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Integrating Play and STEM in Early Childhood Education: Learning the Respiratory System through Fun and Engaging Activities

Rajarajeswary Gnanasagaran[1,*]

[1] Quest International University Jalan Raja Permaisuri Bainun, 30250 Ipoh, Perak, Malaysia

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ABSTRACT

Early childhood education (ECE) plays a pivotal role in shaping foundational cognitive, emotional, and social competencies. Integrating play with STEM (Science, Technology, Engineering, and Mathematics) not only engages young learners but also fosters inquiry-based learning and cross-disciplinary skills. This research explores how a hands-on, play-based activity using a model of the human respiratory system enhances conceptual understanding in children aged 4–6 years. Using Vygotsky's social constructivism, Piaget's cognitive development theory, and Gardner's multiple intelligences as theoretical frameworks, this qualitative study investigates the impact of role-play, storytelling, and model construction on young children's scientific knowledge and holistic development. Findings indicate that combining STEM with playful learning boosts engagement, promotes collaboration, strengthens language and numeracy, and builds body awareness. This paper advocates for integrative, child-centered approaches in ECE STEM curricula to build lifelong learners equipped with 21st-century skills.

1. Introduction

Early childhood is a crucial phase in human development where foundational learning experiences significantly shape a child's cognitive, emotional, and physical growth. According to research in neuroscience and developmental psychology, the early years are marked by rapid brain development and synaptic formation, making them ideal for introducing meaningful and engaging learning activities [36]. During this critical period, children develop core capabilities such as attention, memory, self-regulation, and reasoning skills that are fundamental for later academic success.

The early years of a child's life are critical for cognitive development. Neuroscience and educational psychology consistently affirm that early experiences influence brain architecture, setting the stage for future learning, behavior, and health. Among various pedagogical strategies, play-based learning stands out for its ability to engage young children in meaningful and joyful

* *Corresponding author.*
E-mail address: rajarajeswary.gnanasagaran@qiu.edu.my

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exploration [21]. At the same time, there is a growing demand to introduce STEM education from an early age to build a pipeline of scientifically literate citizens and problem-solvers.

In early childhood education (ECE), play is more than mere recreation it is the primary context for learning. Play-based learning enables children to explore, experiment, and make sense of the world in ways that are developmentally appropriate and intrinsically motivating [43]. It supports the holistic development of children by integrating social interaction, emotional regulation, cognitive processing, and language acquisition into a unified experience. Given its versatility and child-centered nature, play is an ideal platform for integrating emerging domains like STEM (Science, Technology, Engineering, and Mathematics) into early learning.

Concurrently, there is a growing global interest in promoting STEM education from the early years. Early exposure to STEM supports critical thinking, inquiry, creativity, and problem-solving skills capabilities that are essential for future academic and career success in a rapidly changing, technologically driven world [30]. However, incorporating STEM into early childhood settings requires thoughtful integration with play-based pedagogies to ensure developmentally appropriate practices are maintained [22].

However, teaching abstract scientific concepts, such as human anatomy, to young children presents unique challenges. This study addresses this gap by examining how the human respiratory system typically considered too complex for early learners can be taught effectively through a play-based, hands-on STEM activity. Children built a simple respiratory model using everyday materials, engaged in doctor-patient role-play, and explored their own bodies' functions through movement and observation.

1.1 Background of the Study

Early childhood represents a critical period for cognitive, social, and emotional development. During this stage, children's brains exhibit heightened neuroplasticity, making them especially responsive to environmental stimuli and learning experiences [8]. Play-based learning during this phase provides rich opportunities for exploration, problem-solving, and social interaction, all of which are essential for holistic development. Neuroscientific and developmental psychology research highlights that enriching experiences in the early years lay the foundation for future academic achievement and emotional well-being [36,42].

Despite the increasing emphasis on STEM, the life sciences particularly topics like human anatomy are often overlooked in early childhood curricula. This omission is largely due to the perception that biological systems are too complex for young learners to grasp. However, recent pedagogical research suggests that when abstract concepts are presented through concrete, hands-on, and playful experiences, young children are capable of meaningful scientific understanding [16]. There is a growing need to design interdisciplinary activities that promote scientific literacy and health awareness among young children in ways that align with their natural learning styles.

Play-based learning has been widely recognized as an effective pedagogical approach in early childhood education (ECE), as it nurtures children's curiosity, creativity, and problem-solving skills while aligning with their natural modes of learning [3]. Through guided play, children engage in meaningful exploration and experimentation, which supports cognitive and socio-emotional development. Concurrently, there is a growing global emphasis on the integration of STEM (Science, Technology, Engineering, and Mathematics) in early childhood settings to foster scientific literacy, critical thinking, and inquiry-based learning from an early age [24,30]. By combining play with STEM concepts, educators can create engaging, developmentally appropriate experiences that lay the foundation for lifelong learning.

Despite the growing emphasis on STEM integration in early childhood education, the teaching of biological sciences particularly human anatomy remains underrepresented in early years curricula, largely due to perceptions of its complexity and developmental inappropriateness [32,39]. However, emerging research suggests that with developmentally appropriate strategies, even complex biological systems such as the respiratory system can be introduced effectively to young learners. By leveraging integrative and play-based STEM activities, educators can make abstract concepts more accessible, engaging, and meaningful for children [6,17].

This study builds on that foundation by exploring the use of a play-based STEM activity designed to teach the respiratory system to preschool-aged children. Through constructing a simple model using plastic bottles, straws, and balloons, and engaging in guided role-play scenarios, children interact with abstract biological concepts in a tangible and enjoyable manner.

1.2 Problem Statement

Despite increasing global and national efforts to strengthen STEM (Science, Technology, Engineering, and Mathematics) education in early childhood, there remains a critical gap in its practical application particularly in the area of biological sciences. Research has shown that topics like human anatomy are often excluded from early childhood education (ECE) curricula due to perceptions of their complexity and educators' limited confidence in simplifying these concepts for young learners [35,36]. As a result, young children are often denied opportunities to develop early scientific literacy and body awareness through structured, age-appropriate learning experiences.

This issue has been further exacerbated by the disruptions caused by the COVID-19 pandemic. Prolonged school closures and shifts to remote learning led to widespread learning loss, especially among preschool and early primary-aged children, who missed out on tactile, interactive, and socially rich learning environments [14]. This period highlighted the importance of restoring hands-on, engaging learning strategies particularly in subjects that require embodied understanding, such as the human respiratory system.

Moreover, recent reports have raised concern over declining physical activity and health literacy among young children. According to UNICEF [40], early learners are spending more time in sedentary, screen-based activities, with reduced awareness of their own physical wellbeing. Teaching biological functions such as breathing through play and movement-based activities can directly contribute to reversing this trend by making health education accessible, memorable, and fun.

Despite policy frameworks like Malaysia's STEM4All Strategy [27] emphasizing the importance of early STEM exposure, classroom implementation remains inconsistent due to a lack of teacher training and confidence in STEM integration. There is an urgent need for practical, developmentally appropriate strategies that align STEM concepts with play-based pedagogies, making scientific learning meaningful and engaging for young children.

This study seeks to address these intersecting challenges by examining the effectiveness of a play-integrated STEM activity that teaches the human respiratory system to preschoolers. By using hands-on modeling and role-play, the study aims to offer a replicable, child-centered approach to bridging the gap between policy, pedagogy, and real classroom practice.

While STEM integration in early childhood education (ECE) is gaining momentum, the incorporation of life sciences particularly human anatomy remains significantly underrepresented.

This is largely due to the scarcity of age-appropriate teaching strategies that make complex biological systems comprehensible and engaging for preschool-aged children. Educators often face challenges in translating abstract scientific content into developmentally appropriate experiences that align with how young children learn best through play, hands-on activities, and meaningful social interactions [16]. As a result, young learners are frequently excluded from opportunities to explore foundational scientific knowledge about their own bodies. This exclusion not only limits their scientific literacy but also their awareness of health and bodily functions. There is, therefore, a pressing need for innovative, play-integrated teaching approaches that make science both accessible and developmentally appropriate, while fostering holistic learning in early childhood settings.

1.3 Purpose of the Study

The purpose of this study is to explore the effectiveness of integrating play and STEM principles to teach the human respiratory system to children aged 4 to 6 years. Specifically, the study investigates how hands-on model-making, interactive role-play, and cross-disciplinary activities can enhance scientific understanding and foster engagement, collaboration, and holistic development in early learners.

1.4 Research Questions

1. How does integrating play and STEM influence children's understanding of the human respiratory system?
2. What role does interactive model construction and role-play play in promoting engagement and conceptual learning?
3. How does the activity support development across multiple learning domains (e.g., language, math, art, physical awareness)?

1.5 Research Objectives

1. To examine the impact of play-based STEM activities on children's conceptual understanding of the respiratory system.
2. To evaluate the effectiveness of hands-on modeling and role-play in promoting scientific inquiry and engagement.
3. To analyze how integrating multiple disciplines through a single activity supports holistic development in early childhood education.

This paper aims to:
1. Explore the effectiveness of integrating play and STEM in ECE through the lens of a biological science activity.
2. Examine how role-play and interactive modeling affect understanding of the respiratory system.
3. Analyze how cross-disciplinary learning enhances developmental outcomes in language, math, art, and physical health.

2. Theoretical Framework
2.1 Vygotsky's Social Constructivism

Lev Vygotsky emphasized the importance of social interaction in cognitive development, asserting that learning occurs most effectively within the Zone of Proximal Development (ZPD) the range between what a child can do independently and what they can achieve with guidance from a more knowledgeable peer or adult [41]. In the context of early childhood education, play especially role-play provides an ideal framework for activating the ZPD. When children engage in guided play, such as a "Doctor’s Visit" scenario to explore the human respiratory system, they participate in shared social experiences that scaffold their understanding of abstract scientific concepts. Constructing a model of the lungs and simulating the breathing process not only reinforces their cognitive grasp of bodily functions but also allows them to co-construct meaning through interaction, questioning, and imitation. The presence of educators or peers during these activities serves as a scaffold that helps children internalize complex knowledge, such as inhalation and exhalation, in ways that align with their developmental stage. This aligns with Vygotsky’s belief that knowledge is co-constructed and mediated through social tools, including language and symbolic play, making such STEM-integrated, play-based learning activities both meaningful and developmentally appropriate.

2.2 Piaget’s Theory of Cognitive Development

Jean Piaget identified the preoperational stage (approximately ages 2 to 7) as a critical period in which children begin to develop symbolic thinking, imagination, and rapid language acquisition, but still struggle with abstract reasoning [34]. During this stage, young learners rely heavily on tangible, sensory-rich experiences to make sense of the world. In this context, integrating STEM learning through play becomes particularly powerful. Activities such as constructing a model of the human respiratory system using balloons and straws provide children with concrete, hands-on opportunities to explore abstract biological functions like inhalation and exhalation. By physically manipulating the model watching the balloons expand and contract as they simulate breathing children build cognitive schemas that represent real-life biological processes. This aligns with Piaget’s assertion that children in the preoperational stage learn best when they can actively engage with and experiment within their environment. Such experiences not only strengthen conceptual understanding but also support the transition from concrete to more abstract thinking, laying the groundwork for future scientific learning.

2.3 Gardner’s Multiple Intelligences

Howard Gardner’s theory of multiple intelligences emphasizes that intelligence is not a single, fixed attribute, but rather a diverse set of modalities through which individuals process and express knowledge [19]. In early childhood education, this perspective supports a holistic and inclusive pedagogy, where children are encouraged to engage with content in ways that resonate with their individual strengths. The hands-on respiratory system activity in this study—constructing lung models, engaging in role-play, and narrating health-related scenarios—provides opportunities to activate multiple intelligences simultaneously. Linguistic intelligence is engaged as children describe the breathing process and participate in storytelling; logical-mathematical intelligence is applied when counting breaths and measuring changes in breathing rate; bodily-kinesthetic intelligence emerges as they manipulate materials and simulate breathing; and visual-spatial intelligence is fostered through model-building and drawing the respiratory system. Additionally, interpersonal intelligence is evident as children collaborate in role-play, while intrapersonal intelligence is strengthened through increased body awareness and self-reflection. This multifaceted engagement not only enhances conceptual learning but also ensures that all children, regardless of their dominant learning style, have meaningful access to STEM education.

3. Literature Review

Play is a natural and developmentally appropriate medium for learning in early childhood. It fosters curiosity, creativity, collaboration, and the exploration of complex ideas through concrete, enjoyable experiences. Research consistently shows that when play is guided with clear educational intent, it significantly enhances academic achievement, executive functioning, and social-emotional development [21]. Purposeful play allows children to internalize new concepts through physical manipulation, narrative construction, and social interaction all of which are key modes of learning in the early years.

In recent years, there has been growing recognition of the need to embed STEM (Science, Technology, Engineering, and Mathematics) education in early childhood curricula. Although once considered too advanced for young learners, studies now affirm that children as young as four can grasp foundational STEM concepts when taught through hands-on, play-based methods. For instance, Brennan *et al.*, [7] demonstrated that preschoolers could understand basic engineering principles by engaging in block-building and design-based challenges. Similarly, Worth and Grollman [42] showed that inquiry-based science activities significantly enhanced young children's vocabulary, reasoning, and observational skills.

More recent studies from 2020–2025 continue to emphasize the importance of integrating STEM into early years education. Toma and Menon [36] reported that structured, inquiry-driven STEM experiences in preschool settings promoted not only content understanding but also children's confidence, collaboration, and metacognitive skills. Furthermore, a study by Alford *et al.*, [1] found that embedding STEM within socio-dramatic play contexts improved children's retention of science content and increased their motivation to explore scientific ideas. The researchers highlighted that young learners were particularly responsive to activities that linked science to real-life phenomena, such as bodily functions, weather changes, or mechanical movement.

Despite these promising developments, biological sciences particularly human anatomy remain underrepresented in early childhood education. The complexity of internal bodily systems, coupled with limited teacher training and a lack of age-appropriate resources, contributes to the marginalization of life science topics [35]. Children are often introduced to plants, animals, and environmental science, but receive little to no formal instruction about their own bodies beyond superficial health messages.

While numerous studies have emphasized the benefits of integrating STEM in early childhood through playful approaches [6] critical gap remains in how these approaches address foundational scientific concepts like the respiratory system. Most research prioritizes mathematical and engineering aspects (e.g., building structures, coding games), leaving physiological systems underrepresented in playful STEM activities. Moreover, studies such as Davis [12] focus predominantly on structured play, while others [17] argue for more open-ended, child-led exploration. This inconsistency signals a need to reconceptualize how play is leveraged across STEM domains, especially in biological education for young learners.

This gap is concerning, given the increasing focus on health literacy and bodily autonomy in early education. Recent data from UNICEF [40] and McLaughlin *et al.*, [25] emphasize that young children are capable of understanding bodily systems when these are introduced through sensory-rich, playful learning experiences. Studies indicate that such instruction not only deepens children's scientific knowledge but also contributes to self-awareness and physical confidence. For example, incorporating activities that teach how the lungs work using tangible materials like balloons and straws allows children to visualize and understand respiration in a meaningful way [11].

Moreover, cross-disciplinary STEM activities have been shown to boost holistic learning. According to Torres-Crespo *et al*., [38], integrating science with art, math, and storytelling in preschool lessons fosters deeper conceptual understanding and nurtures multiple intelligences. Activities that blend disciplines such as drawing the respiratory system after a model-building exercise or measuring breathing before and after physical activity promote critical thinking, fine motor skills, vocabulary development, and social collaboration.

In summary, although early STEM education has gained significant traction over the past decade, there remains a critical need to broaden its scope to include biological sciences like human anatomy. Play-based, integrated STEM activities represent a powerful strategy for addressing this gap. They not only make abstract scientific concepts accessible to young children but also empower them to become curious, confident, and health-aware learners from an early age.

4. Methodology

4.1 Research Design

Qualitative research is defined as a method of inquiry that seeks to understand human behavior and the reasons that govern such behavior, focusing on the "how" and "why" rather than the "what" or "how many" [26]. It is particularly valuable in early childhood education settings, where children's learning experiences are shaped by rich social, emotional, and environmental contexts. Within qualitative research, the case study approach allows for an in-depth, holistic examination of a specific phenomenon within its real-life context [45].

In this study, a qualitative case study design was employed to investigate how play-integrated STEM activities influence young children's understanding of the human respiratory system. The aim was to explore not only what children learned but also how they engaged with the activity, how they collaborated with peers, and how multiple learning domains were activated during the experience. By focusing on a single group of learners in a real-world early childhood classroom, the study provided a detailed, contextualized understanding of the learning process.

The case study approach was appropriate for this research because it enabled the researcher to observe complex interactions between children, educators, and materials over time. It also supported the analysis of non-verbal behaviors, role-play scenarios, and creative outputs (e.g., drawings and model-building), which are crucial components of early childhood learning but difficult to capture through quantitative methods.

The research was interpretivist in nature, grounded in the belief that knowledge is socially constructed and best understood through the perspectives of those directly involved [10]. The flexible, open-ended nature of qualitative inquiry made it possible to capture children's spontaneous questions, imaginative narratives, and embodied expressions of learning all of which contributed to a comprehensive view of how STEM and play can be effectively integrated in early education.

4.2 Participants

In qualitative research, participants are selected not to represent a population statistically, but to provide deep, contextual insights into the phenomenon under study [33]. Purposeful sampling is commonly used to identify individuals or groups who are especially knowledgeable or experienced with the topic being explored [26]. In early childhood education research, young children are considered valuable participants because their behaviors, expressions, and interactions offer authentic perspectives on learning processes in real-time contexts.

This study involved a purposeful sample of 20 children, aged 4 to 6 years, from a local early childhood education center in a semi-urban setting. The group included 12 girls and 8 boys from diverse socio-economic backgrounds. The selection criteria were based on the children's age group, developmental readiness for structured play-based learning, and the center's willingness to collaborate in a research project focused on STEM integration.

Two experienced early childhood educators, each with over five years of teaching experience, facilitated the learning sessions. They played a dual role as both instructors and observers, maintaining structured observation logs and providing narrative reflections on children's engagement and responses throughout the activity period.

This participant group was chosen because children within this age range are developmentally situated in Piaget's preoperational stage, a period characterized by symbolic thought and rapid language development—ideal conditions for learning through guided play and hands-on exploration [34]. Their active participation in constructing, manipulating, and reflecting on a model of the respiratory system offered meaningful insights into how play-integrated STEM strategies support conceptual understanding in early learners.

4.3 Procedure

The project was designed to engage children in a comprehensive exploration of the respiratory system through interactive and fun activities, blending play and STEM concepts. Over the span of five days, each day offered a unique experience that reinforced key concepts related to the lungs and breathing in a developmentally appropriate way for early childhood learners. Below is a detailed breakdown of the procedure for each day:

Day 1: Introduction to Lungs Through Storytelling and Body Exploration
The first day of the project was focused on introducing the concept of lungs and breathing. Storytelling was used as a vehicle to capture children's attention and connect the topic to their everyday experiences. A story about a character learning how their lungs work helped to personalize the concept. Children then engaged in body exploration activities where they practiced deep breathing and felt the rise and fall of their chests, linking the physical experience to the concept of breathing.

Day 2: Group Construction of the Respiratory Model
On Day 2, the children were introduced to the process of building a simple model of the respiratory system. Using common materials such as plastic bottles, straws, balloons, and rubber bands, the children worked together in small groups to construct a functioning model that demonstrated how the lungs work. This hands-on activity emphasized teamwork, problem-solving, and understanding of the mechanics of breathing. The children learned how air enters and exits the lungs, with the balloons representing the lungs' expansion and contraction.

Day 3: Role-Play Session ("Doctor's Visit")
Day 3 focused on reinforcing the knowledge acquired so far through a role-play activity. Children participated in a "Doctor's Visit," where they used the respiratory model they built to demonstrate how a doctor might explain how the lungs work. This session allowed children to actively engage with the concept of respiration, taking on roles as doctors, patients, or nurses. The role-play encouraged the children to apply their new knowledge in a realistic context, making learning both meaningful and enjoyable.

Day 4: Drawing and Describing the Respiratory Process
On Day 4, the children had the opportunity to creatively express what they had learned. They were tasked with drawing a picture of the respiratory system and labeling the parts, including the lungs, diaphragm, and windpipe. Alongside the drawing, they were asked to verbally describe the respiratory process, reinforcing their understanding. This activity allowed children to synthesize the knowledge they had gained in a way that integrated both artistic expression and scientific learning.

Day 5: Physical Activity and Reflection on Breathing
The final day of the project involved physical activity, such as running or jumping, to encourage the children to experience firsthand the changes in their breathing during exercise. Afterward, children gathered to reflect on how their breathing had changed during physical exertion, discussing how the body responds to activity. This reflective discussion helped to connect the concept of breathing to real-life experiences, reinforcing the relevance of the respiratory system in their daily lives.
The sequence of activities was designed to ensure that the children were engaged through multiple learning modes, including storytelling, hands-on building, role-playing, creative expression, and physical activity. The combination of these elements was intended to promote a deeper understanding of the respiratory system while integrating play and STEM in early childhood education.

4.4 Data Collection

Data collection in this project was designed to capture a comprehensive picture of children's learning and engagement throughout the five-day process. A variety of methods were employed to ensure that both qualitative and quantitative aspects of the children's responses, behaviors, and interactions were documented. The following data collection methods were used:

Educator Journals
Educator journals served as an essential tool for documenting the children's responses and behaviors during the activities. The educator took detailed notes on individual and group interactions, highlighting any notable changes in understanding or behavior, as well as how children engaged with the activities. The journals also provided insight into how the children processed the information and how their understanding evolved throughout the project. According to Dewey reflective journaling by educators is an effective tool for assessing children's learning and development, allowing for a deeper analysis of their cognitive and emotional engagement.

Video and Audio Recordings
To supplement the written records, video and audio recordings were used to capture the children's verbal and non-verbal interactions during the activities. These recordings provided rich data on how children communicated their understanding of the respiratory system, both in terms of language and physical expression. Through video, the researcher could analyze children’s gestures, facial expressions, and group dynamics, while audio recordings captured the nuances of their verbal exchanges. This method aligns with Vygotsky's [41] theory, which emphasizes the role of social interaction and language in cognitive development. The use of video and audio recordings allowed for a more accurate and comprehensive analysis of the children's learning experiences.

Artifacts
Artifacts from the project, including children's drawings, breath-count logs, and model designs, were also collected as tangible evidence of their learning process. The drawings provided a visual representation of the children's understanding of the respiratory system, allowing for the analysis of how they conceptualized the components of the system. Breath-count logs, in which children recorded their breath rates before and after physical activity, offered a quantitative measure of their understanding of how physical exertion affects breathing. The model designs provided insight into how children understood the mechanical process of breathing and the role of the lungs in respiration. Artifacts such as these align with Piaget's [34] constructivist theory, which posits that children actively build knowledge through interactions with their environment and through creating physical representations of abstract concepts. These three data collection methods—educator journals, video/audio recordings, and artifacts—provided a multifaceted approach to documenting and analyzing children's learning throughout the project. This comprehensive data collection process allowed for a deeper understanding of how play-based learning and STEM activities contribute to early childhood education.

4.5 Data Analysis

Data analysis in this study was conducted using thematic analysis, following the method outlined by Braun and Clarke [5]. Thematic analysis is a widely used qualitative research technique that allows for the identification, analysis, and reporting of patterns or themes within data. It is particularly effective for analyzing rich, qualitative data and provides insights into participants' experiences, behaviors, and interactions. In this study, thematic analysis was applied to the diverse data collected from educator journals, video/audio recordings, and artifacts to identify key themes related to children's learning of the respiratory system.

Inductive Coding
The data were initially coded inductively, meaning that codes were generated from the data itself rather than based on pre-existing theoretical concepts. This approach allowed for the emergence of themes grounded in the children's experiences during the project. According to Braun and Clarke [5], inductive coding ensures that the analysis remains closely aligned with the data, enabling the researcher to capture the participants' perspectives without being influenced by preconceived notions.

Theme Development
Once initial codes were developed, these were grouped into broader themes. The themes that emerged from the data analysis process included:

Engagement
Engagement was a key theme, as it captured how involved and motivated the children were throughout the activities. This theme was particularly important because active engagement is a fundamental component of effective learning in early childhood education [13]. Instances of engagement were identified through children's enthusiasm, participation, and sustained attention during the activities.

Comprehension
Comprehension themes were drawn from the children's ability to understand and explain the concepts related to the respiratory system. This theme was evident through the children's verbal responses, their ability to describe the process of breathing, and their application of the knowledge in role-play and model construction activities.

Social Interaction
The theme of social interaction highlighted how children interacted with their peers and educators during the activities. This theme was important in understanding the collaborative nature of learning, as children worked together to build the respiratory model and participated in group discussions. Vygotsky [41] emphasized the significance of social interaction in cognitive development, particularly in shared activities that promote learning.

Cross-Domain Skill Transfer
This theme explored how the children transferred skills from one domain of learning to another. For example, children used their fine motor skills during the construction of the respiratory model, as well as their artistic skills during the drawing activity. The concept of cross-domain skill transfer aligns with Piaget's [34] idea that children's cognitive development is enhanced when they engage in activities that require them to apply knowledge and skills in various contexts. By identifying and analyzing these themes, the data analysis process provided valuable insights into how the children engaged with the concept of the respiratory system and how their learning progressed throughout the project. Thematic analysis allowed for the identification of key patterns and highlighted the impact of play-based learning and STEM activities on early childhood education.

5. Findings
5.1 Scientific Understanding

One of the key findings of this project was the children's ability to describe the basic mechanics of breathing using accurate scientific terminology. After engaging in a range of activities designed to explore the respiratory system, children were able to verbally articulate their understanding using terms such as "inhale," "lungs fill," and "air goes in." This demonstrated not only their comprehension of the fundamental process of respiration but also their ability to use appropriate vocabulary to express this knowledge. According to Piaget [34], children actively construct knowledge through direct interaction with their environment, which was evident in their ability to apply specific terms learned through hands-on activities.

In addition to using the correct terminology, children demonstrated an understanding of the physical mechanics of breathing, explaining that "lungs expand with air" and "contract when air is released." This was reinforced through the hands-on construction of the respiratory model, where children could visualize and manipulate the elements to observe the mechanics of lung expansion and contraction. This aligns with Vygotsky's [41] concept of the zone of proximal development, as children were able to grasp complex ideas through guided interaction with peers and educators.

Several children also made connections to their own bodies, further deepening their understanding of the respiratory system. For example, one child commented, "When I run, my lungs go faster!" These types of statements indicate that the children were able to relate the scientific concepts they learned to their own experiences and bodily sensations. This type of experiential learning is critical in early childhood education, as it allows children to build knowledge through personal relevance and real-world application [4].

These findings suggest that play-based activities, such as storytelling, model construction, and physical activity, can effectively support the development of scientific understanding in young children. The use of accurate terminology and the ability to make personal connections to the respiratory process highlights the potential for STEM integration in early childhood education to promote both cognitive and physical learning.

5.2 Engagement and Motivation

Engagement and motivation are key indicators of effective learning in early childhood education. Engagement refers to the level of attention, curiosity, interest, and enthusiasm that children exhibit during learning activities, while motivation involves the internal drive to initiate and sustain participation in those activities [18]. In this study, the integration of storytelling and role-play proved to be powerful strategies for enhancing both engagement and motivation among the children.

The storytelling activity on Day 1 introduced the concept of lungs in an imaginative and relatable context, sparking initial interest and providing a narrative framework for the learning that followed. Storytelling has long been recognized as an effective pedagogical tool in early childhood settings because it supports emotional connection, language development, and conceptual understanding [23].

Role-play, particularly during the “Doctor’s Visit” activity on Day 3, significantly boosted motivation and social participation. Children eagerly assumed roles as doctors and patients, took turns using the respiratory model, and explained how lungs function. This imaginative engagement fostered a sense of ownership and pride in their learning. According to Vygotsky [41], role-play allows children to operate within their zone of proximal development, facilitating the acquisition of new knowledge through social interaction and scaffolding.

Children also demonstrated emotional investment and enthusiasm in their creations, frequently admiring and discussing the models they had built. Their motivation was evident in the way they carefully handled materials and showed excitement in explaining their work to peers and educators. This pride in learning aligns with Deci and Ryan’s [13] Self-Determination Theory, which posits that intrinsic motivation is enhanced when learners feel competent, autonomous, and connected to others.

Curiosity emerged as another strong indicator of engagement. Children asked insightful questions such as, “What happens if a lung pops?” and “Why do we need two lungs?” These inquiries show that children were not only absorbing information but also actively thinking about the implications and deeper mechanisms of the respiratory system. This type of questioning reflects higher-order thinking and suggests that the play-based STEM approach successfully stimulated cognitive curiosity and investigative thinking.

In summary, the integration of storytelling and role-play effectively enhanced engagement and motivation in the children. The approach encouraged active participation, emotional investment, and the pursuit of deeper understanding, thereby supporting meaningful learning experiences in early science education.

5.3 Social Collaboration

Social collaboration in early childhood education refers to the ways in which children work together, share ideas, and support one another’s learning through interaction. Collaborative learning environments promote communication skills, empathy, cooperation, and shared problem-solving critical components of both cognitive and social-emotional development [3]. In this study, social collaboration emerged as a significant theme, particularly during group-based STEM activities such as the construction of the respiratory system model.

The group construction task on Day 2 required children to work collectively, share materials, and negotiate roles, naturally encouraging teamwork and turn-taking. These cooperative behaviors were evident as children passed around supplies, discussed how to assemble parts of the model, and waited for their turn to contribute. This process fostered a sense of community and mutual responsibility, reinforcing the value of working together toward a shared goal.

Peer learning was a central component of this collaboration. For example, one child took the initiative to explain how the model worked to a peer, using gestures and simplified language to convey the concept of lung expansion. This act of peer teaching reflects Vygotsky's [41] concept of scaffolding within the Zone of Proximal Development (ZPD), where a more competent peer supports the learning of another, enabling understanding that may not have been achieved independently. Such interactions underscore the idea that learning is inherently social and is often facilitated through meaningful exchanges between children.

Additionally, social collaboration was observed during role-play and reflection sessions. Children helped each other recall scientific terms and reenact the function of lungs using the model, further emphasizing the reciprocal nature of learning in a collaborative environment. These moments illustrate how social interaction not only supports content knowledge but also strengthens communication, leadership, and empathy skills.

In line with sociocultural learning theory, the collaborative structure of the activities provided opportunities for children to co-construct knowledge and develop deeper scientific understanding through social means. This supports the assertion that well-designed group tasks in early STEM education can simultaneously nurture both cognitive and social growth.

5.4 Cross-Disciplinary Integration

Cross-disciplinary integration in early childhood education refers to the purposeful blending of content and skills from multiple subject areas into a unified learning experience. This approach is especially effective in STEM education, as it mirrors real-world problem-solving and supports deeper, more meaningful learning across cognitive domains [2]. Integrating disciplines such as mathematics, science, art, language arts, and physical education enables children to explore concepts holistically and apply knowledge in diverse, interconnected ways.

In this project, the activities were intentionally designed to promote cross-disciplinary learning, allowing children to engage with the concept of the respiratory system through multiple lenses:

Mathematics: Children engaged in counting their breaths per minute, using timers to record the number of breaths before and after physical activity. They compared their results across different time points and among peers, practicing basic numeracy, data collection, and comparison. These tasks support the development of early mathematical reasoning and problem-solving [9].

Art: On Day 4, children were encouraged to illustrate the respiratory system through colorful, labeled diagrams. This artistic representation allowed them to express scientific understanding visually, reinforcing anatomy concepts while nurturing creativity and fine motor skills. Integrating visual arts into science learning supports dual coding and enhances retention [15].

Language Arts: Throughout the week, children participated in storytelling and narrative exercises related to doctor visits, breathing experiences, and the function of lungs. They used descriptive language, dialogue, and sequencing to convey their understanding, which fostered both language development and scientific communication. According to Nicolopoulou [31], storytelling is a key tool for making abstract ideas concrete and personal in early childhood settings.

Physical Education: On Day 5, children engaged in physical activities such as running, then measured and reflected on how their breathing changed. This kinesthetic approach helped them connect bodily sensations to scientific concepts. Physical education experiences like this also contribute to health awareness and self-regulation [20].

This cross-disciplinary integration not only made learning more engaging and accessible but also encouraged children to transfer knowledge across domains a hallmark of deep learning. It illustrates how complex concepts like the respiratory system can be effectively taught through a rich, multi-modal curriculum in early childhood education.

6. Discussion

Integrating STEM and play in early childhood education offers a powerful pedagogical approach that supports both conceptual understanding and developmental growth. STEM education, when merged with play-based strategies, allows young children to explore complex scientific ideas in developmentally appropriate, meaningful, and enjoyable ways [28]. This study demonstrated that teaching the respiratory system through storytelling, role-play, and hands-on model construction significantly enhanced children's engagement, comprehension, and ability to relate science to their lived experiences.

The use of a physical model, paired with imaginative play, aligns strongly with Piaget’s [34] theory of cognitive development, which emphasizes that young children learn best through direct manipulation of their environment. By building and using a lung model, children could simulate inhaling and exhaling, thereby concretizing abstract biological processes. These sensorimotor interactions made the concept of breathing tangible and memorable, validating Piaget's view that active exploration fosters deeper learning in early childhood.

Moreover, the interdisciplinary design of the activities merging science, mathematics, art, language arts, and physical education reflected authentic, real-world learning scenarios. This holistic integration allowed children to encounter the respiratory system through multiple entry points, enabling a broader range of learners to connect with the content in ways that resonated with their individual strengths. Here, Gardner’s [19] theory of Multiple Intelligences was particularly helpful in explaining how different children engaged with the material. Some demonstrated deep understanding through artistic representation, others through storytelling or movement, highlighting the value of offering diverse modes of expression and learning.

Importantly, the project also supported the development of health literacy a critical but often overlooked component of early childhood education. As children learned how lungs function and how breathing changes during physical activity, they began to build awareness of their own bodies and health. This type of learning fosters a sense of body ownership and can empower young children to make informed decisions about their well-being. Health literacy, especially when introduced through developmentally appropriate science content, contributes to the broader goals of holistic education, which aims to nurture the cognitive, emotional, physical, and social dimensions of the child.

In summary, this study highlights the transformative potential of combining STEM and play. By situating science within stories, movement, art, and hands-on construction, children not only grasped the function of the respiratory system but did so with enthusiasm, curiosity, and personal relevance.

7. Implications for Early Childhood Education

The findings from this study have several important implications for early childhood education, particularly in how educators, curriculum developers, and families can support young children's scientific learning through integrative and play-based methods.

Firstly, curriculum design in early childhood education should prioritize integrative approaches that blend STEM content with play, storytelling, arts, and movement. Embedding STEM learning from the ground up ensures that young children are introduced to scientific thinking in a way that is developmentally appropriate and engaging. A curriculum that allows for cross-disciplinary connections not only supports cognitive growth but also nurtures creativity, problem-solving, and critical thinking from an early age.

Secondly, teacher training is essential to the success of such integrative approaches. Educators must be equipped with the knowledge, resources, and confidence to design and implement STEM-rich activities that align with the developmental needs of young children. Training should include strategies for hands-on learning, classroom management during exploratory play, and techniques for guiding inquiry through open-ended questions. When teachers understand the pedagogical foundations of play-based STEM learning, they are better able to facilitate meaningful learning experiences.

Thirdly, parental engagement plays a vital role in reinforcing STEM learning beyond the classroom. Parents should be informed about the benefits of hands-on science activities at home and encouraged to use everyday materials to foster curiosity and inquiry. Simple activities such as observing nature, building with recyclable items, or discussing bodily functions like breathing can spark valuable conversations and learning opportunities. Strengthening the home-school connection helps create a consistent and enriched learning environment for the child.

Lastly, the study underscores the importance of alternative assessments in early childhood education. Traditional tests may not effectively capture the depth of young children’s understanding. Instead, tools such as portfolios, observational notes, video recordings, and student-created artifacts (like drawings and models) offer a more comprehensive view of learning outcomes. These forms of assessment honor the diverse ways children express knowledge and provide educators with meaningful insights into each child’s developmental progress.

In sum, this study advocates for a holistic, integrated, and collaborative approach to early science education one that supports young children in becoming confident, curious, and capable learners.

8. Limitations and Recommendations

While the findings of this study are encouraging and demonstrate the effectiveness of integrating STEM and play in early childhood education, several limitations must be acknowledged.

One key limitation is the small sample size, which was restricted to a single early childhood center. This limits the generalizability of the results to broader populations. Larger, more diverse samples would provide a more representative understanding of how different groups of children respond to similar interventions.

Another limitation is the short duration of the project. Conducted over just five days, the study provided only a snapshot of children's learning and engagement. While immediate responses were positive, it remains unclear how well the children retained their understanding over time or how deeply their conceptual knowledge developed. Future research should consider longer-term studies to explore the sustainability of learning and the potential for deeper cognitive growth.

Additionally, the study focused specifically on the respiratory system, which, while effective, represents only one aspect of human biology. To further validate the model, future research could apply similar play-based STEM approaches to other bodily systems, such as the digestive or circulatory systems. This would help determine whether the instructional framework is adaptable and effective across a broader range of scientific content.

Based on these limitations, several recommendations are proposed for future research. Longitudinal studies that track children's learning over extended periods would offer insight into retention and conceptual development. Moreover, studies involving larger and more diverse populations including children from different cultural, linguistic, and socioeconomic backgrounds would strengthen the generalizability and applicability of the findings. These efforts would contribute to a deeper understanding of how integrated, play-based STEM education can be scaled and adapted to various early learning environments.

9. Conclusion

Integrating play and STEM principles in early childhood education significantly enhances children's engagement, motivation, and understanding of complex scientific concepts, such as the respiratory system. Through hands-on activities like model construction, role-playing, storytelling, drawing, and physical exploration, young learners can grasp abstract biological processes in ways that are meaningful and developmentally appropriate. These strategies not only facilitate cognitive development but also support physical, social, and emotional growth.

The study's findings extend sociocultural theories of learning [40] by demonstrating how collaborative, play-based STEM activities serve as cultural tools that mediate children's understanding of abstract biological systems. Additionally, the integration of embodied learning through role-play and sensory experiences suggests a refinement of Piagetian principles by illustrating how concrete operations can support comprehension of internal, invisible systems like respiration. This theoretical contribution underscores the value of aligning content-specific STEM goals with developmentally appropriate pedagogies, paving the way for more nuanced models of early childhood STEM education.

The findings from this study support existing research that highlights the value of play-based STEM learning in fostering inquiry, creativity, and critical thinking among young children [6]. When children are given the opportunity to explore scientific ideas through multiple modes of expression—whether through building, movement, dialogue, or art—they are more likely to engage deeply and retain knowledge. Furthermore, the interdisciplinary nature of the activities mirrors real-life learning experiences and encourages children to make connections across subjects, promoting holistic development [28].

Importantly, this approach also nurtures a love for learning by making science enjoyable, relatable, and relevant to children's everyday lives. By blending structured content with imaginative play, educators can create enriched learning environments that prepare children not just for future academic success, but also for lifelong curiosity and problem-solving.

In conclusion, this study affirms the pedagogical value of integrating STEM and play in early childhood settings. It emphasizes that playful, hands-on learning is not merely a supplementary method, but a foundational strategy for cultivating confident, competent, and enthusiastic learners from an early age.

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