multimodal learning opportunities, and improved collaboration and communication skills [28].

Efforts to effectively integrate robotics technology into the mathematics curriculum at various educational levels have yielded promising results. Studies have shown that the use of robotics in mathematics education significantly improves student attention and motivation, laying the groundwork for an effective teacher-tool relationship and ultimately leading to better learning outcomes in mathematics [29]. Educators with prior experience in educational robotics are supportive of its integration into school curricula, advocating for its inclusion even at early educational stages [27].

Finally, while the integration of robotics technology into mathematics education offers significant benefits, including enhanced student engagement, cognitive benefits, and solutions to existing challenges, the need for qualified teachers and alignment with curriculum outcomes remains a critical consideration for effective implementation. The potential of educational robotics to improve accessibility, motivation, and engagement, particularly among vision-impaired learners, underscores the importance of further research and intervention studies to explore and refine its integration into mathematics education.

III. Research Design and Methodology

A. *Research Design*

Design and Development Research (DDR). The employment of DDR methodology in this study is justified by its efficacy in bridging theory and practical application. DDR is particularly esteemed for its capacity to establish innovative procedures, techniques, and tools through specific needs analysis [30]. The DDR approach has been referred to by various names in the literature, including design-based research, formative research, and design research [31, 32].

DDR is defined in the educational context as the systematic study of design, development, and evaluation processes to establish an empirical foundation for the creation of instructional and non-instructional products. It focuses on the iterative development and testing of educational interventions, ensuring that the resulting products are both theoretically sound and practically viable [30].

Moreover, Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model was used as a guide to produce an effective design in the development of an effective training manual. This model is an approach that helps instructional designers, content developers, or even teachers to create an efficient and effective teaching design by applying the processes of the ADDIE model to any instructional product. In addition, this systematic process is represented in the acronym ADDIE, which stands for the important components in the process of creating the instructional design, which runs sequentially through analysis, design, development, implementation, and evaluation. Each phase in the ADDIE model is related to and interacts with each other.

B. *Participants*

One of the main factors surrounding the purpose of this study is the low performance of the Philippines in international standardized tests. An example would be the results of the country in the Program for International Student Assessment (PISA). This also seeks to contribute to the enhancement of the country's student assessment results. For this study, the participants were the thirty (30) purposively selected Junior High School mathematics teachers in the province of Iloilo, Western Visayas region of the Philippines. Purposive sampling was utilized in this study because it can offer reliable results and insights in a cost-effective manner. It allows for targeted inclusion of participants who can provide detailed information on specific aspects of a phenomenon [33]. Additionally, it enables researchers to explore smaller sample sizes in-depth, which can lead to significant findings.

The participants were identified by the mathematics division supervisor who has acquired knowledge with Grade 7 topics and is thus technology-adept. The Department of Education Division of Iloilo conducted an assessment of all their Mathematics teachers' technological skills during their summer in-service program. Based on this evaluation, the mathematics teachers who demonstrated a high level of technological proficiency were selected by the supervisor to participate in the study. These teachers were involved in the analysis of challenging mathematics learning topics using a checklist and also participated in the pilot implementation of the Robotics Training Manual (RTM). The feedback from these 30 teachers during the pilot phase became instrumental in aligning mathematics learning topics with robotics activities, which informed the development of the training manual.

Moreover, six experts evaluated the acceptability of the developed RTM. Among these six experts, two were curriculum development experts, one was a grammar/English professor, another one was a Regional Education Program Supervisor in Mathematics, and the last two were Robotics and Information and Communication Technology (ICT) coordinators.

C. Research Instrument

To gather data for the study, two research instruments were used, namely, a checklist of difficult learning topics in Mathematics 7 and a robotics manual evaluation sheet.

Checklist of Difficult Learning Topics in Mathematics 7. The instrument utilized in this study is a 5-point Likert checklist specifically designed to evaluate the most essential learning topics in the K to 12 Mathematics Curriculum for Grade 7. It consists of 64 items which include all Mathematics 7 learning topics/competencies prescribed by the Department of Education's K to 12 curriculum guide. These topics are: Number and Number Sense, Measurement, Geometry, Patterns and Algebra, and Statistics.

Participants are required to assess each competency based on its perceived difficulty to teach, with options ranging from "Very Difficult" to "Not Difficult." The data gathered from this checklist serves as the foundation for developing an RTM, which is tailored to address the areas identified as particularly challenging.

To ensure the validity and reliability of the instrument, it underwent rigorous validation by subject matter experts, confirming its content validity. Furthermore, reliability testing was conducted using Cronbach's alpha, resulting in a coefficient of 0.84. This high reliability coefficient indicates that the instrument consistently measures the perceived difficulty of the topics, thus providing a dependable basis for the development of effective training resources.

Robotics Manual Evaluation Sheet. The evaluation sheet was employed to identify which aspects of the RTM were acceptable and which could be improved. It is divided into three sections, each containing ten statements addressing the areas of objectives, content, and assessment.

The objectives section evaluates whether the goals of the training manual are clearly defined, relevant, and achievable. The content section assesses the material provided in the training manual, examining its accuracy, comprehensiveness, and engagement level. Finally, the assessment section focuses on the methods and tools used to evaluate the learners' progress and understanding.

The researcher-developed instrument, structured as a Likert scale, underwent rigorous content validity testing before its implementation. As a reliability measure, the Cronbach alpha shows a result of $\alpha = 0.78$ indicating that the evaluation sheet is reliable. Participants' scores were based on a five-point scale, where participants indicated their level of agreement with each item, as follows: 5—Strongly Agree (SA), 4—Agree (A), 3—Neutral (N), 2—Disagree (D), and 1—Strongly Disagree (SD).

D. Data Collection Procedure

The research followed the ADDIE model comprehensively.

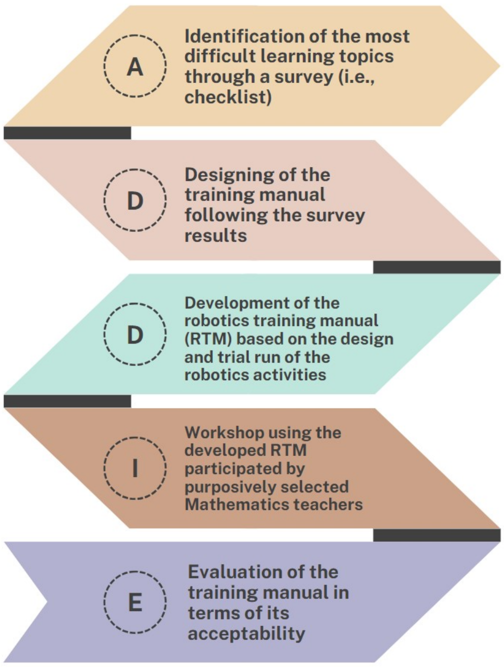


Fig. 1. The ADDIE model for the robotics training manual development.

Analysis. In this stage, the checklist of Mathematics learning topics was created to identify the challenging learning topics in Mathematics to teach from the K to 12 Mathematics Curriculum. After establishing validity and reliability, the checklists were given to the teachers and were retrieved after. The results were analyzed using mean, standard deviation and rank to determine the most difficult topics for Mathematics 7. The outcomes of this analysis served as basis for the development of the RTM.

Design. This stage involved several key steps: determining initial data, deciding on content, creating the design, and finalizing the design. The identified learning topics served as the foundation for the RTM. The content was structured to include preliminary sections, objectives, a contextual overview, detailed content, procedures, assessments, reflections on learning, and concluding remarks. The design was crafted using Canva, a free online layout platform. After creating the initial layout, the researcher completed the planning and designing phase.

Development. During the development stage, the researchers focused on the feasibility of the robotics activities and their alignment with the learning topics. The development of the training manual and the trial run of the robotics activities were conducted simultaneously. The RTM consists of five activities: Robotics on Algebraic Expression, Robotics on Arithmetic and Geometric Sequences, Robotics on Simulator Calculator, Robotics on Protractor, and Robotics on Visualizing 3D Polygons. The manual and associated research instruments were submitted for validation, and feedback was gathered to enhance the instructional material.

After the development of the training manual, it underwent face and content validity to help the researcher in the enrichment and enhancement of mathematical concepts and content. A validation instrument adapted from Good and Scates [34] was used to determine the validation of RTM. Suggestions, comments, and recommendations were gathered also to further enhance the training manual.

Implementation. For the implementation stage, thirty Mathematics teachers under the K to 12 Curriculum were purposively selected to participate in the training workshop. Following approval from the Schools District Office of Iloilo Superintendent, a division memo listing participants and outlining activities was released. The researchers conducted a 2-day workshop on the implementation of the RTM in Mathematics 7 on March 19-20, 2024, from 7:30 AM to 4:30 PM at West Visayas State University- Center for Teaching Excellence.

During the implementation stage, teachers provided constructive feedback aimed at enhancing the manual. One key issue raised was that certain chapters required resources, such as robotics kits and specific materials, which were not readily available or affordable for some schools. To address this concern, the manual was revised to suggest the use of alternative, low-cost materials or activities that would still fulfill the educational objectives without the need for specialized equipment. Additionally, for those keen on working with robotics, the manual recommends borrowing Arduino starter kits from schools that already offer robotics programs.

Another significant piece of feedback involved the clarity of instructions. Some teachers, particularly those with limited experience in robotics, found the instructions unclear or overly technical. In response, the researchers revised several activities by providing more explicit, step-by-step instructions and incorporating additional visuals to better guide both teachers and students throughout the process.

Evaluation. After the implementation stage, thirty (30) Mathematics Teacher looked into the acceptability of the RTM in terms of objectives, content, and assessment. The results were analyzed using mean and standard deviation. Also, two (2) curriculum development experts, one (1) grammar/English professor, one (1) regional education program supervisor in Mathematics, and two (2) Robotics and ICT coordinators evaluated the RTM on its acceptability using mean and standard deviation.

Fig. 1 shows a visual representation of the ADDIE model-based procedure of this research.

Data collected from the Checklist of Difficult Learning Topics in Mathematics 7 were analyzed using mean and standard deviation. Meanwhile, the results taken from the Robotics Manual Evaluation Sheet were also analyzed using mean and standard deviation.

E. Ethical Consideration

This research was conducted by observing and subscribing to the ethical policies and guidelines prescribed by the American Psychological Association [35] and the graduate school of the College of Education of the West Visayas State University. The researchers made sure that there was no harm, either physical or psychological, inflicted upon the respondents/participants. Moreover, their participation was classified to be voluntary, i.e., they could withdraw anytime they wanted to. Also, the study observed confidentiality and the researchers did their best to protect the participants' anonymity and identity. In instances where their identities could be divulged through the posting of pictures, for example, their permission and full consent were accordingly sought.

IV. Result and Discussion

A. Results

1) Most difficult learning topics in mathematics

Understanding the most difficult mathematics topics is crucial in designing an effective curriculum [36, 37]. The process of identifying challenges in education is crucial for educators to prioritize topics, sequence them logically, and scaffold learning experiences [38].

The study assessed Grade 7 mathematics topics based on teachers' perceptions as shown in Table 1. The most challenging competency was solving quadratic equations by factoring ($M = 3.74$, $SD = 0.43$), indicating significant student struggles with both the procedural and conceptual aspects. Following closely, solving quadratic equations by extracting square roots ($M = 3.56$, $SD = 0.34$) and solving problems involving algebraic expressions ($M = 3.23$, $SD = 0.45$) were also highly challenging for learners. These findings point to a need for targeted interventions and support in these areas.

Several other topics were also identified as challenging. Describing principal roots and determining their rationality ($M = 3.19$, $SD = 0.42$) requires learners to understand both the concept of roots and number classification. Solving problems involving rational and irrational numbers ($M = 3.11$, $SD = 0.65$) and performing operations involving trigonometric functions ($M = 3.03$, $SD = 0.24$) are difficult due to their abstract nature. Additional difficulties were noted in solving problems involving the sides and angles of a polygon ($M = 2.94$, $SD = 0.53$), illustrating various types of angles ($M = 2.91$, $SD = 0.51$), determining geometric means and the nth term of a geometric sequence ($M = 2.89$, $SD = 0.49$), and solving problems involving sequences ($M = 2.01$, $SD = 0.32$).

Table 1. Most difficult learning topics in mathematics

Learning Topics	SD	M	Rank
solves quadratic equations by factoring	0.43	3.74	1
solves quadratic equations by extracting square roots	0.34	3.56	2
solves problems involving algebraic expressions	0.45	3.23	3
describes principal roots and tells whether they are rational or irrational	0.42	3.19	4
solves problems involving rational and irrational numbers	0.65	3.11	5
performs operations involving trigonometric functions	0.24	3.03	6
solves problems involving the sides and angles of a polygon	0.53	2.94	7
illustrate supplementary angles, complementary angles, congruent angles, vertical angles, and adjacent angles	0.51	2.91	8
determines geometric means and nth term of a geometric sequence	0.49	2.89	9
solves problems involving sequences	0.32	2.01	10

2) *Robotics Training Manual in Mathematics Education*

After the most difficult learning topics were identified, the training manual on robotics was designed and developed.

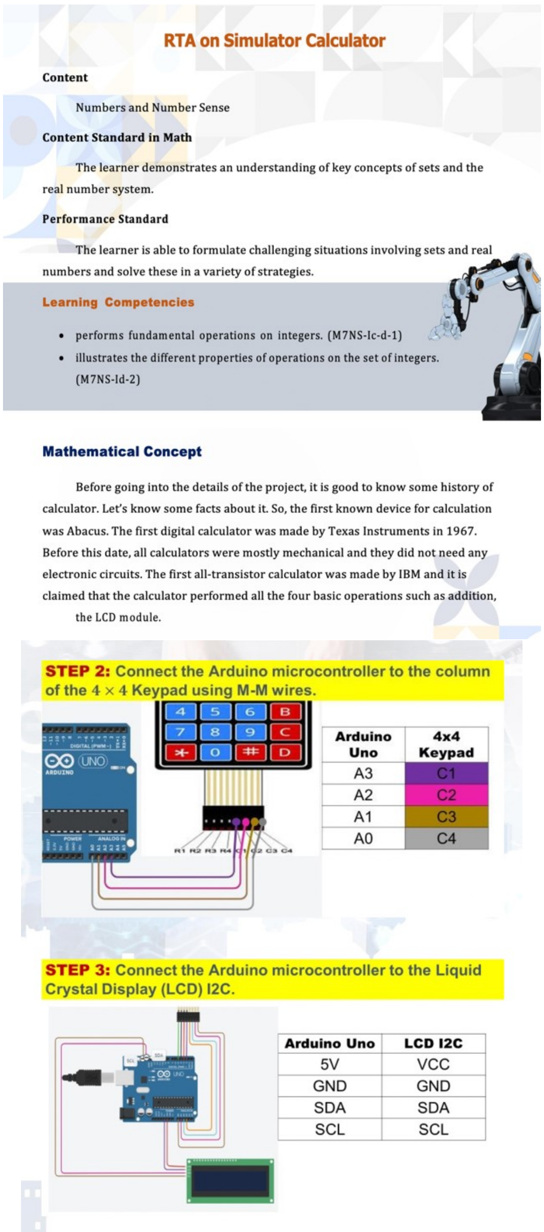
The RTM includes five activities: Robotics on Algebraic Expression, Robotics on Arithmetic and Geometric Sequence, Robotics on Simulator Calculator, Robotics on Scientific Calculator, Robotics on Protractor, Robotics on Measurement, and Robotics on Visualizing 3D Polygons. The learning topics that attained the highest rating (or mean) were clustered according to the general mathematics topic/s it corresponds to. For example, solving quadratic equations by factoring and solving quadratic equations by extracting square roots were clustered together into one main topic. Afterwards, robotics activities were developed for algebraic expressions (including the two topics mentioned). All the top 10 identified most difficult learning topics were integrated in these seven RTM. These activities integrate robotics with key learning topics, providing a hands-on, interactive approach to mathematics education. This integration supports the development of a coherent and effective mathematics curriculum, improving student engagement and outcomes.

Each learning topic listed on the table corresponds to a specific learning competency set by the Department of Education in the Philippines. An example would be M7NS-Ic-1. This can be interpreted fundamentally by its beginning letters and Fig. 2. For example: M7NS-Ic-1 would refer to a certain learning competency in Mathematics 7 [39].

After the alignment as shown in Table 2, the RTM for mathematics was developed to provide comprehensive guidance and structured learning materials for integrating robotics into mathematics education. Following this, the training manual was meticulously crafted to include step-by-step instructions, practical exercises, and theoretical explanations designed to enhance learners' understanding of mathematical concepts through the use of robotics. The development of this manual marked a significant step towards innovative and interactive mathematics education, utilizing the power of robotics to enhance student engagement and learning outcomes.

Table 2. Alignment of RTM to topics and learning topics in mathematics

RTM	Topic	Learning Topics
RTM 1	Algebraic Expression	solves quadratic equations by factoring (M7AL-Ic-1) solves quadratic equations by extracting square roots (M7AL-Id-1) solves problems involving algebraic expressions (M7AL-IIg-2)
RTM 2	Arithmetic and Geometric Sequence	determines geometric means and nth term of a geometric sequence (M10AL-Ie-1) solves problems involving sequences (M10AL-If-2)
RTM 3	Scientific Calculator	describes principal roots and tells whether they are rational or irrational (M7NS-Ig-1) solves problems involving rational and irrational numbers (M7NS-Ij-1) performs operations involving trigonometric functions (M9GE-Ii-1)
RTM 4	Protractor	illustrate supplementary angles, complementary angles, congruent angles, vertical angles, and adjacent angles (M7GE-IIIb-1)
RTM 5	Visualizing 3D Polygons	solves problems involving the sides and angles of a polygon. (M7GE-IIIj-1)



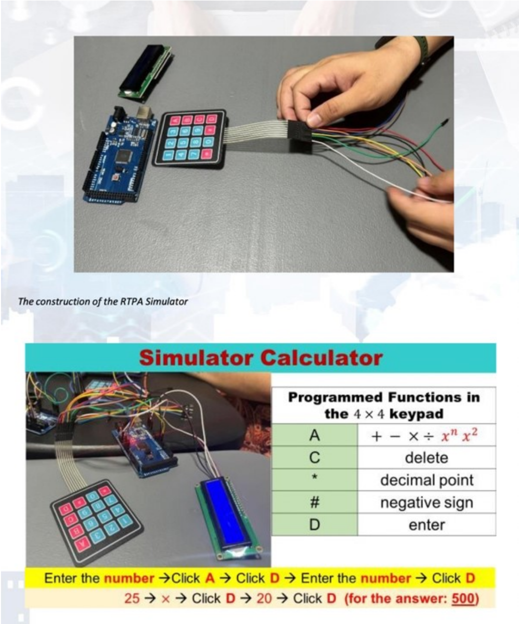


Fig. 2. Sample robotics training manual.

3) *Acceptability of robotics training manual*

This study determined the overall acceptability of the developed RTM in terms of its objective, content and activities and assessment. Thirty (30) Mathematics teachers and six experts have examined and evaluated the developed RTM Training Manual to determine its acceptability.

Table 3 shows that the RTM has been evaluated as *highly acceptable,* achieving an overall mean score of 3.73 with a standard deviation of 0.45. This indicates that the manual meets the high standards of quality for instructional material in mathematics, with participants consistently rating it highly suitable for Grade 7 learners.

Table 3. Acceptability level of the robotics training manual in mathematics education

Indicators	SD	M	Description
Objective	0.44	3.75	Highly Acceptable
Content and Activities	0.41	3.79	Highly Acceptable
Assessment	0.50	3.66	Highly Acceptable
Grand Mean	0.45	3.73	Highly Acceptable

Note: 3.51–4.00 (Highly Acceptable), 2.51–3.50 (Acceptable), 1.51–2.50 (Slightly Acceptable) and 1.00–1.50 (Not Acceptable)

Participants rated the content and activities sections the highest (M = 3.79, SD = 0.41), followed by the objectives (M = 3.75, SD = 0.06). The assessment section, while receiving the lowest mean rating, was still rated highly (M = 3.66, SD = 0.50). These ratings suggest that the RTM aligns well with the K to 12 Curriculum learning topics. The content and activities are relevant to learners' needs, and the assessments effectively foster higher-order thinking skills.

Although all aspects of the manual were evaluated as highly acceptable, revisions were made in response to the feedback provided by teachers and evaluators to ensure the highest level of usability and effectiveness. These revisions were not indicative of deficiencies but rather opportunities for refinement and improvement. For instance, some activities were adjusted to simplify instructions and make them more accessible for teachers with varying levels of experience in robotics. Additionally, suggestions from the evaluators prompted the inclusion of alternative, cost-effective resources to accommodate schools with limited access to specialized equipment. These revisions were intended to enhance clarity, practicality, and the overall alignment of the manual with both curriculum standards and the realities of diverse educational settings.

B. *Discussion*

Developing educational materials targeting specific topics, especially those identified as difficult topics, can significantly improve student outcomes in mathematics. The top three challenges—solving quadratic equations by factoring, extracting square roots, and working with algebraic expressions—suggest a need for enhanced instructional strategies, scaffolding, and additional resources. Moreover, understanding challenges related to roots, rationality, and trigonometric functions indicates potential areas for curriculum improvement. Hands-on activities and real-world applications could help explain these concepts to learners.

Overall, these findings underscore the importance of targeted support and intervention in mathematics education. By addressing these difficulties, educators can help learners build a strong foundation for more advanced concepts, ultimately improving their success in mathematics [40, 41]. Teachers' insights into these challenges are invaluable for shaping effective instructional practices and curriculum design.

Integrating robotics into mathematics education strengthens the STEM curriculum by harnessing 21st-century innovations for both teachers and learners. The Department of Education (DepEd) supports the robotics programs in schools nationwide, recognizing the importance of technology in student success. Robotics provides interactive learning opportunities, which Eguchi [42] found beneficial for student engagement. Moreover, educational robots can improve learners' accessibility, motivation, and engagement in mathematics by providing engaging and unique interactions [43, 44].

Robotics also offers tangible feedback through movements, enhancing understanding in mathematical games [45]. Li *et al*. [46] suggested that real robot interactions might generate greater enjoyment than virtual ones. The RTM for mathematics education was developed to apply these insights, enhancing student interest and making mathematical concepts more engaging through interactive and visual class discussions.

Mathematics is essential for all life stages, extending beyond the classroom. The K to 12 for Junior High School curriculum focuses on critical thinking and problem-solving and includes five content areas: Numbers and Number Sense, Measurement, Geometry, Patterns and Algebra, and Probability and Statistics, each fostering specific skills and processes. Also, the K to 12 Mathematics Curriculum lays a solid foundation for further studies in Grades 11 and 12, equipping Filipino learners with essential concepts and life skills.

Meanwhile, the findings of the evaluation of the RTM correspond with research on Computer-Generated Instructional Material (CGIM), which concluded that if the ratings of the objectives, content, activities, and evaluations are very high, then it would mean that the materials developed were well-suited for the target audience, contributing to the enhancement of mental habits, critical thinking, and problem-solving skills [47, 48]. Similarly, Sagge *et al.* [49] concluded that if the evaluation learning objectives, style, and presentation of developed video modules are very high, then it means that the material is adequate, sufficient, and appropriate for the intended users. These video lessons meet the standards for quality instructional materials, making them ideal supplementary resources to help learners perform well and actively in their tasks at their own pace. Tailored to match learners' cognitive levels, these modules effectively engage learners in learning topics, particularly mathematical concepts [50, 51].

As a result, the training manual, when combined with robotics technology, has the potential to help students learn mathematics more efficiently and effectively.

By providing practical applications of mathematical concepts, it can significantly enhance academic performance. Supporting this aim, Varaman *et al.* [52] demonstrated the positive impact of RTMs on mathematics education, highlighting the benefits of hands-on, inquiry-based learning experiences. These experiences promote mathematical understanding and achievement, enhancing learners' proficiency and interest for STEM subjects. Thus, the RTM not only aligns with curriculum standards but also fosters deeper engagement with mathematics by advancing pedagogical methodologies in teaching.

V. Conclusion

Identifying the most difficult learning topics in mathematics is crucial in providing targeted instruction, personalizing learning experiences, improving curriculum design, guiding assessment practices, and implementing effective interventions in instructional material development.

The integration of robotics technology in teaching mathematics presents new learning opportunities and innovations, enabling teachers to maximize their potential in mathematics instruction. Diverse pedagogical approaches should be provided to strengthen the strategies used in teaching mathematics to 21st-century learners.

Developing an RTM specifically tailored to mathematics can significantly enhance academic performance by offering practical applications of mathematical concepts. The RTM can serve as supplementary material in teaching and learning mathematics, creating new learning opportunities for both teachers and learners. By offering comprehensive guidance and resources, RTM empowers educators to effectively integrate robotics technology into mathematics instruction and inspire learners to explore mathematical concepts innovatively.

Meanwhile, robotics integration in mathematics education varies in terms of its setup, strategy of implementation and assessment types, time requirement among others. It is recommended that robotics in mathematics education be implemented in a manner that it follows the curriculum goals, and aligns with the school's prescribed classroom pedagogies and strategies. Diversion from the institutional guidelines may have implications on educators and also on the completion of the delivery of instruction of courses/subjects. It is positively suggested that the integration and implementation of robotics in mathematics education be done in collaboration with school stakeholders, administrators and leaders. This is to maximize its potential and deliver the best results of this likely new perspective in teaching mathematics concepts to learners.

Integrating robotics technology into mathematics education improves the learning experience, enhances mathematical proficiency, and prepares learners for success in a technology-driven world. Teachers may use robotics' engaging and interactive nature to foster curiosity, creativity, and confidence in mathematics learning. Exploring teachers' experiences with robotics technology in mathematics education provides valuable insights in the integration of innovative teaching methods.

By incorporating robotics into mathematics lessons, teachers can highlight the interconnectedness of different subject areas and demonstrate the application of mathematical concepts across various fields. This interdisciplinary approach fosters a holistic understanding of mathematics and its relevance in diverse contexts. Integrating robotics technology into mathematics education in a theoretically grounded manner can enhance learning outcomes and foster learners' mathematical understanding and problem-solving skills.

Overall, robotics technology offers a rich and engaging context for learning and applying mathematical principles. Through practical experimentation, problem-solving, and algorithm development, individuals can deepen their understanding of mathematics and acquire valuable skills applicable across various domains.

Conflict of Interest

The authors declared no conflict of interest.

Author Contributions

All authors contributed significantly to the completion of the work. IJMG contributed to the preparation and presentation of the published work, specifically by writing the initial draft, programming, software development, and testing code components; RGSJ and SPBJ were responsible for critical review, revisions, proofreading the article, and finalizing the format; RVHJ handled the application of statistical, mathematical, and computational techniques to analyze data; FIDS assisted with the implementation and testing of code. All authors had agreed the final version of the paper.

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