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Effectiveness of an Inquiry-Based Science Program on Enhancing Science Process Skills and Knowledge Among Moroccan Preschool Children

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Abstract: This study evaluates the effectiveness of a twelve-week Inquiry-Based Science (IBS) program on enhancing science process skills and scientific knowledge among preschool children in Morocco. Conducted in a quasi-experimental setting, it involved 105 children (M = 60.46 months, SD = 4.32), with 37 in the IBS group and 68 in the control group. The program utilized the 5Es instructional model and the Engineering Design Process (EDP) to engage children in active, hands-on learning experiences. Statistical analysis demonstrated that the IBS group achieved substantial improvements in both science process skills and scientific knowledge relative to the control group, with between-group effect sizes (Cohen's d) ranging from 1.02 and 2.31. These findings highlight the significant impact of structured inquiry-based approaches in early childhood education. The study underscores the need for integrating such methods into the preschool curriculum to foster scientific understanding and skills from a young age, thereby better preparing Moroccan children for future academic and professional challenges. The results advocate for educational stakeholders to consider adopting inquiry-based learning frameworks to enhance the overall quality of early childhood education in Morocco.

Keywords: *Early childhood, inquiry-based learning, preschool education, science education, science process skills.*

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Introduction

In the face of rapid scientific and technological advancements, early science education is increasingly recognized as crucial for foundational learning and future success (Fleer & Pramling, 2015; National Science Teachers Association ([NSTA], 2014); Ravanis, 2022). This global emphasis on early scientific literacy aims to enhance lifelong learning capabilities and facilitate future academic and professional achievements (Cabe Trundle, 2015; Njagi, 2016; NSTA, 2014; Ravanis, 2022). Early engagement in science not only sparks children's curiosity but also develops their science process skills, fostering cognitive and conceptual growth essential for deeper scientific understanding later in life (Eshach & Fried, 2005; Hadzigeorgiou, 2002).

Research underscores that environmental influences on intellectual growth are most pronounced in the early years, highlighting the importance of stimulating and appropriate stimuli for cognitive development (Aaron, 1988; Bornstein, 1989; Epstein, 1978; Sternberg & Berg, 1992). A pivotal element of modern educational reform is the shift toward inquiry-based learning (NSTA, 2014; Ravanis, 2022). Traditional methods focused on rote memorization are increasingly yielding to dynamic, hands-on approaches that equip children to explore, investigate, and discuss scientific concepts using higher-order thinking skills (Johnson et al., 2019).

Inquiry-based learning significantly enhances children's science process skills, including observation, questioning, classification, inference, prediction, and conducting investigations (Ergül et al., 2011; Jirout & Zimmerman, 2015). These skills are crucial as they mirror the behaviors of scientists and are applicable across different scientific disciplines, fostering active learning and empowering students to take responsibility for their educational paths (Ergül et al., 2011).

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This method promotes teaching strategies that align with the natural curiosity of children, creating an environment conducive to active exploration and comprehension of the world (Gallenstein, 2005; NSTA, 2014).

Engaging young learners in early childhood science activities captures their interest and provides educators with opportunities to nurture broad, essential skills. Early setbacks in these activities encourage children to engage in trial-and-error processes, fostering risk-taking, persistence, and the ability to handle frustration (Bustamante et al., 2018; Lind, 1998). This approach helps children construct their own understanding, linking abstract concepts with tangible experiences and honing critical scientific skills like data interpretation, problem-solving, and communication (Marian & Jackson, 2020; NSTA, 2014).

Reflecting global trends, Morocco has embarked on significant educational reforms, placing a strong emphasis on preschool education as a fundamental component of its national system (Ouabich et al., 2023). However, the integration of science education within this framework remains insufficient. Moroccan early childhood education is predominantly play-based, offering limited structured opportunities for scientific inquiry (Ouabich et al., 2023), which are crucial for enhancing educational outcomes through the development of scientific concepts, active learning, and critical thinking (Bulunuz, 2013; Saçkes, 2015). Despite the curriculum's emphasis on exploration and discovery, there is a lack of clear guidelines for implementing inquiry-based learning (Ouabich et al., 2023). This lack of direction leaves educators underprepared and lacking confidence in conducting science activities, further impeding young learners' scientific understanding.

A significant gap is the undervaluation of science within early childhood education. Recent findings reveal that only 22.21% of preschool educators who participated in the study consider science to be a highly important component of the curriculum, compared to much higher percentages for literacy, art, and mathematics (Ouabich et al., 2024). This reflects a broader trend where science is underrepresented, contributing to a lack of emphasis on developing scientific process skills in early education. Moreover, research on early childhood science education in Morocco is limited, with most studies focusing on educators or higher education levels rather than preschool-aged children.

This study seeks to address these critical gaps by introducing an inquiry-based science education program specifically designed for Moroccan preschools. The program integrates the Engineering Design Process (EDP), a five-step iterative method guiding children through questioning, hypothesis creation, planning, execution, and refinement (Schindler et al., 2019), with the 5E instructional model—engagement, exploration, explanation, elaboration, and evaluation (Akuma & Callaghan, 2019; Yoon & Onchwari, 2006). Following Schindler et al. (2019), the program emphasizes the initiation, evaluation, and revision of educational practices in real-world settings. This integrated approach is intended to enhance exploratory learning and deepen children's understanding through varied and complex questioning.

This study evaluates the effectiveness of the IBS program in developing science process skills and knowledge acquisition among Moroccan preschoolers. The following hypotheses were tested:

1. Preschoolers participating in the IBS program will develop enhanced science process skills.
2. Preschoolers participating in the IBS program will develop enhanced science knowledge.

Literature review

Harnessing Science Process Skills and Content Knowledge in Early Childhood Science Education

In an era marked by rapid technological and informational advancements, early childhood science education is pivotal for preparing children to navigate future challenges. Martin (1997) emphasizes that the Information Age demands education to transcend traditional knowledge transmission, focusing instead on cultivating essential skills, attitudes, and habits of mind. These elements enable children to question, think critically, solve problems, and make informed decisions, thereby shaping the future of society. Shonkoff (2017) further underscores the profound impact of early experiences on brain development, highlighting the importance of interactive processes between children and adults. These interactions are fundamental not only for cognitive and emotional growth but also for fostering the development of scientific thinking and inquiry skills in children.

Transitioning from the cognitive and emotional foundations of early learning to the development of both content and process skills in science, Charlesworth and Lind (2012) assert the necessity of basic scientific process skills such as observing, comparing, and measuring—skills foundational to both science and mathematics. Effective science education involves the development of robust methods of inquiry, including observing, communicating, inferring, and controlling variables. These skills are crucial for solving interdisciplinary problems and are shaped by early interactions (Charlesworth & Lind, 2012). The introduction of domain-specific knowledge is equally crucial for deepening children's understanding of specific scientific fields such as biology, chemistry, and physics. Eshach and Fried (2005) advocate for integrating this knowledge with process skills to provide a balanced approach to science education, mitigating the risk of misconceptions by ensuring that scientific concepts are introduced in a developmentally appropriate manner (Black & Harlen, 2002).

Building upon these foundational skills, Tolmie et al. (2016) identify key competencies for early scientific learning, including observational skills, descriptive and explanatory skills, and scientific reasoning. These skills involve making accurate observations, understanding causal relationships, and investigating mechanisms, which are essential for children to navigate and interpret their surroundings effectively. Greenfield et al. (2009) expand this list to include questioning, description, comparison, prediction, experimentation, reflection, and collaboration. These skills are optimally developed through hands-on experiences that encourage children to engage with and investigate phenomena, setting the stage for more advanced tasks such as data organization, inferring relationships, and hypothesis testing.

Innovative Curricula in Early Science Education

Innovative curricula have transformed early science education by presenting varied approaches that focus on interdisciplinary learning and engagement. Programs such as ScienceStart! (L. French et al., 2002), the Young Scientist Series (Chalufour & Worth, 2003), Preschool Pathways to Science (PrePS) (Gelman & Brenneman, 2004), and Mudpies to Magnets (Williams et al., 1987) integrate literacy and math into science education to promote scientific processes and higher-order thinking skills. The Full Option Science System (FOSS) (Delta Education, 2024) engages students through active investigation and hands-on learning across various scientific domains, including life, earth, and physical sciences. Science Companion (Chicago Education Publishing Company) employs inquiry-based strategies to reinforce the learning of scientific and mathematical concepts. Additionally, 'La Main à la Pâte', launched in France in 1996, revolutionized science education by promoting inquiry-based learning. This initiative encourages teachers to use experimental and hands-on approaches to teach science, facilitating deep engagement and active participation among students (Charpak et al., 2005). The program's methodology centers on exploring real-world phenomena, enabling children to develop critical scientific skills through observation, hypothesis formulation, and experimentation.

Inquiry-Based Learning Approach to Early Science Learning

Inquiry-based learning (IBL) has been a critical component of science education for over fifty years, providing a framework that encourages deep engagement with scientific inquiry to enhance scientific literacy. This literacy is crucial for informed participation in public discussions on scientific and technological issues (Bybee, 1997; Mostafa et al., 2018). IBL employs a range of instructional methods, from minimally guided, discovery-oriented approaches to structured laboratory activities, aiming to deepen learners' understanding of scientific concepts and the processes by which scientists develop explanations based on evidence (National Research Council [NRC], 1996).

IBL encompasses the conceptual domain (knowledge of facts, theories, and principles), the epistemic domain (understanding how scientific knowledge is generated), and the procedural domain (skills for conducting experiments and gathering evidence (Duschl, 2008; Furtak et al., 2012; Organisation for Economic Co-operation and Development ([OECD], 2019). The IBL process involves several cyclical and non-linear phases, including stating scientific questions, generating testable hypotheses, planning and conducting controlled experiments, and analyzing data to draw conclusions, thereby fostering continuous scientific exploration (Arnold et al., 2018; Chang et al., 2011; Germann, Aram, & Burke, 1996; Pedaste et al., 2015). In early childhood education (ECE), IBL helps develop both content knowledge and an understanding of inquiry processes, aligned with standards like the Next Generation Science Standards (NRC, 2012; Osborne, 2014).

In this study, the authors employed IBS learning experiences to "provide children with opportunities to engage in scientific practices by constructing, evaluating, and refining or reconstructing models of the natural world (A. L. A. Samarapungavan et al., 2008, p. 871). The 5-Step Engineering Design Process (EDP) was used as a foundational framework for activity development, chosen for its alignment with the scientific inquiry cycle, which supports iterative learning in engineering and hands-on science education (Bustamante et al., 2018). The five phases of the EDP for young children include: Ask (identifying problems and needs), Imagine (brainstorming and developing potential solutions), Plan (selecting the most promising solution), Create (implementing and testing the solution), and Improve (evaluating and refining designs for enhancements) (Davis et al., 2017).

Incorporating the EDP alongside the 5Es instructional model—engagement, exploration, explanation, elaboration, and evaluation—provides a robust framework for fostering inquiry-based learning in early childhood education (Akuma & Callaghan, 2019; Yoon & Onchwari, 2006). Bybee (2009) advocates for initiating the learning process with activities that capture children's interest and leverage their pre-existing knowledge. Subsequent phases should deepen inquiry, allowing children to formulate and refine innovative ideas. Directed scaffolding supports children in building upon their initial concepts and developing more complex thought processes. Introducing novel and diverse activities further enriches the learning experience, broadening children's scientific process skills. The reflective phase is crucial, where children assess their own learning outcomes and educators evaluate developmental progress (Worth, 2010).

This pedagogical strategy translates into scientific activities designed for active learning within preschool environments, encompassing both physical and natural sciences. For example, in an activity on buoyancy, children were provided with various materials (e.g., paper clips, wooden cubes, plastic rulers) and water-filled containers. They engaged freely with the objects, sparking curiosity and leading to questions and discussions among their peers and with teachers. These interactions guided a more directed exploration process, aligning with the engineering design challenges.

Effects of Early Science Activities

Early science education is essential for fostering foundational skills across diverse domains, including mathematics, language, literacy, and scientific knowledge. The integration of these disciplines in early learning enhances cognitive development, socio-emotional growth, and nurtures essential life skills, significantly contributing to holistic child development. Research has consistently demonstrated that early exposure to science catalyzes cognitive development and enhances academic readiness. Engaging young learners in activities that incorporate fundamental principles of science leads to marked improvements in mathematical and literacy skills, illustrating the expansive impact of these disciplines (Aldemir & Kermani, 2017; Greenfield et al., 2009; Kinzie et al., 2015; Schmitt et al., 2018). Moreover, structured scientific education extends beyond immediate academic competencies to include a comprehensive understanding of scientific knowledge. Through hands-on activities, children grasp fundamental scientific principles and concepts, enabling them to apply this knowledge in their understanding of the natural world (A. Samarapungavan et al., 2011). This process deepens their cognitive operations and fosters a robust scientific mindset, which is crucial for lifelong learning.

Effective science education focuses on the development of essential science process skills, which encompass observing, classifying, experimenting, predicting, and drawing conclusions. These skills are vital for engaging in meaningful scientific inquiry and are cultivated through stimulating learning environments that harness children's natural curiosity (Ouabich & Tifroute, 2023). Specific interventions have demonstrated that targeted lessons can significantly increase children's engagement and enrich their understanding of science. Programs that incorporate activities in diverse environments, such as science centers and nature museums, further support the development of these skills, enhancing children's capacity to think like scientists and apply these skills in various contexts (Nayfeld et al., 2011; Uludağ & Erkan, 2023).

Inquiry-based learning environments, where children collaborate on scientific questions, significantly enhance social skills by fostering cooperation, communication, and emotional intelligence—key components of healthy social development. Structured programs integrating inquiry-based units improve scientific understanding, motivation, and enjoyment, enriching social interactions and emotional intelligence (A. L. A. Samarapungavan et al., 2008; A. Samarapungavan et al., 2011). Early science programs are crucial in developing well-rounded educational foundations for young children. These programs not only enrich cognitive and academic abilities but also foster essential life skills such as curiosity, problem-solving, and resilience. Preparing children for the challenges of formal education and beyond, these programs ensure their development into inquisitive, knowledgeable, and competent learners.

Despite these advancements, several critical gaps remain in the literature on IBS programs in early childhood education. A primary issue is the inconsistent implementation of IBS across different educational contexts, particularly in resource-limited settings. Much of the research has been conducted in Western contexts, focusing on environments with ample resources and trained educators, leaving a gap in understanding how these programs can be adapted to non-Western and resource-limited settings such as Morocco (Eshach & Fried, 2005; Furtak et al., 2012). This study addresses this gap by tailoring an IBS program to the Moroccan educational context, providing valuable insights for similar adaptations elsewhere.

Moreover, there is a notable lack of longitudinal research examining the long-term effects of IBS programs, with existing studies predominantly focusing on immediate outcomes (Minner et al., 2010). While this study is cross-sectional, it offers valuable preliminary insights that may guide future research into the sustainability of early gains in science process skills and knowledge.

Another gap concerns the debate over the appropriate balance between structured guidance and open inquiry in IBS. While some research suggests that too much freedom can lead to misconceptions (Kirschner et al., 2006), there is limited empirical evidence on how to effectively balance these approaches, especially with young children. This study's use of structured frameworks like the 5Es model and the Engineering Design Process offers insights into resolving this issue. This emerging field of research in Morocco necessitates studies that advance beyond descriptive methodologies in favor of more robust and rigorous experimental approaches. Through the implementation of a quasi-experimental design, this study aspires to contribute more substantive and empirical evidence to the discourse on the efficacy of IBS in early childhood education.

Methodology

Study Context and Demographic Overview

The study was conducted in the southern Moroccan prefecture of Inzegane Ait Meloul, which has a population of 541,118, comprising 513,706 urban residents and 27,412 rural residents. The vulnerability rate was 14.16% in rural areas and 9.57% in urban areas, with corresponding poverty rates of 4.92% and 2.13%, respectively (High Commission for Planning, 2021).

Teacher Participation and Training

The methodological framework of the IBS program was characterized by a comprehensive approach to teacher preparation and pre-implementation support. Initially, educators participated in a two-day workshop that provided a thorough introduction to IBL methodologies, with an emphasis on the EDP and the 5Es instructional model. This training also underscored the importance of enhancing questioning techniques, using structured dialogue strategies known as "talk tips," and emphasized the creation of inquiry-based activities to foster a student-centered learning environment.

Following the initial workshop, four educators agreed to participate in a one-week on-site coaching phase. This phase provided them with the opportunity to apply the newly acquired methodologies in their instructional practices, with ongoing pedagogical feedback facilitating the refinement of their approaches and ensuring consistency with the inquiry-driven objectives of the IBS program.

At the conclusion of the coaching phase, however, only two of the four educators demonstrated a willingness to fully engage in the implementation of the IBS program. These two educators were selected for the experimental group based on their active participation, demonstrated proficiency in applying IBL principles, and their capacity to foster an inquiry-oriented classroom environment. The other two educators chose to withdraw from further involvement, likely due to challenges in adapting to the inquiry-based methodologies and the time commitment required, resulting in their exclusion from the subsequent phases of the study.

The study involved four educators with prior training in Early Childhood Education (ECE). Two of these educators, who had previously participated in the support phase, were assigned to the experimental group. The remaining two educators, who had not received the same training, volunteered for the control group. Among these participants, three held bachelor's degrees, while one had completed high school.

To ensure consistency in content delivery across both groups, uniform educational objectives were communicated to all participants. However, the instructional approaches employed differed significantly. The experimental group implemented IBL methodologies, which promoted a more interactive and exploratory learning environment, whereas the control group adhered to traditional, teacher-centered instructional practices.

Study Design and Participants

The research utilized a quasi-experimental design, focusing on children aged 4 to 6 years in public preschools. These schools, categorized into Middle Class (ages 4–5) and Senior Class (ages 5–6), are known for their comprehensive educational and care services. The selection of schools was based on the socio-economic diversity of the student body and the accessibility of established classes. The experimental group included two classrooms with 19 and 18 children respectively, while the control group consisted of two classrooms, each with 34 children.

In the study, the Intervention Group consisted of 37 children with a mean age of 60.89 months (*SD* = 4.74), and the Control Group comprised 68 children with a mean age of 60.22 months (*SD* = 4.10).

Table1. Participants' Characteristics

Demographic characteristics	IBS Group n= 37	Control group n=68	Total N=105
Child gender			
Female	22 (59,5)	41 (60,3)	63 (60,0)
Male	15 (40,5)	27 (39,7)	42 (40,0)
Father education			
Illiterate	10 (27,0)	16 (23,5)	26 (24,8)
Preschool	0 (0,0)	5 (7,4)	5 (4,8)
Primary School	14 (37,8)	21 (30,9)	35 (33,3)
Secondary School	12 (32,4)	26 (38,2)	38 (36,2)
University	1 (2,7)	0 (0,0)	1 (1,0)
Mother education			
Illiterate	9 (24,3)	23 (33,8)	32 (30,5)
Preschool	2 (5,4)	3 (4,4)	5 (4,8)
Primary School	11 (29,7)	24 (35,3)	35 (33,3)
Secondary School	12 (32,4)	15 (22,1)	27 (25,7)
University	3 (8,1)	3 (4,4)	6 (5,7)
Father vocation			
Stay-at-home	0 (0,0)	0 (0,0)	0 (0,0)
Government Employee	0 (0,0)	4 (5,9)	4 (3,8)
Independent Contractor	31(83,8)	44 (64,7)	75 (71,4)
Employee	6 (16,2)	20 (29,4)	26 (24,8)

Table1. Continued

Demographic characteristics	IBS Group n= 37	Control group n=68	Total N=105
Mother vocation			
Stay-at-home	34 (91,9)	62 (91,2)	96 (91,4)
Government Employee	0 (0,0)	2 (2,9)	2 (1,9)
Independent Contractor	2 (5,4)	1 (1,5)	3 (2,9)
Employee	1 (2,7)	3 (4,4)	4 (3,8)
Family economic level			
Low	1 (2,7)	10 (14,7)	11 (10,5)
Relatively Low	10 (27,0)	15 (22,1)	25 (23,8)
Middle	24 (64,9)	39 (57,4)	63 (60,0)
Relatively High	2 (5,4)	4 (5,9)	6 (5,7)

Note. No demographic differences of statistical significance were found between the IBS group and the control group, as indicated by all p-values being above .05. The figures within the parentheses indicate the percentage of each demographic characteristic within the respective groups.

The mean age for the total sample, which included 105 children, was 60.46 months (*SD* = 4.32). Demographic information for these groups is summarized in Table 1. It was found that there were no statistically significant differences between the IBS group and the Control group with respect to key demographic variables, including child age, gender, parental education, and household income, as all *p*-values exceeded .05.

The IBS Program

The IBS program comprises a series of structured activities that transition from play-based engagement to focused inquiry-based learning. The program covers a range of topics, including "What is Science?" to introduce scientific inquiry, "Living/Non-Living" to help distinguish between living and non-living things, "Germination" to deepen understanding of life sciences, "States of Matter" to explore the properties and transformations of solids and liquids, "Floats/Sinks" to investigate buoyancy, and "States of Water" to examine the various phases of water.

The IBS program immerses children in fundamental scientific processes, such as observing, questioning, predicting, investigating, communicating data, and synthesizing information. These activities equip children with essential skills for scientific inquiry, fostering their ability to engage critically with scientific concepts.

In addition to the structured activities, the IBS program places significant emphasis on ongoing teacher development and support. Throughout the implementation, educators engaged in regular coaching sessions and routine group discussions, with the first author actively participating in all instructional units alongside the educators. Following each instructional session, reflective discussions were conducted to monitor progress, address challenges, and refine instructional strategies, ensuring alignment with the study's objectives. This ongoing engagement allowed the first author to provide real-time feedback, ensuring consistent application of the IBS program across various classrooms.

Group Arrangement

In both IBS classes, children were organized into four groups based on voluntary participation. The first class of 18 children had three groups of five children each and one group of three children. The second class of 19 children had three groups of five children and one group of four children.

Throughout the 12-week intervention, groupings remained consistent, with each group participating in 2.5-hour sessions at least once per week. Initially randomized, the sessions were later standardized to occur at the same times and days each week, integrated into the regular school day per the classroom teachers' discretion. Each group participated in 16 sessions. Attendance was carefully recorded, with children attending an average of 15.5 sessions, typically ranging from 15 to 16. Absences were primarily due to illness. Given the high attendance rate, ensuring the robustness and representativeness of the data, all participants were included in the study.

Measures

Demographic Questionnaire: The Demographic Questionnaire in our study captures detailed information on family background and child demographics. It collects data on the child's gender and age, parental education levels (Illiterate, Preschool, Primary School, Secondary School, University), and parental vocations (Stay-at-home, Government Employee, Independent Contractor, Employee). Additionally, it assesses the family's economic status (Low, Relatively Low, Middle, Relatively High). This comprehensive data collection aids in understanding the diverse socio-economic contexts of the participating families.

Science Process Skills Assessment Scale: Drawing on the core features of the inquiry learning process as identified by Pedaste et al. (2015), we developed an assessment scale to evaluate the acquisition of science process skills through an IBS program, adapted for preschool-aged children. The scale comprises four key domains:

Observing/Questioning (4 items, α = .925): Assesses the ability to generate questions, make observations, describe properties, and organize data.

Predicting (3 items, α = .900): Measures the ability to formulate hypotheses, consider investigative approaches, and make predictions.

Investigating/Experimenting (5 items, α = .893): Evaluates the use of investigative methods, handling materials, following protocols, and supporting hypotheses.

Communicating Results/Synthesizing (4 items, α = .774): Assesses communication of findings, expressing understanding, synthesizing information, and articulating conclusions.

Each item is rated on a 3-point scale: 1 (Seldom), 2 (Occasionally), 3 (Frequently). Teachers use these criteria to provide insights into each child's skills. The scale's total reliability, with a Cronbach's alpha of .955, underscores its consistency. The scale was reviewed by early childhood education experts and tested on a separate sample of 30 children, confirming its reliability and validity in measuring scientific process skills in young learners.

Scientific Knowledge and Concept Acquisition Test (SKAT): To assess scientific knowledge and concepts acquired by participants, each child was individually evaluated using a photo-illustrated test before and after the intervention. The test covered all educational units and was administered by two expert early childhood education teachers, blinded to group assignments to ensure unbiased assessments.

The test used a binary scoring system: '1' for correct answers and '0' for incorrect or no answers, with a maximum score of 24 points. Examiners prompted for clarification if a child's response was unclear, asking them to 'show me the image you chose' or 'explain your answer.' This ensured the accuracy of responses.

To prevent response bias, multiple-choice answers were presented in random order, and open-ended questions were included to deepen the assessment of conceptual understanding. The assessments were conducted in a controlled environment, ensuring consistent and fair data collection across all participants.

Data Analysis

To evaluate the initial equivalence of the experimental and control groups, chi-square analyses and independent t-tests were conducted initially. This preliminary analysis ensured that any observed post-intervention differences were due to the educational program and not pre-existing disparities. Prior to applying the Repeated Measures Analyses of Variance (RMANOVA), all relevant assumptions, including normality, homogeneity of variance, and sphericity, were rigorously tested to ensure the appropriateness of the analysis.

RMANOVA was then used to explore group by time interactions, examining the effects of the intervention on both science process skills and the acquisition of scientific knowledge and concepts over time. Subsequent RMANOVA models included covariates such as baseline scientific understanding, child gender, age, and family Socio-Economic Status to control for potential confounding factors. Where significant group by time interactions were found, paired t-tests were conducted post-hoc to assess changes from pretest to posttest within each group.

All statistical analyses were conducted using IBM SPSS software, version 25.0. Effect sizes (Cohen's d) for pre/post differences within and between groups were calculated to quantify the impact of the intervention. These effect sizes were categorized as "small," "medium," or "large" according to Cohen's criteria (Cohen, 1988), providing a standardized measure of the intervention's effectiveness.

Results

At baseline, no significant differences were observed between the experimental and control groups on the Science Process Skills (SPS) and Scientific Knowledge Acquisition Test (SKAT), ensuring comparability at the start of the intervention ($p > .05$). Table 2 presents the results of the RMANOVA for group-by-time interactions, including group means and standard deviations.

Science Process Skills (SPS)

The detailed assessment of SPS using RMANOVA revealed significant group by time interactions for overall SPS scores, $F(1, 103) = 185.81$, $p < .001$ (See Figure 1). This interaction persisted even after adjusting for covariates such as baseline levels, child gender and age, and family socioeconomic status, $F(1, 99) = 179.61$, $p < .001$. The subscale scores further supported this pattern, with the Observing/Questioning (OB/Q) subscale showing F-values of 35.87 initially and 34.68 post-adjustment, both with $p < .001$. Similar results were observed in the Predicting (Pr) subscale, $F(1, 103) = 33.78$ and $F(1, 99) = 34.21$; the Investigating/Experimenting (INV) subscale, $F(1, 103) = 102.21$ and $F(1, 99) = 99.46$; and the

Communicating/Synthetizing (CO/S) subscale, $F(1, 103) = 47.13$ and $F(1, 99) = 44.96$, all maintaining statistical significance after adjusting for the aforementioned covariates.

Table 2. Pretest and Posttest Scores by Group and Assessment

	IBS Groupe n=37		Control Group n=68			
Variables	**Pre-test *M*(*SD*)**	**Post-test *M*(*SD*)**	**Pre-test *M*(*SD*)**	**Post-test *M*(*SD*)**	**Between-group Cohen's *d***	***F***
SPS	1,14(0,12)	1,48(0,19)	1,13(0,11)	1,15(0,09)	2,31	185,81***
SPS -Q/OB	1,17(0,22)	1,45(0,23)	1,18 (0,22)	1,17(0,13)	1,19	35,87***
SPS -HF	1,14(0,24)	1,51(0,32)	1,14(0,20)	1,16(0,22)	1,02	33,78***
SPS -INV	1,13(0,18)	1,50(0,22)	1,11(0,13)	1,11(0,14)	1,73	102,21***
SPS -CO/S	1,13(0,16)	1,44(0,22)	1,11(0,12)	1,15(0,13)	1,07	47,13***
SKAT	12,13(2,38)	18,54(2,79)	11,70(2,39)	14,26(2,66)	1,41	152,55***

*Note. SPS: Science Process Skills; OB/Q: Questioning and Observing; Pr: Predicting; INV: Investigating; CO/S: Communicating and Synthetizing. SKAT: Scientific Knowledge and concept Acquisition Test. Between-group Cohen's d = differences (IBS minus control) between within-group pre/post ds; F= value of group by time interaction. ***p < .001 indicates a highly significant statistical result.*

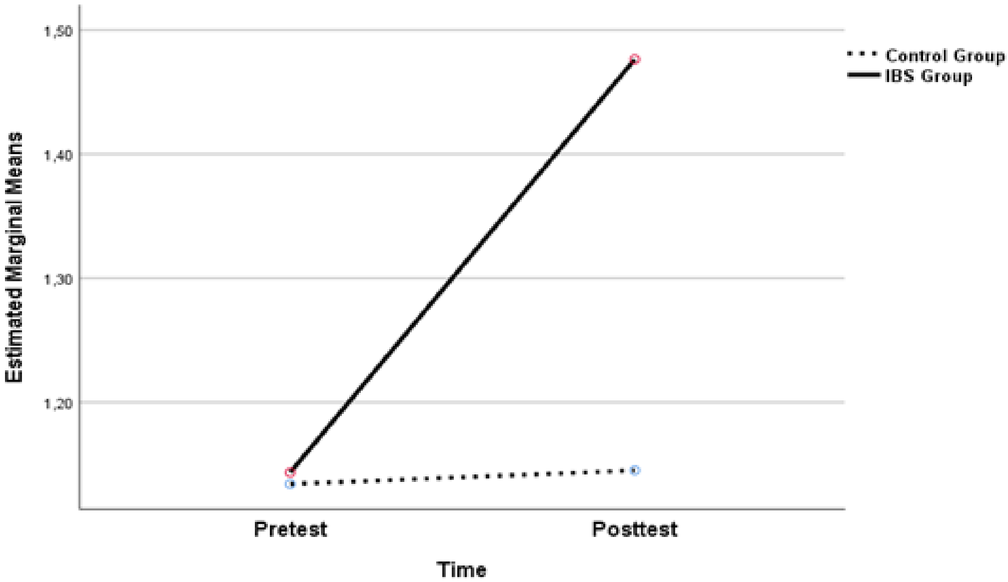

Figure 1. The Intervention Effect on Scientific Process Skills Acquisition

Note. N = 105. Theoretical range of SPS= 1–3. Mean change is separately reported for both the IBS and control groups. A significant group by time (pretest/ posttest) interaction was found in SPS scores, p < .001.

The pre/post within-group effect sizes revealed very large improvements in the IBS group, with Cohen's $d = 2.42$ for overall SPS. The subscales also demonstrated large effects: $d = 1.13$ for OB/Q, $d = 1.11$ for Pr, $d = 1.77$ for INV, and $d = 1.26$ for CO/S. Conversely, the control group exhibited minimal changes, with trivial effect sizes for overall SPS (d = 0.11) and most subscales; OB/Q ($d = -0.06$), Pr ($d = 0.09$), INV ($d = 0.04$), and a small effect size for CO/S ($d = 0.20$).

The between-group effect sizes *ds* revealed a significant advantage for IBS group. For overall SPS, the effect size was very large at $d = 2.31$. Subscale comparisons showed large effects as well, with $d = 1.19$ for OB/Q, $d = 1.02$ for Pr, $d = 1.73$ for INV, and $d = 1.07$ for CO/S.

Scientific Knowledge and Concept Acquisition Test (SKAT)

In the Scientific Knowledge and Concept Acquisition Test (SKAT), RMANOVA analyses revealed a significant group by time interaction, $F(1, 103) = 152.55$, $p < .001$ (See Figure 2). Adjusting for baseline levels, child gender and age, and family socioeconomic status as covariates did not alter the test's significance, $F(1, 99) = 154.07$, $p < .001$. Post hoc paired t-tests showed a very large pretest-posttest change in the IBS group, with an effect size of d = 3.41 (classified as "very high"). Similarly, the control group displayed a significant and very high effect size of d =2.00, p < .001. The between-group effect size was d =1.41, also very high, indicating a significant advantage in scientific knowledge acquisition for the IBS group compared to the control group.

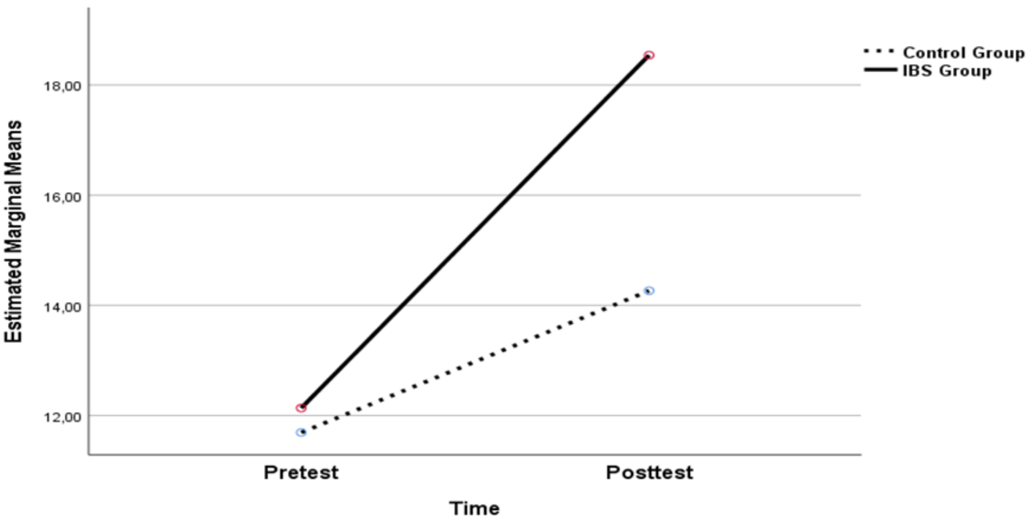

Figure 2. The Intervention Effect on Scientific Knowledge and Concept Acquisition Test.

Note. N = 105. Theoretical range of SPS= 0–24. Mean change is displayed separately for IBS and control groups. A significant group by time (pretest/ posttest) interaction was found in SKAT scores, p < .001.

Discussion

This study, pioneering in its use of an experimental design within Moroccan preschool contexts, substantiates the efficacy of a 12-week Inquiry-Based Science (IBS) program in promoting science knowledge and process skills among young children. This discussion delineates the mechanisms underlying the program's success and positions it within the broader educational landscape.

How the IBS Program Is Significantly Effective

This study, conducted within Moroccan preschools, robustly supports hypotheses H1 and H2, demonstrating that the IBS program significantly enhances preschool children's science knowledge and process skills compared to a control group.

These results corroborate the existing body of literature that underscores the positive effects of early childhood science education, emphasizing enhancements in both knowledge and science process skills (Aldemir & Kermani, 2017; Ergül et al., 2011; Golob & Ungar, 2023; Greenfield et al., 2009; Mulyeni et al., 2019; Nayfeld et al., 2011; A. L. A. Samarapungavan et al., 2008). Unlike many US-based studies, this intervention offers critical insights from Morocco, noted for its academically rigorous and transmissive educational settings (Chafi et al., 2014; Higher Council of Education, 2008). The results illustrate the effectiveness of the inquiry-based approach in enhancing Moroccan preschoolers' scientific knowledge and skills, affirming the adaptability of constructivist theories across various educational systems. Echoing similar findings from Lin et al. (2021) in China, these results underscore the versatility and potential of inquiry-based learning models even in environments dominated by traditional pedagogies.

The IBS program strategically cultivates essential science process skills through activities centered around observing, questioning, predicting, investigating, and communicating. Such activities are pivotal for engaging children in the scientific process and deepening their understanding of natural phenomena through active exploration and interaction (Anastasiou et al., 2015; Kesidou & Roseman, 2002; National Science Board, 2004; NRC, 2013). This hands-on approach not only boosts observational skills but also supports the broader scientific inquiry process (Dilek et al., 2020; Germann, Aram, Odom, & Burke, 1996; Lin et al., 2021; Staver & Small, 1990), serving as a fundamental basis for learning science effectively.

Moreover, the program's focus on enhancing scientific knowledge and concept acquisition is evidenced by the high levels of these competencies observed in the IBS group. This reinforces the notion that IBL significantly impacts student concept learning, corroborating earlier research findings (Chiappetta & Russell, 1982; Ertepinar & Geban, 1996; Gabel et al., 1977; Lin et al., 2021; Mao et al., 1998; Worth, 2010; Worth & Grollman, 2003). It emphasizes that possessing science process skills is not merely beneficial but essential as a foundation for learning science.

Research further suggests that integrating science with an inquiry-based focus prepares children more effectively by developing specific knowledge (Bustamante et al., 2018). Meta-analyses have demonstrated that inquiry-based science education not only improves students' academic achievements and scientific process skills but does so more effectively than traditional teaching methods (Sever & Guven, 2014; Şimşek & Kabapınar, 2010). Moreover, the rich experiential backdrop of the program merges abstract concepts with tangible experiences, vital for fostering independent inquiry capabilities (Chaille & Britain, 2003).

Active engagement in hands-on activities is central to exploring scientific principles. This consistent enjoyment of the learning process by students reinforces the importance of engaging in educational activities for effective science learning, as highlighted by previous studies (Cimer, 2007). The careful planning of investigations and the selection of appropriate materials are crucial factors in effectively developing each facet of the science process skills. Additionally, the practical application of these skills during scientific investigations is a key to deepening students' understanding and capabilities.

This discussion illuminates the underlying mechanisms of the IBS program's success and positions it within the broader educational landscape, demonstrating its potential to transform traditional educational paradigms. Designed to foster the holistic development of scientific skills from an early age, its effectiveness in the culturally distinct Moroccan context not only supports the utility of IBL but also proposes a scalable model for its integration into early childhood education globally. The findings resonate with the principles of the 5Es instructional model (Akuma & Callaghan, 2019; Yoon & Onchwari, 2006) emphasizing that a conducive scientific environment enhances children's innate curiosity and stimulates the further development of their knowledge and skills. This approach not only validates the effectiveness of inquiry-based learning but also underscores that well-structured educational frameworks can significantly impact cognitive and developmental outcomes in young learners.

Why the IBS Program Is Significantly Effective

In this study, the IBS program is guided by the 5Es instructional model (Bybee, 1997, 2009; Yoon & Onchwari, 2006) and incorporates the EDP (Davis et al., 2017) along with the scientific inquiry cycle (Pedaste et al., 2015; Worth, 2010). Through selected thematic projects in physics and biology, the program demonstrates how a cohesive, adaptable inquiry approach can enhance science education. The existing literature provides insights into why the IBS program is highly effective.

First, the core of executive functions (EFs) could be crucial in connecting children's investigative encounters with their improved abilities and understanding (Fridman et al., 2020; Gropen et al., 2011; Jirout & Zimmerman, 2015; Lin et al., 2021). EFs, encompasses abilities that aid in concentration, organization, goal-setting, self-control of actions and feelings, adjustment to novel circumstances, and, ultimately, involvement in conceptual thinking and strategy development (Calderon, 2020). The primary elements of EFs comprise inhibitory control (the capacity to manage impulses), working memory (a form of short-term memory entailing temporary storage and manipulation of information), and cognitive flexibility, also known as shifting (the aptitude to transition between contemplating various subjects) (Calderon, 2020). Each of these abilities evolves at distinct rates, presenting specific periods of growth and opportunities for intervention and are directly involved in information processing (Davidson et al., 2006 ; Diamond & Lee, 2011; Zelazo et al., 2008).

The inquiry approach necessitates robust strategic problem-solving skills, involving the generation and continuous adaptation of hypotheses based on both observed and anticipated outcomes. It also requires the analysis and assessment of data, along with the flexible consideration of different possibilities. Furthermore, it involves speculating about the potential effects of experimental manipulations to ensure a deep and critical engagement with scientific processes. Within the IBS program, children frequently engage in actively manipulating their environment, processes, and materials, consistently developing their executive function skills such as cognitive flexibility and inhibitory control. This active involvement not only enhances their ability to address complex problems but also significantly boosts their motivation and engagement levels (Lin et al., 2021). As a result, children can effectively assimilate new knowledge and skills in a sustained learning process, continually exhibiting various positive qualities. This scaffolded learning environment aligns with educational frameworks advocating for increased autonomy and deeper inquiry, thereby preparing students for higher educational challenges and professional scientific roles. Future evaluations of STEM programs that utilize the inquiry approach should consider including executive functions as potential mediating factors. This inclusion will deepen our understanding of how these cognitive processes contribute to the overall effectiveness of the educational experience. Second, the inquiry method enhances children's engagement with processes like the EDP and scientific inquiry, which correspond with essential science process skills (Greenfield et al., 2009) that are crucial for development.

These activities encompass a cycle of stimulating curiosity through the management of uncertainty, ultimately leading to its resolution (Jirout & Zimmerman, 2015). This approach is underpinned by the notion that young children possess inherent curiosity, and uncertainty is a critical catalyst for this curiosity, serving as a foundational element in scientific inquiry (L. A. French & Woodring, 2012).

Future studies should consider assessing language, literacy, and social-emotional development to comprehensively evaluate the efficacy of the inquiry-based method in early science education. Moreover, evaluating preschool learning behaviors (PLBS), including curiosity, motivation, and persistence within an IBS program, can offer deeper insights into young learners' engagement with science education. These assessments are crucial for understanding the cognitive and emotional development essential for navigating the increasingly complex scientific and technological challenges of the future.

Conclusion

This quasi-experimental study highlights the significant impact of the Inquiry-Based Science (IBS) program on enhancing science process skills and knowledge among Moroccan preschool children. By integrating inquiry-based learning into the existing play-based curriculum, the study found that young learners were better prepared for the complexities of the modern world. The findings support the hypothesis that inquiry-based methods can yield substantial educational benefits in early childhood settings, improving both science-relevant process skills and knowledge.

Empirically, the study provides robust evidence advocating for a shift toward inquiry-based educational frameworks that align with global educational standards. It recommends incorporating the Engineering Design Process and the 5Es instructional model into early childhood education to foster scientific exploration. Educational stakeholders in Morocco are encouraged to adopt these approaches to cultivate young children's curiosity and readiness to learn, thereby preparing them for future challenges. Additionally, educators are urged to implement inquiry-based strategies to sustain children's interest in science, laying a strong foundation for continuous engagement and literacy.

Recommendations

Despite promising findings, several recommendations for future research and practice are necessary. Future studies should broaden the scope and scale of inquiry-based interventions through larger, more diverse samples and randomized controlled trial designs to enhance the robustness and generalizability of findings. Longitudinal studies would also be beneficial in understanding the long-term impact of early science education on later academic and professional outcomes. Considering socio-economic and cultural variables could provide deeper insights into the effectiveness of inquiry-based learning across different contexts. Additionally, integrating digital tools and technologies, such as virtual and augmented reality, into inquiry-based learning environments should be explored. Finally, professional development programs for teachers should be developed to enhance their effectiveness in implementing inquiry-based learning, ensuring that educational reforms translate into improved classroom outcomes.

Limitations

As a quasi-experimental study, the research may have limitations in generalizability due to the absence of randomization and potential selection bias, affecting internal validity. The sample size and focus on the Inzegane Ait Meloul prefecture may not reflect the diversity of preschool settings across Morocco. Additionally, reliance on teacher observations to assess children's skills may introduce bias and limit insights into individual student progress. Addressing these limitations in future research will help refine and optimize inquiry-based approaches, ensuring that early childhood education in Morocco and similar contexts meets the needs of young learners in the 21st century.

Disclosure Statement

No conflicts of interest are present in this study.

Ethics Statements

All procedures carried out in studies involving human subjects were conducted following the ethical standards of the institutional and/or national research committees and the 1964 Helsinki Declaration and its subsequent amendments or similar ethical guidelines. Additionally, informed consent was obtained from all adult participants and the guardians of child participants.

Authorship Contribution Statement

Ouabich: Conceptualization, design, data acquisition, data analysis and interpretation, drafting manuscript. Tifroute: Conceptualization, critical revision of manuscript, final approval. Rafouk: Conceptualization, critical revision of manuscript, final approval.

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