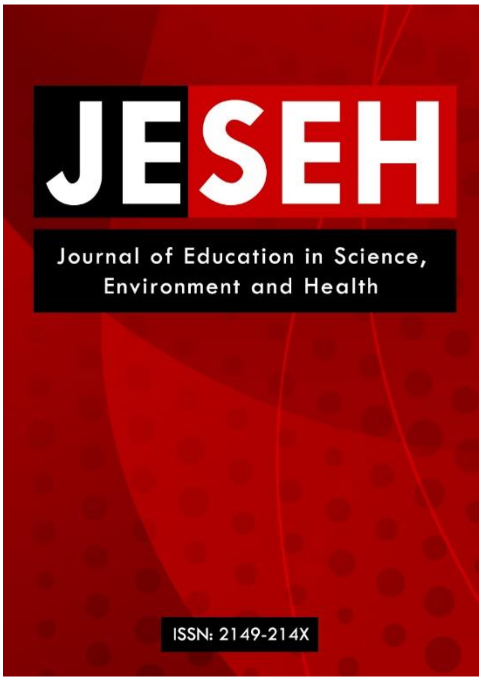

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Moleboheng Ramulumo
University of South Africa

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Abstract

Early STEM (Science, Technology, Engineering, and Mathematics) education plays a pivotal role in shaping children's science and visual literacy skills. However, in South Africa, there are notable challenges such as delayed initiation of science education and inadequate emphasis on visual literacy. This study aims to investigate the influence of early STEM education on science and visual literacy in South African educational contexts. Drawing upon the post-positivist paradigm and Mayer's cognitive theory of multimedia learning, this research employed a mixed-method approach combining quantitative and qualitative analyses, integrating autoethnography to engage with lived experiences during my master's and doctoral studies. The findings suggest that children exposed to STEM education demonstrate higher levels of science and visual literacy. These findings have implications for curriculum design and educational practice, urging stakeholders to integrate STEM principles early in children's educational journey and to prioritize visual literacy to enhance communication and comprehension of scientific concepts. Recommendations are provided for educational institutions and policymakers to facilitate the implementation of effective strategies addressing these challenges and fostering a generation of learners equipped with essential skills for success in the modern world.

Introduction

This study aims to explore the profound impact of early STEM education on nurturing science and visual literacy while advocating for effective strategies to cultivate these essential skills from the earliest stages of development. I used autoethnography as a gateway to engage with my lived experiences during my journey pursuing my master's and doctoral degrees (Méndez, 2013). Ellis and Bochner (2000) define autoethnography as a qualitative research method where the researcher uses their personal experiences to explore and understand broader cultural phenomena. Although my research approach was not strictly formulated around autoethnography, it played a pivotal role as an entry point into the study. This personal narrative provided valuable context and helped shape subsequent research questions and the overall study design.

According to Gotz et al. (2019), pursuing a master's or doctoral degree is often an intensely personal endeavor, which resonates with my own experience. As a mother of two young boys who experienced language delays in their early years, my research interests were sparked by a desire to find innovative ways to support their language development. Delving deeper into language learning, I became increasingly intrigued by the potential of digital educational games to enhance my children's linguistic abilities (Dicheva et al., 2015). Videnovik et al. (2020) describe digital educational games as interactive learning experiences that utilize technologies such as computers, tablets, smartphones, gaming consoles, and online platforms to deliver educational content in a game-like format. Similar to Ozdilek et al. (2020), my exploration of digital educational games revealed their potential to stimulate children's interest in science and mathematics education. This personal journey has directed my research towards enhancing science education through digital educational games, aiming to bridge the gap between early childhood development and STEM learning.

Early exposure to science is widely recognized as crucial for success in STEM fields (Wan et al., 2021). Research indicates that young children possess a natural curiosity about the world, making them ideal scientists (Glauert & Stylianidou, 2021). Therefore, by nurturing this curiosity and providing opportunities for exploration and discovery, early science education can foster a lifelong passion for science, lay the foundation for future STEM learning, promote critical thinking, and improve scientific literacy. Moreover, early science education enhances children's social and emotional skills, including problem-solving, collaboration, and perseverance, all essential for their overall development (Reimers, 2020). Additionally, research suggests that early childhood is crucial for shaping attitudes toward science (Hansson, 2021).

Research Problem

The delayed introduction of science education in early childhood education in South Africa has profound implications beyond immediate academic performance. While early childhood education in South Africa prioritizes various facets of children's development, such as language, mathematics, life skills, physical development, and creative expression (Department of Basic Education, 2019), science education receives comparatively less attention. Although mathematics is seamlessly integrated into the curriculum with a focus on foundational concepts (Chikiwa et al., 2017), science education often remains neglected until later stages, typically starting from the fourth grade onwards (Piasta et al., 2014). This delay has sparked concerns among educators regarding its impact on students' academic readiness and overall scientific literacy.

Delaying science education until the fourth grade hinders students' long-term academic outcomes by impeding their comprehension of complex scientific concepts and meaningful engagement with scientific inquiry (Ramulumo, 2023; Botha, 2012). Furthermore, delayed exposure to science may restrict students' exploration of potential STEM career paths, thereby affecting their future opportunities and the nation's competitiveness in these fields (Newell et al., 2015). Additionally, postponing science education can shape students' attitudes toward science, potentially fostering negative perceptions and discouraging them from pursuing STEM-related studies or careers (Lelliott, 2014; Reddy et al., 2013). This exacerbates the shortage of skilled professionals in the science and technology sectors, impeding national innovation and economic growth (Tytler et al., 2008).

In contrast, countries like Finland and Singapore prioritize early science education, resulting in higher scientific literacy and positive attitudes toward science (Lavonen and Laaksonen, 2009; Ayieko, Gokbel, and Nelson, 2017). To address the delayed introduction of science education in South Africa, understanding potential contributing factors such as curriculum constraints, resource limitations, and pedagogical approaches is essential (Troy et al., 2014). Inadequate training and professional development opportunities for early childhood educators in teaching science further complicate the situation (Van Driel et al., 2001). Moreover, resource constraints, including a lack of teaching materials and access to science facilities, hinder effective implementation (Bauer et al., 2015).

Examining these factors provides a comprehensive understanding of the barriers to early science education. Therefore, addressing these challenges is crucial for developing effective strategies to promote science education from an early age, thereby fostering academic success, career readiness, and national competitiveness in science and technology fields.

Rationale

During my Master of Science degree, I assessed the visual literacy of first-year science students in South African universities, identifying a significant deficiency in their skills (Ramulumo, 2020). According to Schönborn and Anderson (2006), this lack of proficiency impedes students' comprehension of complex scientific concepts due to insufficient emphasis on visual vocabulary in science education. Moreover, this deficiency is concerning given the pivotal role of visual literacy in digital literacy, including applications such as digital educational games (Reddy et al., 2023).

These findings underscore the importance of introducing visual literacy early in education. Research indicates that integrating visual literacy instruction into science curricula enhances students' understanding of scientific phenomena and their ability to interpret visual data (Kobe, 2020; Mnguni, 2018; Guzzetti et al., 2016; Schönborn & Anderson, 2006). Exposure to visual representations from an early age has also been shown to foster interest and engagement in science, laying a foundation for lifelong learning in STEM fields (Shabiralyani et al., 2015). While emphasizing the necessity of early science education, the study highlights the critical need for developing visual literacy skills from a young age. The challenges observed among university-level students in grasping complex scientific concepts may partly stem from the delayed introduction of science education (Ramulumo, 2020). However, even with earlier exposure to science, students would still require strong visual literacy skills to effectively visualize the abstract nature of scientific concepts (Ramulumo, 2023).

Visual literacy research in South Africa may not receive as much global attention as in countries like the United Arab Emirates, Switzerland, Germany, and Australia (Flood et al., 2015). Nonetheless, South Africa has made significant contributions to this field. In an increasingly digitalized world, the importance of visual literacy in comprehending information across diverse contexts has become apparent (Mnyanda & Mbelani, 2018; Jordaan & Jordaan, 2013). Visual literacy encompasses a range of abilities, including spatial visualization, visual-spatial reasoning, perception, and interpretation of visual information (Gadanidis & Namukasa, 2017; Hoffler & Leutner, 2007). Proficiency in visual literacy is crucial for academic success, fostering cognitive development and critical thinking skills essential for effective learning (Braden et al., 2018). Consequently, the intersection of visual literacy and science literacy has become a focal point of research, highlighting their interconnectedness and impact on students' learning outcomes (Aberšek, 2008; Trumbo, 2006). Visual representations, such as diagrams, graphs, and models, play an indispensable role in science education, facilitating the conveyance of complex scientific concepts (Schonborn & Anderson, 2006).

In this context, the study aims to explore the influence of early STEM education on science and visual literacy. It seeks to determine whether children exposed to STEM education demonstrate higher levels of these literacies compared to those who do not receive such exposure. Through this investigation, the study aims to assess whether STEM learning is the optimal approach for introducing these essential skills in early childhood. Additionally, the findings have the potential to inform educational policies and practices aimed at enhancing science education and promoting visual literacy from an early age.

Theoretical Framework

This study adopts a theoretical framework that integrates the Post-Piagetian Theory of Cognitive Development and Mayer's Cognitive Theory of Multimedia Learning to explore the mechanisms influencing children's science learning. This synthesis aims to provide a comprehensive understanding of how cognitive development and multimedia learning principles intersect to enhance educational outcomes for young learners.

The Post-Piagetian perspective challenges Piaget's assertion that young children lack the cognitive abilities for abstract thinking and scientific reasoning. Instead, it emphasizes that children as young as 4 to 6 years old exhibit domain-specific knowledge structures, particularly in subjects like science and mathematics (Case, 1999; Gelman, 1990). This framework delineates developmental milestones and transitions in children's understanding of scientific concepts, from concrete operational thinking to more abstract reasoning, guiding educators in tailoring curricula to match cognitive abilities and conceptual frameworks.

Mayer's theory underscores how multimedia, particularly visual representations, can enhance learning by leveraging cognitive processes such as dual-channel processing and limited working memory capacity (Mayer, 2005). Visuals, when integrated effectively with minimal text, facilitate information retention and cognitive processing, tapping into children's cognitive architecture to optimize learning outcomes. This approach aligns with children's developmental stages and cognitive load constraints, ensuring that educational materials are designed to support effective comprehension and retention of scientific content (Gilbert, 2005).

Research by Chang et al. (2007) implemented Mayer's Cognitive Theory by utilizing animations and diagrams to teach chemistry concepts to middle school students. These visual representations were designed to enhance cognitive processing by presenting complex chemistry concepts in a simplified and interactive format. By aligning with the Post-Piagetian framework, which acknowledges children's evolving cognitive abilities in understanding abstract scientific concepts, this study demonstrated improved comprehension and retention among students compared to traditional text-based instruction.

The Post-Piagetian Theory's emphasis on domain-specific knowledge structures complements Mayer's Cognitive Theory, which advocates for the integration of visually rich materials to enhance cognitive processing. This synergy allows educators to not only acknowledge children's evolving cognitive abilities in science but also strategically design multimedia learning experiences that cater to these developmental stages.

Therefore, by integrating Post-Piagetian insights into children's progression from concrete to abstract thinking with Mayer's strategies for optimizing multimedia learning, educators can foster a comprehensive approach to cognitive development in science. This integration supports the design of instructional materials that scaffold scientific reasoning while respecting children's cognitive load constraints. Scaffolding techniques, such as guided exploration and interactive simulations, support children in constructing and refining their understanding of scientific concepts while managing cognitive load effectively (Wood et al., 1976).

While this framework is promising, it may have limitations in diverse educational settings and among different populations. Future research should explore innovative approaches, such as augmented reality and adaptive learning technologies, to further enhance the application of this theoretical framework. Additionally, investigating the long-term effects of these integrated strategies on children's scientific literacy would be valuable.

In essence, the integration of the Post-Piagetian Theory of Cognitive Development with Mayer's Cognitive Theory of Multimedia Learning provides a robust foundation for advancing children's science education. This theoretical synthesis not only informs instructional practices but also underscores the need for ongoing research to optimize learning environments that foster cognitive and educational development in science and beyond. Therefore, by leveraging developmental insights and multimedia learning principles, educators can create impactful learning experiences that promote deeper engagement and understanding of scientific concepts among young learners.

Method

General Background

The study is rooted in the post-positivist paradigm, which emphasizes epistemological pluralism (Blackwell, 2019). This paradigm reconciles the constraints of positivist and constructivist methodologies by valuing empirical evidence and emphasizing the need for methodical and rigorous research methods (Guba & Lincoln, 1989). Therefore, by embracing a post-positivist perspective, the study integrates quantitative and qualitative methods to thoroughly examine this influence. In this regard, this approach seeks to produce robust evidence on the role of early STEM education in shaping science and visual literacy in young children (Blackwell, 2019; Guba & Lincoln, 1989).

Research Design

The study employed an embedded mixed-method research design to integrate both quantitative and qualitative data, offering a comprehensive understanding of the research questions. Drawing from Creswell's methodology (2014), known for its adaptability, this design ensures flexibility across various research contexts. Quantitative data were prioritized for their structured insights into the impact of early STEM education on science and visual literacy, enabling statistical examination to reveal patterns and trends. Complementarily, qualitative data provide depth and contextualization to the quantitative findings through interviews and analytical processes, resulting in a comprehensive mixed-method structure. Therefore, by integrating autoethnographic insights, the study gained a unique perspective that informed the development of interview questions and guided the interpretation of qualitative data. This methodological blend enhances the breadth of evidence, credibility, guards against biases, enriches conclusions, and maintains a balanced approach, facilitating a more robust exploration of the research questions than a purely quantitative or qualitative approach would allow.

Data Collection

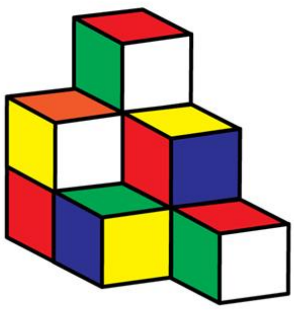
In the quantitative phase of the study, 121 preschool Grade R children from STEM schools and 87 from non-STEM schools in Bloemfontein, South Africa, were purposively selected. These children, aged 5 to 6 years, were chosen in accordance with guidelines established by the Department of Basic Education. These guidelines specify that Grade R learners must be at least five years old and turning six or older by 30 June of the current year (The Department of Basic Education, 2015). Purposive selection was employed to ensure the sample encompassed children from both STEM and non-STEM schools in Bloemfontein, South Africa. This approach aimed to capture a broad range of educational backgrounds and approaches, thereby enhancing the generalizability of the study's findings while minimizing selection biases.

STEM schools were chosen for their dedicated focus on STEM education, particularly science literacy. These schools implement structured STEM curricula aimed at fostering early scientific understanding and skills among preschoolers. In contrast, non-STEM schools were selected based on their adherence to the South African National Curriculum Framework for children aged birth to four years, as sanctioned by the South African Department of Education. This framework guides educational programs for young children but often places less emphasis on science compared to STEM-focused schools (Campbell & Chittleborough, 2014). Including children from both STEM and non-STEM schools aims to capture diverse educational experiences and understand how different approaches impact cognitive development and early childhood science learning. This approach broadens the study's scope, enhancing the applicability of findings while minimizing biases in participant selection.

The quantitative assessment tool was meticulously designed with distinct sections, each comprising closed-ended questions aimed at providing a comprehensive evaluation of children's science learning and cognitive abilities. The tool included two main sections: Firstly, the Content Knowledge Test aimed to assess proficiencies in life sciences, physical sciences, and earth sciences. For instance, within the life sciences section, children were tasked with identifying living and non-living things, employing circling or selection methods (see Figure 1). This approach was chosen to align with children's developmental stages, ensuring the assessment's accessibility and age-appropriateness.

Figure 1. Life science: Knowledge of living and non-living things

Secondly, the Psychometric Test targeted patterns, spatial visualization, visuospatial working memory, and visual perception. An example question from this section involved asking children to count blocks in a visual representation (see Figure 2), which was crucial for evaluating cognitive processing abilities fundamental to scientific learning.



A. 6
B. 7
C. 9
D. I don't know

Figure 2. Spatial visualization: Mental manipulation of two-dimensional and three-dimensional objects

The validation of the assessment tool involved collaboration with a panel of 10 experts, following Hyrkäs et al. (2003), achieving a content validity index score of 82%, exceeding the accepted threshold of 0.79. Reliability was assessed using pilot data, which yielded a Cronbach alpha coefficient of 0.72, indicating satisfactory consistency (Reddy et al., 2022; Taber, 2018). These rigorous validation procedures ensured the tool's reliability and validity in measuring targeted cognitive and science-related competencies among preschool-aged children.

In the subsequent qualitative phase of the study, six preschool participants—three from STEM schools and three from non-STEM schools—were purposively selected from those who had taken part in the earlier quantitative phase. This selection aimed to encompass diverse perspectives and delve deeper into the inquiries raised by the quantitative data. Semi-structured interviews were conducted as the primary method to explore the children's understanding and experiences based on the quantitative findings. Each participant engaged in these interviews using flashcards, a method noted for its unique application in data collection (Cammisa et al., 2011). Each flashcard displayed visual representations corresponding to closed-ended items from the quantitative survey. This approach was chosen to maintain a playful and interactive atmosphere, crucial for engaging young children. The flashcards were shuffled randomly to prevent bias in responses.

Ethical considerations were rigorously upheld throughout the study, with clearance obtained under reference number 2022/02/09/51915987/28/AM. These measures ensured compliance with ethical standards, including obtaining informed consent from parents or guardians, securing assent from the children themselves, and implementing safeguards to protect participants' privacy and well-being.

Data analysis

For the data analysis, SPSS software was utilized to conduct quantitative analysis, enabling the calculation of descriptive and inferential statistics. This approach facilitated the comparison of mean scores related to science literacy and visual literacy between preschool children attending STEM and non-STEM schools. Qualitative data gathered from interviews underwent analysis using a deductive coding approach structured around predetermined themes assessing levels of science and visual literacy. This methodological framework provided deep insights into the proficiency of preschool children across science and visual literacy domains.

Results

The quantitative results reveal that both STEM and non-STEM school children demonstrated a high level of science literacy; however, STEM school children exhibited significantly better performance, achieving an average score of 90.8 (SD = 7.52), compared to non-STEM school children who achieved an average score of 84 (SD = 9.79) (see Table 1). Within the STEM group, the highest performance was observed in the item assessing their ability to determine mass (M = 93, SD = 7.74), while their lowest performance was in the item evaluating their ability to differentiate between living and non-living things (M = 89, SD = 7.74). Conversely, non-STEM school children excelled in the item assessing their ability to determine the weather (M = 87, SD = 10.67), but their lowest performance was evident in the item evaluating their ability to differentiate between living and non-living things (M = 81, SD = 10.01).

Table 1. Summary of the content knowledge test scores on science literacy

Item assessed	Group	N	M	SD	SEM
Living and non-living things	non-STEM schools' children	121	81	10.01	0.91
	STEM schools' children	87	89	7.74	0.83
Weather	non-STEM schools' children	121	87	10.67	0.97
	STEM schools' children	87	91	8.86	0.95
Mass	non-STEM schools' children	121	85	10.01	0.91
	STEM schools' children	87	93	7.74	0.83
Temperature	non-STEM schools' children	121	83	8.48	0.68
	STEM schools' children	87	90	5.69	0.61
Average science Literacy	non-STEM schools' children	121	84	9.79	0.87
	STEM schools' children	87	90.8	7.52	0.81

In the life sciences items, the results indicate that STEM preschoolers outperformed their non-STEM peers by 4%, as evidenced by a significant t-test result ($t(105) = 2.946$, $p < .001$) (see Table 4). Regarding Earth Sciences, STEM preschoolers demonstrated an 8% higher performance compared to non-STEM peers (see Table 2), supported by a significant t-test result ($t(105) = 6.495$, $p < 0.001$) (see Table 4). Overall in science, STEM preschoolers exhibited a mean performance advantage of 7% over non-STEM peers (see Table 2), with a significant t-test result (t(105) = 3.917, p < .001) (see Table 2) specifically in their ability to distinguish items or objects with different temperatures.

Table 2. A comparison of level of science literacy

Items assessed	T	Df	P	MD	Std. Error Difference	99% Confidence Interval of the Difference	
						Lower	Upper
Living and non-living things	6.496	105	*p*<.001	8	6.4959	4.66	11.34
Weather	2.946	105	*p*<.001	4	1.3576	0.36	7.64
Mass	6.495	105	*p*<.001	8	1.2315	4.66	11.34
Temperature	3.917	105	*p*<.001	7	1.7873	1.67	12.33

In essence, the findings reveal intricate patterns in the science literacy performance of children enrolled in both STEM and non-STEM schools. While both groups demonstrated commendable levels of science literacy, a deeper investigation uncovers significant disparities highlighting the influence of school type on proficiency. These performance differences provide compelling insights into the profound impact of a STEM-focused curriculum on the development of science literacy skills among preschoolers. Notably, a curriculum centered on STEM appears to create a conducive environment for fostering higher levels of scientific understanding, thereby preparing children effectively for their academic journey.

Furthermore, children attending STEM schools exhibited superior performance compared to their peers in non-STEM schools across all assessed items, as indicated by their average visual literacy score of 60.5 (SD = 39.83) (see Table 3). They achieved their highest scores in tasks involving pattern completion (M = 81, SD = 28.81). However, it is noteworthy that children in STEM schools showed relatively lower performance in tasks assessing visual-spatial working memory skills (M = 49, SD = 41.88). Conversely, children enrolled in non-STEM schools attained an average visual literacy score of M = 50.8 (SD = 48.02). Similar to their STEM counterparts, the lowest performance among non-STEM school children was observed in tasks measuring visual-spatial working memory, yielding a score of M = 31 (SD = 52.58). Their strongest performance was evident in tasks requiring pattern completion (M = 70, SD = 35.31), highlighting their proficiency in this specific area.

Table 3. Summary of psychometric test scores on visual literacy

Skills assessed	Group	*N*	*M*	*SD*	*SEM*
Patterns	non-STEM schools' children	121	70	35.31	3.21
	STEM schools' children	87	81	28.91	3.10
Spatial visualization	non-STEM schools' children	121	31	52.58	4.78
	STEM schools' children	87	39	43.93	4.71
Visual-spatial working memory	non-STEM schools' children	121	35	50.93	4.63
	STEM schools' children	87	49	41.88	4.49
Visual perception	non-STEM schools' children	121	67	53.24	4.84
	STEM schools' children	87	73	44.58	4.78
Average visual literacy	non-STEM schools' children	121	50.8	48.02	3.21
	STEM schools' children	87	60.5	39.83	4.27

The results indicate that children exposed to science education are anticipated to exhibit higher levels of visual and science literacy. Supporting this hypothesis, Table 4 reveals that 81% of STEM schools' children correctly identified the missing shape, compared to 70% from non-STEM schools (t(105)=2.465, p<0.001). Additionally, both groups of children displayed deficiencies in spatial imagination, with non-STEM school children lagging by 8% (t(105) = 1.192, p < .001). Furthermore, STEM school children demonstrated better performance in visual-spatial working memory, with a mean difference of 6% (t(105)=2.171, p<0.001). Both groups exhibited improved performance in visual perception, with a mean difference of 6% (t(105)=0.882, p<0.001).

The findings indicate that the STEM school environment enhances visual literacy skills, particularly in tasks involving pattern completion and visual perception. Moreover, performance differences were evident among children attending different school types, especially concerning visual literacy aspects. Both STEM and non-STEM children faced challenges in spatial visualization and visual-spatial working memory. Despite these challenges, STEM school children showed notable proficiency in tasks related to pattern completion and visual-spatial working memory. Similarly, their peers in non-STEM schools demonstrated competence in tasks focusing on patterns and visual perception.

Table 4. A comparison of level of visual literacy

Items assessed	t	Df	P	MD	Std. Error Difference	99% Confidence Interval of the Difference	Items assessed
						Lower	Upper
Patterns	2.465	105	p<.001	11	4.4622	Patterns	2.465
Spatial visualisation	1.192	105	*p*<.001	8	6.7105	-9.96	25.96
Visual-spatial working memory	2.171	105	*p*<.001	14	6.4496	-.3.31	31.31
Visual perception	.882	105	*p*<.001	6	6.802	-12.2	24.2

These results suggest a positive impact of science education on visual literacy, underscored by significant performance disparities between STEM and non-STEM school children. These outcomes highlight the potential benefits of integrating science literacy with visual literacy in early childhood education to enhance overall learning outcomes. Furthermore, the performance differences underscore the importance of tailoring teaching methods to individual skills, addressing unique attributes that may influence performance regardless of school type.

In the qualitative exploration, the analysis of children's responses revealed a diverse range of viewpoints. However, the presentation of findings will primarily focus on those that notably highlight significant differences between the two participant cohorts. This approach aims to improve clarity in understanding variations in the utilization of visual and scientific understanding between STEM and non-STEM children. While statistically significant disparities were observed, it's crucial to acknowledge that individual responses from children in both groups highlighted their unique strengths and encountered challenges when interacting with and interpreting visual and scientific information. Regarding the spatial visualization item, children were asked: "Can you tell me how many blocks are in Figure 3? Why do you think that is the correct number of blocks?"

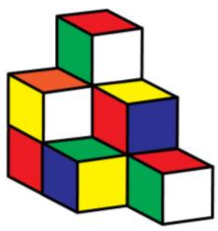


Figure 3. Spatial visualization: Mental manipulation of two-dimensional and three-dimensional objects

STEM Child 1 responded, "9, because other blocks are hiding behind the blocks I see in the picture."
Non-STEM Child 1 answered, "6, because I counted them."

The comparison of responses from children in both STEM and non-STEM schools reveals that both groups were able to count the blocks in Figure 3, demonstrating a fundamental cognitive skill reflective of the initial phase of cognitive functioning internalization. This suggests that both sets of children have reached this cognitive developmental stage.

However, STEM participants exhibited superior levels of spatial visualization ability compared to non-STEM participants. They demonstrated proficiency in mentally manipulating and rotating the image using principles of visual occlusion, indicative of the advanced externalization phase—the highest level of cognitive functioning. This advanced cognitive function requires refined spatial reasoning skills and indicates a deeper comprehension of spatial relationships.

These findings underscore the positive influence of exposure to STEM education and training on spatial visualization skills. They also emphasize the importance of nurturing these skills from an early age, as they are crucial for success across various STEM disciplines. Educators can contribute to the development of these skills by providing opportunities for children to engage in activities that promote spatial thinking and visualization.

Such efforts will establish a foundation for children to excel in their future academic and professional endeavours.

To evaluate the visual-spatial working memory of the children, they were instructed to closely observe Figure 4. Subsequently, they were asked to fold the paper along the broken line and copy the elements from the left side of the paper onto the folded right section, relying on their memory of the visual details. This task assesses their ability to retain and recall spatial information.

Figure 4. Visual-spatial working memory: Ability to recall their perceived observations

Figure 5 depicts drawings by children from both STEM and non-STEM schools based on their memories. The drawing on the left was created by a child from a non-STEM school, while the one on the right was made by a child from a STEM school.

In Figure 5 it is apparent that the child from the non-STEM school depicted a total of 13 apples on the tree, whereas the child from the STEM school drew only three apples on the same tree.

non-STEM school child	STEM school child

Figure 5. Pictures drawn by the children from memory

Following the drawing task, the children were asked to estimate the number of apples in their recreated image and explain their reasoning for their count. A comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 2: “3, because that is how many I remember seeing on the tree.”
non-STEM child 2: “13, because there were many apples on the tree.”

The findings indicate that both STEM and non-STEM children possess the ability to recall all elements of the image depicted in Figure 5, including the sun, the butterfly, and the presence of apples on the tree. This observation suggests they exhibit a cognitive competence known as ground perception, involving an internalized visualization process (Mnguni et al., 2016), representing the foundational level of cognitive function. However, the results also highlight that exclusive accuracy in recalling the specific count of apples depicted in the image was demonstrated solely by the STEM school child. This observation suggests that cognitive processes rooted in memory retrieval, requiring a heightened cognitive stage characterized by conceptualization and externalization (Mnguni et al., 2016), are more pronounced in this context.

An intriguing insight emerges from the drawings of the non-STEM child, suggesting they retained a memory of more apples than were actually depicted in the image. This proposition could indicate that the presence of multiple objects within the image introduced a potential distraction. This finding aligns with the principles established by the Cognitive Theory of Multimedia Learning, emphasizing that excessive use of visuals can lead to overstimulation, potentially hindering the learning process (Mayer, 2011).

In response, the study underscores the pivotal importance of incorporating Mayer's Redundancy Principle into the design of educational materials for children. This principal advocates for the omission of extraneous images, even if contextually relevant, with the goal of mitigating cognitive overload and optimizing the pedagogical experience.

For the item assessing the children's ability to differentiate between living and non-living entities, they were asked two questions. First, they identified items in Figure 6 they perceived as living and non-living. Then, they elaborated on the attributes or traits influencing their determination of whether an entity is classified as living or non-living. These questions aimed to understand the reasoning behind their classifications and assess their comprehension of living and non-living characteristics.

Figure 6. Life science: knowledge of living and non-living things

The comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 3: “It is the dog, the boy, and the chicken because the dog, boy, and chicken can breathe and need water to grow.”
non-STEM child 3: “It is the boy because the dog and chicken cannot talk.”

The findings suggest that children from STEM schools exhibited a heightened aptitude for discriminating between living and non-living entities. Their ability to discern traits such as growth and the importance of water underscores the effective integration of the seven fundamental characteristics of life within STEM curricula. This proficiency reflects a comprehensive understanding of the defining attributes of life, highlighting the enduring impact of STEM education. In contrast, the response from the non-STEM child, which associates vitality with communication, underscores the need for a more comprehensive educational approach regarding living organisms. For the item assessing the children's comprehension of mass, they participated in an interview where they were prompted to explain which of the two entities, the elephant or the insect (depicted in Figure 7), they considered to be heavier. Additionally, they provided reasoning for their choice, specifying why they perceived either the elephant or the insect to possess greater mass.

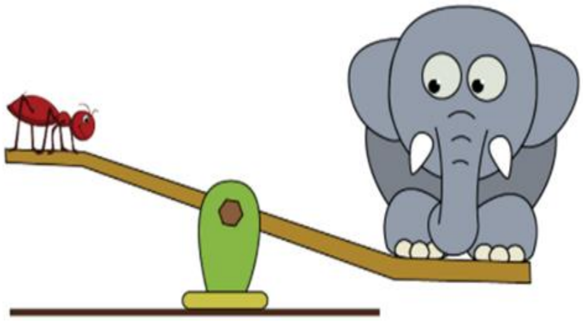


Figure 7. Physical science: Comprehension of mass

The comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 2: “The elephant, because the elephant has more kilograms.”
non-STEM child 1: “The elephant, because the elephant is big.”

The findings highlight that STEM school children demonstrate a more robust understanding of mass concepts compared to their non-STEM counterparts. This distinction is evident as non-STEM participants associated weight with size, whereas the STEM school child exhibited a deeper awareness that mass is quantified in kilograms, indicating their advanced understanding rooted in subject-specific knowledge. These results underscore the importance of subject-specific education, particularly in STEM disciplines, in fostering a comprehensive grasp of fundamental concepts like mass. The enhanced understanding among STEM school children suggests the effectiveness of STEM curricula in laying a strong foundation in scientific principles. Conversely, the observation of non-STEM participants associating weight with size underscores the need to address misconceptions and provide holistic education across all disciplines. This highlights the significance of educational strategies that promote critical thinking and subject-specific knowledge to ensure a well-rounded understanding of scientific concepts.

Fundamentally, the qualitative findings enriched the understanding of how contextual factors influence students' outcomes in science and visual literacy. Therefore, by exploring students' reasoning processes, educational backgrounds, and learning experiences, the qualitative analysis provided valuable insights that complemented the quantitative results. This comprehensive approach helped uncover the complex relationship between STEM education and students' proficiency in science and visual literacy skills.

Discussion

The findings of this study echo the National Science Foundation's call for increased STEM education during early childhood, aligning with the growing demand for STEM-related careers (Dickman et al., 2009). Tsai et al.'s (2016) research complements these assertions by illustrating how STEM education not only enhances visual literacy skills but also fosters critical thinking and problem-solving abilities essential for science literacy. This perfectly aligns with the study's objective of investigating the relationship between STEM education and the development of science and visual literacy in early childhood. Therefore, by emphasizing visual and science literacy through STEM education, children can be better prepared for success in various STEM disciplines.

For science literacy, the study's findings corroborate the research conducted by McClure et al. (2017), which highlights the significant role of early STEM exposure in shaping children's comprehension of intricate scientific concepts, such as differentiating between living and non-living entities. This alignment underscores the importance of early engagement in STEM education to foster a solid foundation in science literacy among young learners. Moreover, as previously stated, Gelman (1990) provides further support by indicating that children between the ages of 5 to 6 have competence in learning science, contrary to Jean Piaget's proposition that they lack the abstract thinking abilities required for science literacy. Additionally, Spektor-Levy et al. (2013) further support these findings, highlighting the potential of early STEM education in nurturing children's scientific understanding and challenging conventional assumptions about their cognitive capabilities in this domain.

The study's findings on the significant correlation between early STEM exposure and improved visual literacy in preschoolers align with Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2005). According to

Mayer's theory, learning is enhanced when information is presented through both visual and auditory channels. Early STEM exposure, which includes visual representations and interactive technologies like digital educational games, supports this theory and can effectively enhance visual literacy among children. This perspective is supported by the World Economic Forum's Future of Jobs Report (World Economic Forum, 2018), which emphasizes the importance of nurturing visual skills from childhood. Therefore, by aligning educational resources with children's cognitive capacities, educators can optimize learning outcomes and promote visual literacy from an early age. This approach equips children with the necessary skills and competencies for future careers in visual-centric fields.

Conclusion

Akin to the study by Tsai et al. (2016) emphasizing the pivotal significance of early STEM education in cultivating visual and science literacy skills among preschoolers, our study reinforces the imperative for the seamless integration of STEM education into early curricula. This integration not only equips children with vital proficiencies in STEM domains but also fosters versatile competencies spanning diverse fields. We advocate for educators to prioritize the cultivation of visual literacy through early STEM education, empowering young intellects to embrace a future abounding in prospects. The implications of our study resonate across the domains of early childhood education, STEM-based pedagogy, such as digital educational games, and the augmentation of science and visual literacy.

Recommendations

We recommend that educational institutions and policymakers duly acknowledge the importance of instilling STEM principles from the commencement of a child's educational journey. Such integration must be accompanied by a discernible emphasis on visual literacy, recognizing its role in fostering efficacious communication and comprehension of intricate concepts. Therefore, by enacting these recommendations, educators can lay a sturdy foundation for the comprehensive growth of children, furnishing them with the proficiencies and outlooks requisite for thriving in an increasingly STEM-oriented world. While offering valuable insights, our study has limitations. Data collection from young children may introduce response biases, and the quantitative assessment tools might overlook certain aspects of literacy. Additionally, the subjectivity of qualitative analysis and the study's cross-sectional nature limit causal inference. Longitudinal research would provide more comprehensive insights. Nonetheless, the mixed-method approach offers a holistic understanding of science and visual literacy development in early childhood.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the author.

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Author(s) Information

Moleboheng Ramulumo
University of South Africa
Preller St, Muckleneu, Pretoria, 0002, South Africa
Contact e-mail: *Ramulmm@unisa.ac.za*
ORCID iD: https://orcid.org/0000-0002-5134-954X