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ENGAGING MINDS WITH EDUCATIONAL ROBOTICS: VALIDATION OF A MATHEMATICS TEACHING PROGRAM BASED ON INSTRUCTIONAL DESIGN

Involucrar mentes con la robótica educativa: validación de un programa de enseñanza de matemáticas basado en el diseño instruccional

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Abstract

This paper presents the design and validation of a methodological framework for teaching Mathematics using Educational Robotics to develop students' competencies (knowledge, abilities, and attitudes). The program design adhered to Robert Gagné's instructional design proposal, incorporating learning activities from a holistic perspective. An important step in this process was identifying the contents suitable for applying educational robotics as a learning mediation tool. The program underwent validation through expert judgment, employing the Delphi Method to select the experts. The validation results, evaluated using the Aiken V index, demonstrated a high level of agreement among the experts regarding the validity of the pedagogical and functional dimensions, with Aiken V indexes of 0.97 and 0.92, respectively.

Resumen

Este artículo presenta el diseño y validación de un marco metodológico para la enseñanza de Matemáticas utilizando la Robótica Educativa para desarrollar las competencias (conocimientos, habilidades y actitudes) de los estudiantes. El diseño del programa se apegó a la propuesta de diseño instruccional de Robert Gagné, incorporando actividades de aprendizaje desde una perspectiva holística. Un paso importante en este proceso fue identificar los contenidos adecuados para aplicar la robótica educativa como herramienta de mediación en el aprendizaje. El programa fue validado mediante juicio de expertos, empleando el Método Delphi para seleccionar a los expertos. Los resultados de la validación, evaluados mediante el índice V de Aiken, demostraron un alto nivel de acuerdo entre los expertos sobre la validez de las dimensiones pedagógica y funcional, con índices V de Aiken de 0,97 y 0,92, respectivamente.

Keywords

Mathematics education, Educational Robotics, Competency development, Instructional design, Delphi Method validation.

Palabras clave

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1. Introduction

In the dynamic world of education today, teachers are constantly challenged to adapt and improve their skills. This scenario includes adopting innovative methods and strategies to develop and enhance students' skills and competencies (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2021). Among the diversity of strategies, educational robotics is presented as a tool that contributes to developing these skills and awakens interest in learning (Caballero-González & García-Valcárcel, 2020). Educational robotics is a discipline whose purpose is the conception, creation, and implementation of specialized programs for pedagogical purposes (Ruiz-Velasco, 2013). Furthermore, it guides students to develop thought patterns and progressively enhance the organization of logical and formal thinking, accomplished through various challenges. Learning with robotics enables the exploration of fresh thinking and learning strategies in an interdisciplinary manner, as it facilitates the integration of diverse subject matter into activities tailored to individual students' characteristics and needs (Gómez y Martínez, 2018; Valiente y Montaño, 2017).

As a discipline applied in education, educational robotics is grounded in the pedagogical principles of constructionism and constructivism. According to Vygotsky's perspective, the objective is for students to engage and collaborate, actively fostering an optimal learning process. Consequently, the student's cognitive development begins from an actual starting point and progresses toward a state of potential cognitive development through interactive engagement with the teacher (Molina, 2023). According to constructivist theory, students are perceived as designers and builders of projects where they can imagine, simulate, create, and innovate. In this way, learning with robotics develops basic skills, such as logical mathematical thinking, computational thinking or problem-solving, so that students can interact with technology during their development (Jurado et al., 2020). The constructionist approach, based on constructivism, enables students to learn through experience, fostering the development of mental structures that organize and relate information to everyday situations (Papert & Harel, 1991). As a result, the constructionist approach to teaching through educational robotics contributes to creating heuristic learning contexts primarily supported by student participation. This approach facilitates learning through students' experiences during design, construction, and prototype testing (Caballero-González & García-Valcárcel, 2020, p.75)

The use of robotics in education enables the development of concepts that are often abstract for students. Additionally, it fosters the acquisition of new skills while strengthening the student's systemic, logical, structured, and formal thinking. Educational Robotics has evolved and been settled as a complete methodology aiming to present challenges constantly to students, giving incentives to reflect and formulate ideas on how to solve such obstacles (Moura, 2021, p.17). In other words, integrating robotic elements in teaching and learning processes allows for the development students' competencies. Competencies encompass the capacity to acquire knowledge, skills, values, and attitudes that enable individuals to respond appropriately to everyday situations within their context (Carrillo et al., 2018). The methodological guidelines for competence development are based on the principle of essentializing content, aiming to foster rational and critical thinking and encourage both individual and cooperative work.

In this proposal, students can actively engage with the robot through hands-on manipulation and experimentation, utilizing basic routines to control its actions. To facilitate this process, we have considered the stages outlined by Bravo-Sánchez and Forero-Guzmán (2012) for the successful implementation of robotics in the classroom. These stages are as follows:

1. Integrating robotics-based technological resources into the curriculum: In this initial stage, the curriculum content is analyzed, along with determining how robotics can be involved in their development.

2. Restructuring pedagogical practices: Based on the theories above, the student assumes an active role in the learning process, while the teacher is a mediator and facilitator of learning.

3. Implementation: In this stage, the teacher and students need to know how the robot functions as a learning tool.

4. Defining the pedagogical use of technological resources: In this final stage, the learning activities are developed.

The premise of this process assumes that learning derived from instructions reaches its full development by offering students opportunities to construct (Vicario, 2010). Therefore, these stages serve as references for incorporating robotics as a learning tool within Instructional Design. The instructional design allows for proposing learning activities from a holistic process perspective to achieve learning objectives. Instructional design is considered a teaching process that enables the creation of educational materials highlighting detailed specifications that guide the process. The instructional design is appropriately adjusted to develop competencies through cognitive activities that enable students to construct active knowledge. An important starting point for designing an appropriate and relevant curriculum for any course is a clear delineation of articulating the body (mass) of knowledge, along with the skills and learning outcomes of any course. (Petraki & Herath, 2022, p.50). Hence, instructional design must be essential in curriculum development as it facilitates effective instructional design using various methodologies that utilize new technologies as learning mediation tools (Losada & Peña, 2000).

In this article, our objective is to propose an instructional program that utilizes robotics to facilitate learning. For this purpose, we have based our teaching approach on Robert Gagné's Instructional Events Model. This model draws upon contributions from cognitive-constructivist theories and organizes the teaching process into sequential phases, employing various teaching strategies to achieve learning objectives.

2.

Methodology

This research proposes a framework for teaching mathematics using educational robotics as a learning tool. The framework design is based on Instructional Design drawing from Gagné's Nine Events of Instruction. This model provides a theoretical framework to enhance information understanding, usage, and application through systematic, methodological, and pedagogical structures.

First, and in correspondence with the instructional design phases, we carry out a needs analysis to identify the specific requirements of the target audience, as well as the topics and tasks to be covered in the proposal. In this sense, the proposal was designed for the Higher Basic sublevel students. In this sublevel, students range in age from 13 to 15. Design Thinking methodology was used to identify the characteristics and requirements, particularly in its empathy phase. This phase allows for identifying users' relevant desires and needs, including factors that influence learning, such as preferences, interests, social interactions, circles, and contextual environment, among others.

Secondly, through documentary analysis, we have gained insights into specific segments of information from the official documents of the Ecuadorian Ministry of Education (MINEDUC). This analysis has allowed us to determine the theme and tasks that will be implemented for teaching purposes. Consequently, we have identified the content and learning outcomes, which can be described as follows: the theme aligns with the curriculum content, while the tasks and learning achievements outline the necessary steps for students to accomplish the learning objectives.

In crafting the instructional design, we have aligned Gagne's nine instructional events with pertinent learning theories underpinning our proposal and the phases of integrating robotics into the classroom. Therefore, we have adopted constructivist for each instructional event, including Explicit Teaching, Activation of Prior Knowledge, Cognitive Modeling, and Metacognition. Each strategy is accompanied by its respective technological tool for effective implementation.

The validation process of the framework proposal involved expert judgment and engaging individuals with substantial expertise in utilizing technology for mathematics education. As expert selection was carefully executed using the Delphi Method. Each expert conducted a self-assessment to ascertain their proficiency in the subject matter, culminating in calculating a Knowledge Coefficient (kc). The following formula determined this coefficient:

$$kc = n*(0.1) \qquad (1)$$

Kc represents the coefficient of knowledge, and n denotes the self-assessment value of the expert. By employing this rigorous validation process, we ensured that the teaching proposal received input from highly knowledgeable experts in the field, thereby enhancing its credibility and effectiveness.

Continuing with the procedural phases, the subsequent stage in expert validation entails assessing the experts' coefficient of argumentation or foundation (ka) regarding the subject matter. Drawing upon the framework proposed by Cabero and Borroso (2013), which outlines six argumentation sources alongside their respective assessments, as delineated in Table 1, we navigate this phase. This evaluation, contingent upon the experts' insight, requires computing the cumulative total to ascertain the coefficient of argumentation.

Table 1.

Assessment of the argumentation sources.

Argumentation sources	Degree of influence of each of the sources in the criteria		
	High (H)	**Medium (M)**	**Low (L)**
Theoretical analysis conducted by the expert.	0.3	.02	.01
Gained experience.	0.5	0.4	0.2
National studies on the subject.	0.05	0.05	0.05
International studies on the subject.	0.05	0.05	0.05
Personal knowledge about the problem abroad.	0.05	0.05	0.05
Expert intuition.	0.05	0.05	0.05

To ascertain the selection of proficient experts for the proposal's validation process, the Delphi Method prescribes the evaluation of a competence coefficient (K). This coefficient is determined by calculating the arithmetic mean of the combined value of the knowledge coefficient (kc) and the argumentation coefficient (ka)

$$K = \frac{1}{2} * (kc + ka) \quad (2)$$

To assess the suitability of experts for the validation process, we followed the Delphi method, considering experts with a K value exceeding 0.8 as appropriate (Espinoza, 2015). Once these experts were identified, we presented the proposal and administered the Delphi questionnaire to gather insights into their perceptions of the work. The questionnaire included inquiries about specific dimensions evaluated within the proposal, with responses captured on a Likert-type scale. For clarity, the questions within the Delphi questionnaire, as administered to the experts, were categorized into two dimensions: pedagogical and functional.

To validate the proposal, we opted for Aiken's V technique, which was chosen for its effectiveness in assessing agreement among experts. This decision was driven by the need to validate the proposed framework thoroughly. To gather data, we administered a comprehensive questionnaire to experts in the field, yielding valuable insights. Each dimension under evaluation was validated using data obtained from the questionnaire. This validation process involved applying the following formula:

$$V = \frac{X - l}{k} \quad (3)$$

Where V represents the Aiken's V coefficient, represents the arithmetic mean of the values assigned by the experts, l denotes the smallest value on the rating scale (Likert scale), and K is the result of the difference between the highest and lowest values on the rating scale (Likert scale).

The validation value of Aiken (V) was computed for each dimension that conforms to the proposed framework. Furthermore, we determined the limits and ranges within which the value of V can be positioned by calculating 95% confidence intervals. Aiken's formulas, which are essential for determining the lower and upper limits, are presented below:

$$L = \frac{2nkV + z^2 - z\sqrt{4nkV(1-V) + z^2}}{2(nk + z^2)} \quad (4)$$

$$U = \frac{2nkV + z^2 + z\sqrt{4nkV(1-V) + z^2}}{2(nk + z^2)} \quad (5)$$

Where V = Aiken's V coefficient, L = lower limit, U = upper limit, l = lower limit of the rating scale, k = Rating scale range minus 1 (5 - 1; 5 corresponds to the highest value on the Likert scale), z = 1.96 corresponding to the 95% confidence interval.

3.

Results

To establish the characteristics and requirements of the intended recipients of our proposal, we have employed the Empathize phase of the Design Thinking model. Through this analysis, the following key insights have been gleaned: The target group comprises students aged between 13 and 14. These students exhibit a keen interest in technology's utilization and advancement. Furthermore, it has been observed that employing technology as an instructional tool contributes significantly to cultivating spatial reasoning abilities and enhancing the capacity for object visualization and manipulation.

Through document analysis, we have identified the specific skills that need to be developed, along with their corresponding performance criteria and evaluation indicators. Additionally, we have established a standard for learning quality, reflected in the achievement level. In the subsequent section, we will provide a clear definition of the various components of the curriculum (refer to Table 2).

Table 2.

Table of content analysis and tasks.

Knowledge learning	Development of skills or procedural content	Learning attitudes or values	Skills to develop
Classification of triangles and their characteristics	Sort out Build	Use knowledge to solve problems	Mathematic and Digital

To develop the instructional design, we have considered adapting the nine instructional events based on the theoretical framework related to the learning theories that influence the proposal and the teaching phases of mathematics. Thus, two important adaptations are presented: first, the appropriate teaching strategy for each instructional event and its respective technological tool. Second, the variation in the presentation of instructional events follows the sequence from instructional event 3, proceeds to events 5 and 6, and then returns to event number 4 to achieve Brunner's discovery learning and Ausubel's meaningful learning. Finally, the typical sequence is resumed after this variation, concluding with events 7, 8, and 9. In Event 5 and Event 6, we suggest using the Robot as a learning tool. The plotter robot precisely follows user instructions to depict geometric figures essential for content development. This approach aligns with Bravo-Sánchez and Forero-Guzmán's (2012) proposition, enabling students to engage with the robot through manipulation and experimentation using basic routines. All of the aforementioned is presented in Table 3.

Table 3.

Adaptation of Gagné's 9 instructional events for the teaching proposal.

Events	Strategy	Technological tool proposal
Event 1. Gain attention	Explicit Teaching: The actions and processes involved will be clearly communicated using multimedia resources.	Exelearning
Event 2. Inform learner of objectives	Introducing Objective: To comprehend, apply, and analyze notable points and lines of triangles in order to utilize them in problem-solving.	Exelearning
Event 3. Prior learning	Activation of previous knowledge. Selection of prerequisites to start the learning activity.	Geogebra
Event 5. Provide guidance	Cognitive modeling – Second level (participatory modeling) Implementation of robotics in Instructional Design: instrumentation stage Implementation of robotics in Instructional Design: restructuring stage in pedagogical practices.	Use of the robot through Chilipeppr (robot movement by coordinates)
Event 6. Elicit performance	Cognitive modeling – Third level (reciprocal modeling) Implementation of robotics in Instructional Design: restructuring stage in pedagogical practices. Implementation of robotics in Instructional Design: stage of definition of the pedagogical use of the resource,	Use of the robot through Chilipeppr (robot movement by coordinates)
Event 4. Present the content	Cognitive modeling – First level (perceptual modeling) Learning by discovery Significant learning Implementation of robotics in Instructional Design: restructuring stage in pedagogical practices. Implementation of robotics in Instructional Design: stage of definition of the pedagogical use of the resource	GeoGebra
Event 7. Provide feedback	Specific feedback	Digital forms
Event 8. Asses performance	Formative assessment	Rubistar
Event 9. Enhance retention and transfer to the job	Metacognition	Use of the robot through Chilipeppr (robot movement by coordinates)

Proposal validation through the Delphi Method

This study enrolled 11 participants who first went through a self-assessment to evaluate their knowledge regarding the proposed topic. The outcomes of the self-assessment, displayed in Table 4, show the knowledge coefficient (Kc) using the formula Kc = (n * 0.1). Table 5 presents the corresponding Kc values for each participant.

Table 4.

Expert self-assessment results.

Expert	Knowledge self-assessment									
	1	2	3	4	5	6	7	8	9	10
Expert 1									x	
Expert 2								x		
Expert 3								x		
Expert 4										x
Expert 5									x	
Expert 6									x	
Expert 7									x	
Expert 8								x		
Expert 9									x	
Expert 10									x	
Expert 11									x	

Table 5.

Knowledge coefficient (Kc).

Expert	Knowledge Coefficient
Expert 1	0.9
Expert 2	0.8
Expert 3	0.8
Expert 4	1.0
Expert 5	0.9
Expert 6	0.9
Expert 7	0.9
Expert 8	0.8
Expert 9	0.9
Expert 10	0.9
Expert 11	0.9

The second step in expert selection is to determine the argumentation coefficient. This coefficient is calculated by summing the values assigned according to the Argumentation Source table proposed by Cabero & Borroso (2013). In this regard, Table 6 below summarizes the values assigned by the experts for each item.

Table 6.

Argumentation Coefficient.

Argumentation Source	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Experience gained through professional practice	0	0	0	0	0	0	0	0	0	0.3	0.3
Theoretical-regulatory analysis on the matter under consideration.	0	0	0	1	1	0	0	1	0	0.4	0.4
References of national works on the topic.	0	0	0	0	0	0	0	0	0	0.1	0.1
References of foreign works on the subject	0	0	0	0	0	0	0	0	0	0.1	0.1
Knowledge about the state of the problem	0	0	0	0	0	0	0	0	0	0.1	0.1
Professional intuition	0	0	0	0	0	0	0	0	0	0.1	0.1
Ka argumentation coefficient of each expert	1	1	1	1	1	1	1	1	1	0.9	0.9

The suitability of the experts was determined by calculating the proficiency coefficient, which is the result of the arithmetic mean of the sum of Kc and Ka. The conditions posed by the Delphi Method were considered for the suitability analysis. If 0.8 < K <1, then K has a high level. These results are presented in Table 7 below.

Table 7.

Proficiency coefficient.

Expert	Knowledge coefficient	Argumentation coefficient	Proficiency coefficient	Proficiency level
Expert 1	0.9	0.9	0.90	High
Expert 2	0.8	0.9	0.85	High
Expert 3	0.8	0.8	0.80	High
Expert 4	1.0	1.0	1,00	High
Expert 5	0.9	1.0	0.95	High
Expert 6	0.9	0.9	0.90	High
Expert 7	0.9	0.8	0.85	High
Expert 8	0.8	1.0	0.90	High
Expert 9	0.9	0.8	0.85	High
Expert 10	0.9	0.9	0.90	High
Expert 11	0.9	0.9	0.90	High

Aiken's V coefficient

The chosen experts thoroughly examined the proposal and articulated their criteria in the Delphi questionnaire. Each criterion was expressed through the assigned ratings for the respective questions. The collected data, questions, and corresponding assessment areas are presented in Table 8.

Table 8.

Experts' assessment: questions and areas to be validated.

ID	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
Learning objective	5	5	5	5	5	4	5	5	5	5	5
Pedagogical conception	5	5	3	5	5	5	5	5	5	5	4
Teaching strategy	5	5	5	5	4	5	5	5	4	5	5
Learning sequence	5	5	5	5	4	5	5	5	5	5	5
Platform use	5	5	4	5	5	4	5	5	4	4	4
Images use	5	5	4	5	4	5	5	4	5	4	5
Digital tools	5	5	4	5	4	4	5	5	5	5	5
Content	5	5	5	5	5	5	5	5	5	5	5
Robot use	5	5	5	5	5	4	4	4	5	5	5
Relevance	5	5	4	5	5	5	5	5	5	5	4

These data have been classified according to the dimensions of the proposal's validation analysis; thus, the tables with each of the dimensions analyzed are presented below. Table 9 presents the results of the Pedagogical and Functional Dimensions.

Table 9.

Pedagogical and functional dimensions.

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Total	Mean
Pedagogical dimension													
Learning objective	5	5	5	5	5	4	5	5	5	5	5	54	4.91
Pedagogical conception	5	5	3	5	5	5	5	5	5	5	4	52	4.73
Teaching strategy	5	5	5	5	4	5	5	5	4	5	5	53	4.82
Learning sequence	5	5	5	5	4	5	5	5	5	5	5	54	4.91
Content	5	5	5	5	5	5	5	5	5	5	5	55	5.00
Functional dimension													
Platform use	5	5	4	5	5	4	5	5	4	4	4	50	4.55
Images use	5	5	4	5	4	5	5	4	5	4	5	51	4.64
Digital tools	5	5	4	5	4	4	5	5	5	5	5	52	4.73
Robot use	5	5	5	5	5	4	4	4	5	5	5	52	4.73
Relevance	5	5	4	5	5	5	5	5	5	5	4	53	4.82

The Aiken V coefficient for each dimension was calculated by summing the totals of each area and applying the appropriate formula. To lower and upper limits were also calculated to assess the method's reliability. The results of these calculations can be found in Table 10.

Table 10.

Dimension validation.

	Aiken's V value	Upper limit	Lower limit
Functional dimension	0.92	0.97	0.81
Pedagogical dimension	0.97	0.99	0.87

Aiken's V value for the Pedagogical Dimension can vary between 0.99 and 0.87. Since Aiken's V value is equal to 0.97 in this case, it indicates that the proposal in this dimension has been positively validated. Similarly, Aiken's V value for the Functional Dimension can fluctuate between 0.97 and 0.81. This dimension has also been favorably validated since Aiken's V value is 0.92.

4.

Discussion

The findings presented in this study provide compelling evidence that educational processes must be tailored to meet the evolving demands of the contemporary educational landscape. These demands necessitate educators to possess a diverse set of competencies in order to fulfill their role as facilitators of learning effectively. Consequently, the judicious selection and utilization of various tools and technologies become paramount considerations, as they can profoundly impact the teaching and learning experience. As aptly noted by Castellanos (2015), the application of technology in education must be purposeful and well-suited to the learning objectives, as its inappropriate usage may yield unintended and detrimental consequences.

Within this context, integrating technology into educational practices promises to empower students to acquire essential competencies through multiple avenues. This integration encompasses providing alternative perspectives on key concepts, fostering intrinsic motivation to tackle and solve complex problems, nurturing creativity, and promoting collaborative engagement among learners.

Thus, educators and educational institutions must embrace technology to augment and fortify the educational experience. However, this necessitates a thoughtful and strategic approach, ensuring that technology is seamlessly integrated into pedagogical practices and aligned with the overarching educational goals. By doing so, educators can harness the full potential of technology to enhance teaching effectiveness and student achievement while mitigating any potential pitfalls associated with its haphazard implementation.

It is important to note that integrating technology in education gains momentum in the teaching process when any resource used mediates learning. At this point, the teacher must possess theoretical, curricular, and digital knowledge to propose teaching processes that enable the achievement of the proposed learning objectives by implementing appropriate learning strategies and using relevant technological tools.

One resource that has gained traction in recent years is educational robotics. In this regard, Ruiz-Velasco (2012) identifies educational robotics as an important tool due to its diverse contributions to the educational process, as it facilitates learning in different fields of knowledge. This notion aligns with Gros y Noguera (2013), who emphasizes that using technology to enhance learning opportunities is a significant factor in education.

5.

Conclusions

Based on a comprehensive analysis, the proposal is firmly rooted in constructivist and constructionist learning theories. While it draws upon Albert Bandura's theory of learning through imitation, this specifically applies to the instructional model. The constructivist model is apparent in the proposal through the incorporation of Lev Vygotsky's scaffolding process, enabling students to take on a primary role in learning after initial instructions from the teacher. In contrast, the teacher transitions into a facilitator. Moreover, the instructional approach has been carefully adjusted to align with mathematics teaching, facilitating a seamless transition from the concrete to the abstract. In this project, this progression involves utilizing the robot as a learning tool and leveraging digital resources to interpret acquired knowledge.

The proposal underwent validation through a rigorous Delphi method involving experts. Expert selection served as a crucial means to ensure the reliability of the research, as it encompassed diverse perspectives from teachers who possess expertise in mathematics education and technology integration. The credibility of these perspectives was further reinforced through statistical testing, with Aiken's V coefficient calculation providing reliability for the experts' criteria. The results obtained from the analysis were highly favorable, as evidenced by the statistical evaluation indicating a specific range within which the Aiken's V value could be situated. These findings underscore the importance of seeking validation for teaching proposals from subject matter experts.

Teaching proposals are invaluable opportunities for teachers and students to engage in meaningful learning experiences. Developing instructional programs firmly grounded in theory, pedagogical principles, and user needs undoubtedly significantly enhances student education. Therefore, there exists a steadfast commitment to advancing the implementation of this proposal, gathering diverse usability criteria, and presenting it as an exemplary teaching prototype. Moreover, this endeavor leaves ample room for exploring other topics from a similar perspective to attain favorable outcomes in teaching and learning processes.

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