PROMOTING DEVELOPMENT AND ENVIRONMENTAL AWARENESS IN CHILDREN WITH DISABILITIES: AN APPROACH WITH ADAPTED PHYSICAL EDUCATION AND FUZZY LOGIC

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ABSTRACT
This study aimed to develop a fuzzy logic model to evaluate the impact of interventions in Adapted Physical Education and Environmental Education on the development of children with disabilities, covering physical, cognitive and environmental awareness aspects. The research sought to transcend conventional assessment approaches, implementing scenario simulations that mimic real conditions and incorporating variables such as motor coordination and understanding of environmental concepts. The interventions were evaluated using fuzzy rules, in order to measure the impacts on the various dimensions of development. Although the model has not been applied in a practical context with children, validation tests suggest its future applicability in practical studies. The results indicate that integrated and balanced interventions can effectively improve both physical and cognitive development. The use of fuzzy logic proved to be a robust tool for the detailed evaluation of progress, indicating that the developed model can contribute significantly to inclusive pedagogical practices and guide educational policies aimed at the needs of children with disabilities, reinforcing the importance of sustainability in environmental education.

Keywords: Adapted Physical Education. Environmental education. Fuzzy logic. School Inclusion. Environmental Awareness.

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INTRODUCTION

Inclusive education in Brazil has made significant progress, particularly in the integration of children with disabilities, reflecting a reinforced commitment to creating school environments that support the full participation of all students. Current educational policies underscore the need to adapt these spaces to facilitate comprehensive development, highlighting the importance of environments that foster both students' physical and cognitive growth (Moraes Barth & Schmickler, 2022). However, these children still face significant challenges, especially those related to motor coordination and social interaction, which can limit their engagement in school activities. The adaptation of activities, especially in physical education, is essential to overcome these obstacles and ensure effective inclusion (França, Rocha & Oliveira, 2023).

Learning environments that support inclusion are crucial for the integral development of children, including cognitive aspects and the strengthening of socio-emotional skills. Appropriate inclusive practices can enrich everyone's educational experience, promoting collaboration and empathy (Anjos Junior & Santos, 2023). Adapted physical education, in this context, offers a safe space for motor activities that respect individual limitations and potentialities, essential for socialization and inclusion in the school environment (Nogueira, 2019). In addition, integrating elements of environmental education into these activities adds significant value, promoting not only ecological awareness, but also important social and emotional skills. Outdoor activities and contact with nature benefit physical development and promote values such as care and respect for the environment, expanding the reach of a truly inclusive education (Medeiros, 2020).

This integrative approach, which combines adapted physical education with environmental education, transcends the confines of the conventional classroom, creating a dynamic learning environment that values hands-on teaching. The inclusion of games and play activities focused on the environment offers a valuable platform for the joint development of children's motor and social skills, underlining the importance of integral development (Senhoras, 2022). To properly assess the progress of children with disabilities, assessment methods that capture the nuances of their development are key. Fuzzy logic emerges as a promising alternative, allowing for a more detailed and informative analysis of progress, suitable for informing pedagogical decisions and adapting interventions effectively (Zanata & Silva, 2021). In short, this study aims to integrate physical and environmental education interventions with fuzzy logic, exploring the complexity of the development of children with disabilities in an inclusive context, with the aim of enriching pedagogical knowledge and contributing to the formulation of more effective and inclusive educational policies.

LITERATURE REVIEW

ADAPTED PHYSICAL EDUCATION AND SCHOOL INCLUSION

Adapted Physical Education (EFA) is essential to promote school inclusion, providing an environment where children with disabilities can develop motor, social, and emotional skills (Oliveira & Ambiental, 2021; França, Rocha & Oliveira, 2023). The practice of EFA favors social integration and the construction of a positive identity, creating safe and inclusive spaces that value diversity (Anjos Junior & Santos, 2023; Nogueira, 2019).

In addition to the impact on motor development, EFA also promotes environmental awareness by integrating outdoor activities, encouraging children to take care of the environment (Santos & Moraes, 2020). The adaptation of physical activities helps children to overcome specific challenges progressively, improving their autonomy and motor capacity (Dias & Borragine, 2020; Ladies, 2022). By incorporating environmental education, EFA not only strengthens physical and cognitive development, but also nurtures an ecological awareness among students (Medeiros, 2020).

EFA, as a school inclusion strategy, not only provides equitable participation in school activities, but also improves academic performance and socio-emotional development, highlighting the importance of a curriculum that includes inclusive and sustainable practices (Patrício, 2021; Moraes Barth & Schmickler, 2022). This transformative pedagogical approach is crucial to prepare students as conscious citizens, equipped to face environmental and social challenges of the future.

ENVIRONMENTAL EDUCATION AND COGNITIVE DEVELOPMENT

Environmental Education (EE) in the school context is an essential tool to sensitize students about the importance of sustainable practices and has a significant impact on cognitive development. By integrating theoretical learning with practical experiences, EE fosters a comprehensive understanding of natural processes and the importance of preserving the environment (Soares, 2020; Melo et al., 2020). Through cognitive games and playful activities, EE stimulates creativity, problem-solving, and critical thinking, preparing students to face and solve environmental challenges in a responsible and ethical manner (Ramos & Vieira, 2023).

In addition, EE contributes to the development of socio-emotional skills, such as empathy and cooperation, which are crucial for academic and cognitive performance.

Contact with the natural environment through outdoor activities expands reasoning capacity and attention, which are fundamental for effective and meaningful learning (Almeida, 2022; Medeiros, 2020).

EE is also a pillar for the integral formation of students, integrating ethical, social and emotional aspects in education. Activities such as school gardens and recycling projects provide a hands-on approach that facilitates the understanding of complex concepts and fosters a sense of responsibility and belonging to the natural world. This holistic approach not only enriches the school curriculum but also prepares students to be conscious and active global citizens (Kolcenti & Médici, 2020; Ramos & Vieira, 2023).

Finally, sustainable educational practices have the potential to generate positive environmental impacts by encouraging ecologically responsible behaviors among students, educators, and communities. The implementation of these practices not only strengthens environmental knowledge, but also stimulates a collective awareness of the importance of conscious consumption and sustainable management of resources (Sousa & Yoshioka, 2020; Mendes & Feitoza, 2022).

ENVIRONMENTAL IMPACTS OF EDUCATIONAL PRACTICES: FOSTERING AWARENESS AND SUSTAINABILITY

Educational practices integrated with sustainability have a significant impact on promoting environmentally responsible behaviors among students, educators, and communities, forming ecologically conscious citizens (Sousa & Yoshioka, 2020). Activities such as tree planting, composting, and the use of renewable energy illustrate how education can transcend theoretical knowledge and have direct and positive impacts on the environment, as well as teaching the importance of sustainable actions and conscious consumption (Mendes & Feitoza, 2022).

Beyond the school context, these sustainable educational practices extend to families and communities, generating significant changes through a multiplier effect. Interdisciplinary school projects that address environmental issues empower students to understand and address ecological challenges, enabling them to propose innovative solutions to local problems, such as waste management and ecosystem conservation (Rosa & Bernaldino, 2023).

Despite the challenges, the long-term benefits of sustainable practices justify the investments, preparing students to become future leaders in sustainability and influencing public policies and community practices, thus contributing to the construction of a more equitable and sustainable society.

ENVIRONMENTAL IMPLICATIONS OF EDUCATIONAL INTERVENTIONS

Educational interventions focused on environmental awareness play a crucial role in shaping sustainable behaviors, integrating theoretical knowledge with practices that foster waste reduction and recycling (Sousa & Yoshioka, 2020). The implementation of practical projects, such as school gardens and environmental monitoring, allows students to directly experience the impact of their actions on the environment, reinforcing the connection between theory and practice (Maia & Albuquerque, 2021).

In addition, the responsible use of natural resources in schools has shown effective results in reducing energy and water consumption, contributing significantly to the mitigation of adverse environmental impacts (Rosa & Bernaldino, 2023). Expanding these practices beyond schools, reaching communities and families, creates a multiplier effect, promoting sustainable practices on a broader scale (Hoernig & Júnior, 2021).

Continuous evaluation of these interventions is essential, using environmental impact indicators to ensure that the changes promoted are sustainable and adapt projects to maximize their benefits.

The inclusion of sustainable practices in the school curriculum is vital to cultivate an ecological awareness among students, combining theoretical teaching with practical activities such as composting and community gardens (Mendes & Feitoza, 2022). These initiatives not only teach about responsible waste management, but also promote cooperation and practical skills among students. Projects that include the use of renewable energy and the reduction of plastic consumption exemplify how schools can transform into living laboratories for sustainable practices (Oliveira & Andrade, 2022).

Interdisciplinarity is crucial to the success of this integration, with disciplines such as science, mathematics, and geography exploring environmental issues from diverse perspectives, while the arts and literature raise awareness about the cultural dimensions of sustainability.

The use of information and communication technologies expands the possibilities for student engagement and innovation, allowing the exploration of creative solutions to environmental problems. Implementing these practices in the curriculum prepares students to address environmental challenges in a proactive and innovative way, cultivating future environmentally conscious and responsible citizens.

FUZZY LOGIC

Fundamental Concepts of Fuzzy Logic

Fuzzy Logic, established by Lotfi A. Zadeh in 1965, extends classical binary logic to deal with values between 0 and 1, reflecting the uncertainty and subjectivity of real data. The main tool of Fuzzy Logic is pertinence functions, which quantify the degree of truth of statements on a continuum of values, rather than fixed binary values of true or false (Nogueira, 2017).

Mathematical Structure and Operations with Fuzzy Sets

Fuzzy sets allow for a more flexible representation of information through varying degrees of pertinence between 0 and 1, rather than the absolute states typical of classical sets.

- **Fuzzy Union:** The union of two fuzzy sets is defined by the maximum degree of relevance that an element has in any of the sets. Mathematically, for sets A and B with an element x, the union is expressed as (Jain, 2020):

$$\mu A \cup B(x)=max(\mu A(x),\mu B(x)) \quad (1)$$

where μ indicates the function of belonging of the set.

- **Fuzzy intersection:** The intersection of two fuzzy sets considers the lesser degree of pertinence of an element in the sets. For A and B (Li et al., 2023):

$$\mu A \cap B(x)=min(\mu A(x),\mu B(x)) \quad (2)$$

This operation is essential for modeling situations where an element must satisfy multiple conditions simultaneously.

- **Fuzzy complement**: The complement of a fuzzy set A is defined by the degree of non-relevance of an element in the set, calculated as (Martinez & Pereira, 2019):

$$\mu complA(x)=1-\mu A(x) \quad (3)$$

This operation helps to understand how far an element is from satisfying the characteristics of a set.

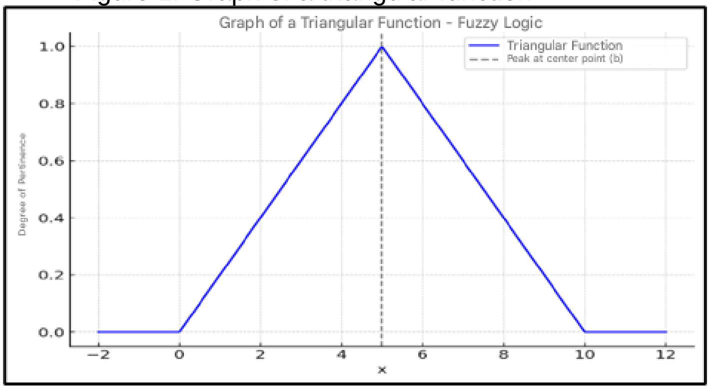
Pertinence Functions and Fuzzy Modeling

Pertinence functions play a crucial role in defining the degree of belonging of elements to fuzzy sets, allowing fine gradations of pertinence.

- **Triangular Function**: Represented by three points that define the beginning, peak, and end of the function. If a, b, and c are the points, then the triangular function μ\muμ for an element x is:

$$\mu_{\text{triangular}}(x) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \tag{4}$$

Figure 1: Graph of a triangular function.

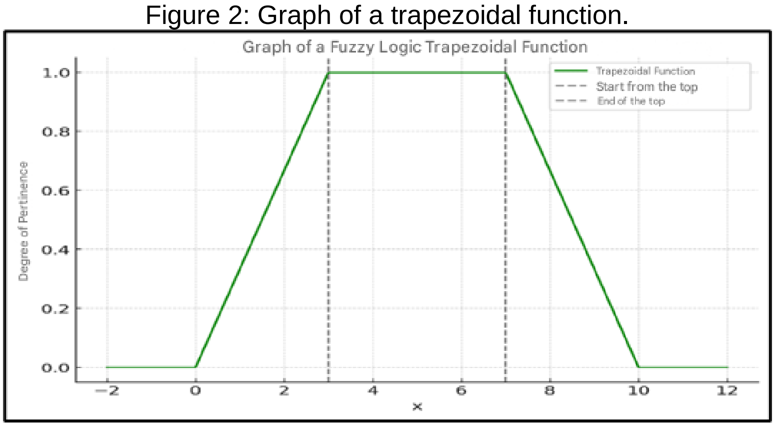


Source: Adapted from (Boratto, 2022).

- **Trapezoidal Function**: This function is an extension of the triangular, adding a flat part at the top. If a, b, c, and d define the function, the expression for x is (Kreinovich, 2020):

$$\mu_{\text{trapezoidal}}(x) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \tag{5}$$

Figure 2: Graph of a trapezoidal function.

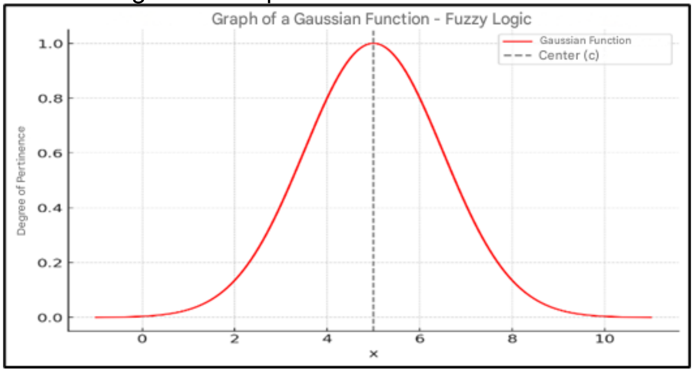


Source: Adapted from (Russo, 2022) and (Pujaru, 2024).

- **Gaussian function**: Used for smooth transitions, it is defined by two parameters: the center c and the standard deviation σ. The function for x is (Jain, 2020):

$$\mu_{\text{gaussiana}}(x) = e^{-\frac{(x-c)^2}{2\sigma^2}} \tag{6}$$

Figure 3: Graph of a Gaussian Function.



Source: Adapted from (Mazzutti, 2018).

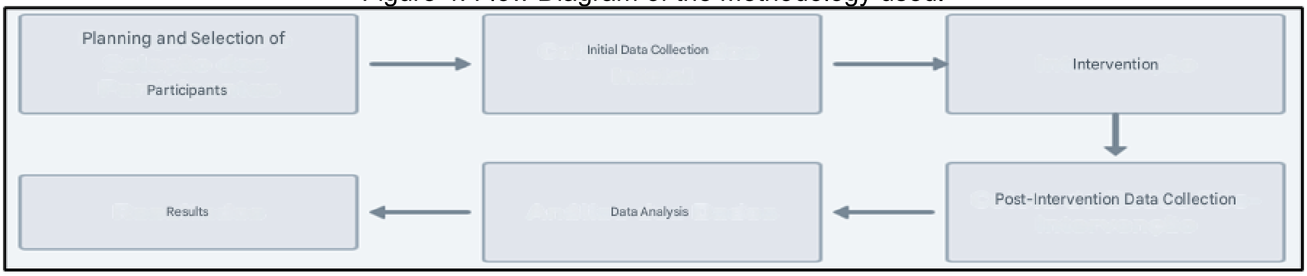
METHODOLOGY

The methodology adopted in this research was structured in six main steps, as shown in the flow diagram (Figure 4). This meticulously designed process ensures the validity and accuracy of the results, from initial planning to analysis and final conclusions.

Initially, the research begins with the careful planning and selection of participants, followed by the initial data collection. Subsequently, carefully planned interventions and a subsequent reassessment of the data are carried out. The analysis of the collected data precedes the last stage, where the conclusions are formulated and discussed.

The purpose of this method is to simplify the understanding of the investigative procedure, allowing a clear view of each phase and its interrelationship in achieving the research objectives.

Figure 4: Flow Diagram of the Methodology used.



Source: Author.

PLANNING AND SELECTION OF PARTICIPANTS

This research adopts a mixed approach, using quantitative and qualitative methods to examine the impact of Physical Education and Environmental Education interventions on the development of children with disabilities. Due to the practical limitations, it was decided to simulate scenarios that authentically reproduce the real conditions of these groups, enabling a detailed and controlled analysis of the interventions.

Participants: Three simulated scenarios were developed, each reflecting different special needs and environmental contexts, to illustrate the dynamics between the control and intervention groups.

Inclusion/Exclusion Criteria

- **Inclusion:** Included schools that already implement sustainable practices or located in areas of environmental relevance. Students from 6 to 12 years old benefited from the integration of physical and environmental educational practices were selected virtually.
- **Exclusion:** Excluded scenarios that do not have infrastructure for sustainable practices or that do not comply with ethical norms for the inclusion of children with disabilities.

Methodology in Practical Studies: The methodology is designed to be applied in real school environments, with selection of children with the consent of the parents and the educational institution. Intervention and control groups would be formed, and initial data collection would serve as a reference to assess progress after interventions.

Description of Interventions

- **Physical Education:** Use of recyclable and eco-friendly materials to promote physical development and environmental responsibility.
- **Environmental Education:** Implementation of school gardens, recycling programs and resource conservation, detailing the frequency and materials used to promote sustainable education.

Rationale for Using Simulated Scenarios: The choice for simulations is due to practical and logistical constraints, facilitating the modeling and evaluation of complex interventions under controlled conditions. This strategy allows testing and validating the fuzzy model for future practical applications, providing a solid theoretical and methodological basis for future studies that will directly measure the effects of interventions.

INITIAL DATA COLLECTION

The initial data collection phase of this study involves the use of simulated scenarios to model real conditions of children with disabilities, employing representative variables that allow robust and ethical initial analyses, suitable for future practical applications. For this, standardized assessment instruments are used that measure physical, cognitive and environmental aspects of the participants. These instruments include questionnaires and activities that assess everything from muscle strength and motor coordination to environmental awareness, focusing on sustainability and conservation practices.

Collection procedures have been carefully tailored to reduce environmental impact, with the use of digital technology for data collection and processing, minimizing paper usage and saving energy. Ethical aspects are strictly followed, with documents such as the Letter of Consent and the Informed Consent Form ensuring transparency and adherence to ethical standards. All data is treated with high confidentiality and anonymity, ensuring responsible and ethical collection of information.

INTERVENTION

The intervention phase of this study involves structured physical and environmental education activities designed to promote both physical development and environmental awareness among students. Physical education activities include running and jumping on natural or recycled surfaces, throwing and endurance using sustainable materials, and adapted games that encourage recycling and responsible use of resources. At the same time, environmental education activities engage students in planting and caring for school gardens, outdoor classes that explore local ecosystems, and educational games that teach about sustainability and energy conservation.

Interventions occur two to three times a week over the course of three to six months, allowing students adequate time to internalize the concepts taught and observe the practical effects of their actions on the environment. This method ensures deep learning and practical application of the acquired knowledge, aiming for a lasting impact on the participants' sustainable practices.

POST-INTERVENTION DATA COLLECTION

The post-intervention data collection phase in the study used fuzzy simulations to assess the effects of the interventions on the children's physical, cognitive, and environmental dimensions. This method employed variables established during the initial assessment to simulate the expected progress under different hypothetical conditions.

Adjustments were made to the fuzzy logic to include variables that reflect changes in the environmental behavior of the students, allowing a detailed monitoring of the results of the interventions.

New instruments have been developed to measure student engagement in sustainable practices, complementing the physical and cognitive assessment instruments used initially. These include questionnaires and practical activities aimed at assessing the effectiveness of sustainability interventions.

The choice for simulations was motivated by logistical and time limitations, aiming to offer a representation as close as possible to reality and including new environmental aspects. This validated approach under controlled conditions sets the stage for future practical implementations, where the impacts of interventions can be measured directly.

DATA ANALYSIS

The data analysis used fuzzy logic to interpret complex information obtained through questionnaires applied to teachers and guardians, in addition to the results of standardized physical tests. This approach allowed for an accurate and gradual assessment of children's progress, capturing nuances that traditional assessment systems might miss. The analysis also considered environmental aspects, evaluating the efficiency in the use of resources and participation in sustainable activities.

Definition of Fuzzy Variables

The fuzzy variables were divided into input and output variables to facilitate the analysis and interpretation of the collected data and the expected results.

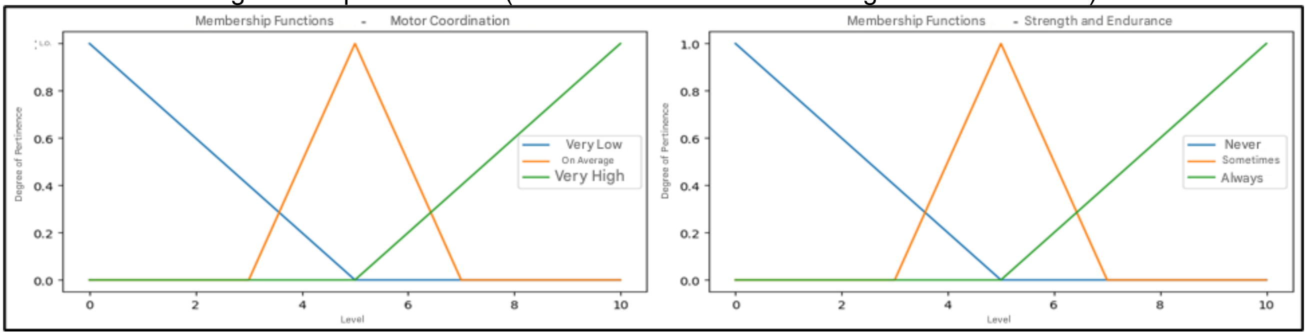
Rationale for the Choice of Input and Output Variables

The selection of variables was guided by frameworks established in the literature on fuzzy logic and educational evaluation, allowing a detailed analysis of educational activities considering imprecise notions such as "good", "bad" and "very good".

Fuzzy Input Variables:

- **Physical Performance:**
  - **Motor Coordination:** Evaluated through the answers about motor skills such as running, jumping, throwing, as recorded in the questionnaire.
  - **Strength and Endurance:** Based on the answers that describe the child's ability to complete and sustain specific physical activities without difficulty.

Figure 5: Input Variables (Motor Coordination and Strength and Endurance)

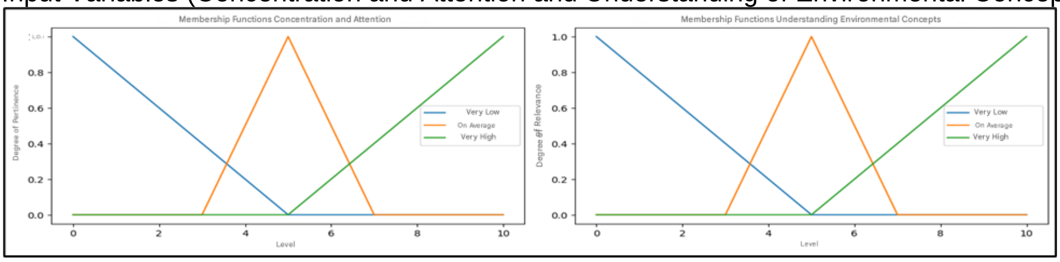


Source: Author.

Figure 5 illustrates the measurement scales for motor coordination and strength and endurance, showing the quantification of these attributes.

- **Cognitive Performance:**
  - **Concentration and Attention:** Assessed based on responses about the child's ability to maintain attention in educational and environmental activities.
  - **Understanding of Environmental Concepts:** Uses the answers about understanding the concepts of sustainability and the environment.

Figure 1: Input Variables (Concentration and Attention and Understanding of Environmental Concepts)

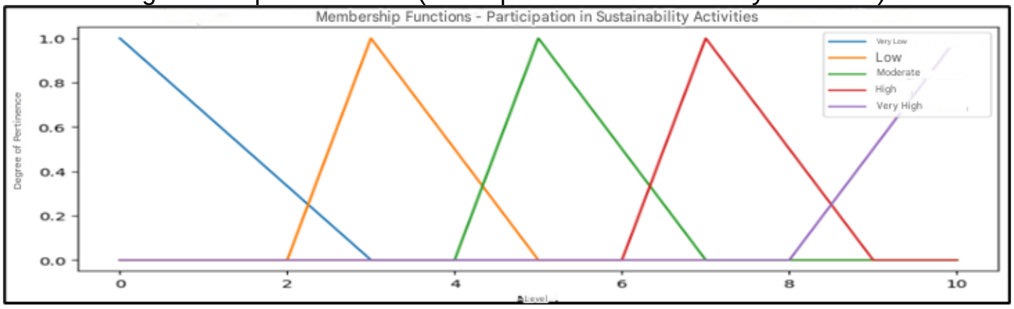


Source: Author.

Figure 6 presents the evaluation methods for concentration and attention, as well as the understanding of environmental concepts.

- **Environmental Behavior:**
  - **Participation in Sustainability Activities:** Student attendance and involvement in activities such as recycling, resource conservation, and other sustainable practices.

Figure 2: Input Variables (Participation in Sustainability Activities).



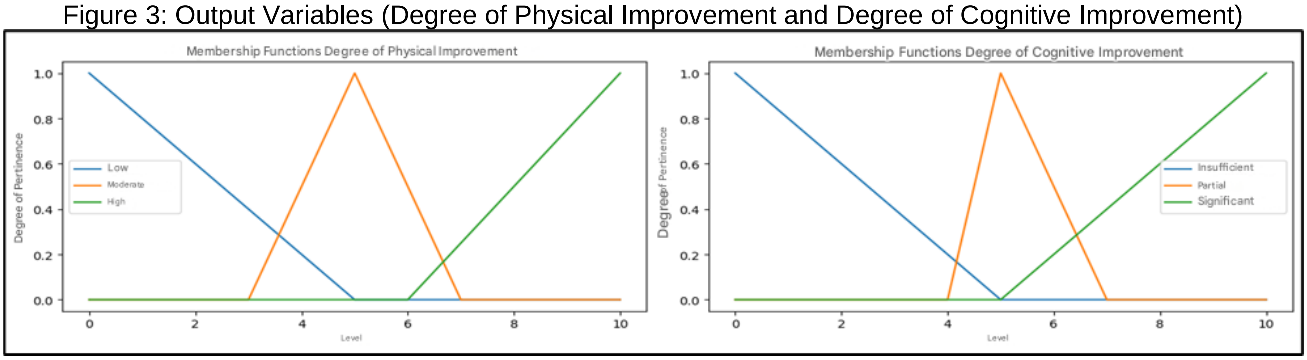
Source: Author.

Figure 7 shows the methodology for evaluating student participation in sustainable activities.

Fuzzy Output Variables:

- **Degree of Physical Improvement:** Categories of "Low", "Moderate", and "High", reflecting improvements in motor coordination, muscle strength, and physical endurance.
- **Degree of Cognitive Improvement:** Categories of "Insufficient", "Partial", and "Significant", evaluating the impact of interventions on cognitive development, including concentration and understanding of concepts.
- **Degree of Environmental Awareness and Behavior:** Categories of "Insufficient," "Basic," "Moderate," "Advanced," and "Excellent," measuring changes in environmental behavior.

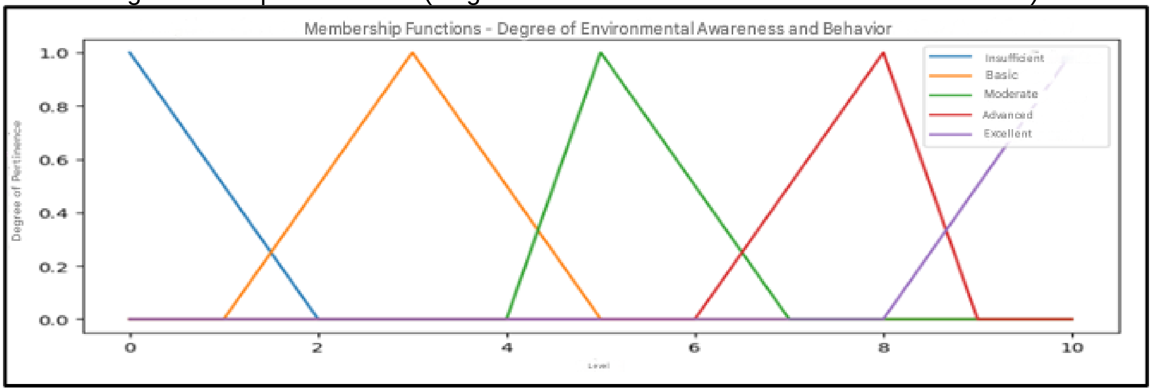
Figure 3: Output Variables (Degree of Physical Improvement and Degree of Cognitive Improvement)



Source: Author.

Figure 8 represents the categories of physical and cognitive improvement resulting from the interventions.

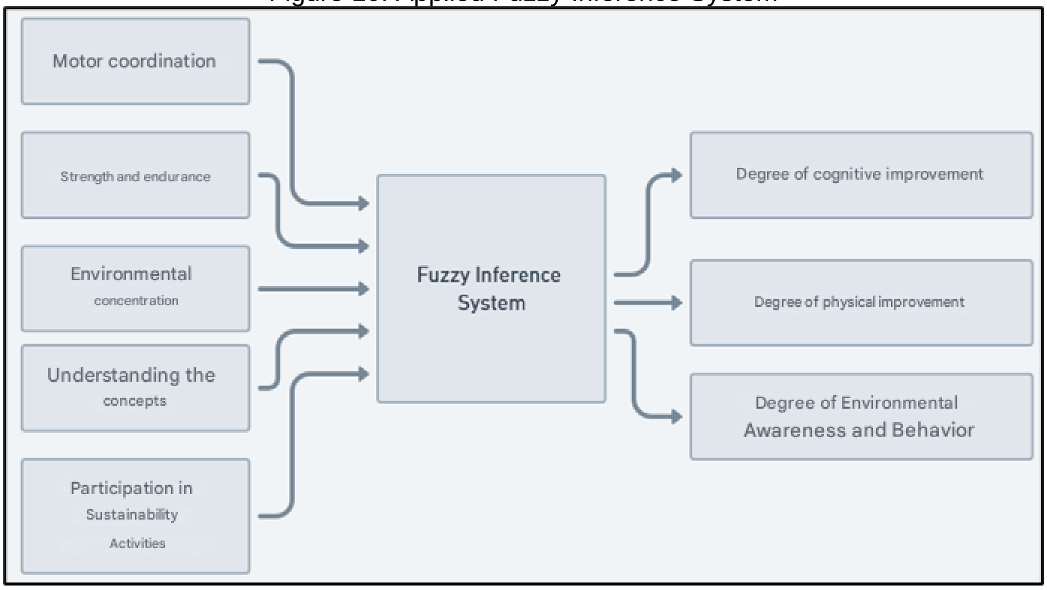
Figure 4: Output Variables (Degree of Awareness and Environmental Behavior).



Source: Author.

Figure 9 illustrates the categories of environmental awareness and behavior, providing a visual representation of the scales used to assess the effectiveness of interventions in terms of environmental education.

Figure 10: Applied Fuzzy Inference System



Source: Author.

Figure 10 compiles all the variables into a fuzzy inference system diagram, showing how the inputs are processed to generate the outputs through the defined fuzzy rules.

Fuzzy Analysis

The fuzzy system will be set up to receive the data collected in the questionnaire and convert it into continuous values that reflect each child's current situation. Using the input variables, the fuzzy system will apply pre-defined rules to generate the output variables, allowing a more detailed interpretation of the children's development, considering multiple variables at the same time.

RESULTS AND DISCUSSIONS

The simulated scenarios were created to represent different initial conditions, highlighting physical performance (such as motor coordination and strength/endurance) and cognitive performance (such as concentration and understanding of concepts). These scenarios were processed in the fuzzy system, which made it possible to predict the results in the output variables: degree of physical improvement and degree of cognitive improvement.

SIMULATION SCENARIOS IN THE FUZZY SYSTEM AND RESULTS

Table 1 aggregates the results of five different simulation scenarios evaluated in the study. Each scenario describes a distinct set of conditions relating to a child's involvement with sustainability activities, along with their cognitive and physical development.

Inputs are categorized into physical, cognitive, and environmental aspects, each evaluated using numerical and linguistic values derived from fuzzy logic.

These simulations help identify the impacts of various educational interventions on children's development, guiding future improvements in teaching strategies and intervention approaches.

Table 1: Summary of the Results of the Simulation Scenarios in the Fuzzy System

Scenario	Motor Coordination	Strength and Endurance	Environmental Concentration	Understanding Concepts	Participation in Sustainability Activities	Degree of Physical Improvement	Degree of Cognitive Improvement	Degree of Environmental Awareness and Behavior
1: Insufficient Participation	3	2	4	2	1	2.04, Low	2.25, insufficient	0.74, insufficient
2: Initial Engagement	5	5	5	5	4	5.0, moderation	5.33, partial	4.0, Basic
3: Highlighted Cognitive Progress	3	4	8	6	7	5.0, moderation	8.06, significant	7.61, Advanced
4: Holistic Advancement	7	7	8	8	9	8.36, high	8.14, significant	9.22, excellent
5: Low Participation, Cognitive Potential	6	5	9	9	2	5.0, moderation	8.28, significant	3.0, Basic

COMPARISON BETWEEN SCENARIOS

This topic analyzes the results of five simulated scenarios, comparing them to identify the different levels of progress achieved in three key dimensions: physical, cognitive, and environmental awareness improvement. This detailed comparison serves to understand how specific input variables influence output variables and to adjust future intervention strategies.

Table 2: Comparative Table of Scenario Results

Scenario	Degree of Physical Improvement	Degree of Cognitive Improvement	Degree of Environmental Awareness and Behavior
Scenario 1	2.04 (Low)	2.25 (Insufficient)	0.74 (Insufficient)
Scenario 2	5.0 (Moderada)	5.33 (Partial)	4.0 (Basic)
Scenario 3	8.37 (High)	8.15 (Significant)	9.22 (Excellent)
Scenario 4	8.37 (High)	8.15 (Significant)	9.22 (Excellent)
Scenario 5	5.0 (Moderada)	8.28 (Significant)	3.0 (Basic)

Comparative Analysis of Scenarios:

- **Physical Dimension:**
  - Scenarios 3 and 4 show the greatest improvements, indicating the positive impact of high levels of motor coordination and strength.
  - Scenario 1 reveals significant limitations, while Scenarios 2 and 5 show moderate improvements.
- **Cognitive Dimension:**
  - Scenario 1 records the least progress, affected by low concentration and comprehension.
  - Scenarios 2 show partial progress, and Scenarios 3, 4 and 5 demonstrate significant improvements, benefiting from high concentration and understanding of the concepts.
- **Environmental Awareness and Behavior:**
  - Scenario 1 is classified as insufficient, Scenario 2 as basic, and Scenarios 3 and 4 achieve excellent results.
  - Scenario 5, despite high cognitive potential, shows basic environmental engagement.

These data suggest that high participation and understanding of sustainable practices are essential to achieve substantial improvements. The analysis also highlights the importance of balancing physical, cognitive, and environmental development to achieve holistic and effective outcomes in educational and therapeutic contexts.

CONCLUSION

This study demonstrated the effectiveness of integrating adapted physical education and environmental education in the development of children with disabilities, using a fuzzy logic model for evaluation. The results of the simulated scenarios underline that balanced and inclusive interventions, which combine physical, cognitive and environmental awareness, are crucial to promote meaningful progress. The practical application of this evaluation model can transform pedagogical practices, making education more inclusive and effective, preparing students to face environmental and social challenges with greater competence and awareness.

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