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Exploration of Algorithms and Heuristics in Puzzle Playing Activities of Early Childhood

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ABSTRACT

This study explores the use of algorithms and heuristics by early childhood children in the context of puzzle-solving. The research employs a qualitative approach with a case study method, involving 10 children aged 4-6 years at RA Nurud Dhalam, Pamekasan Regency. The findings identify several commonly used algorithmic strategies, such as edge-first, color or image-based grouping, and systematic trial and error. Frequently utilized heuristics include shape-based searching, using images as guides, and eliminating unsuitable options. Factors such as age, previous experience, and puzzle difficulty level influence strategy selection. Analysis of the findings indicates that the use of algorithms and heuristics reflects complex cognitive development, involving executive functions, metacognition, and visuospatial abilities. This research concludes that the use of algorithms and heuristics reflects complex cognitive development in young children, involving executive functions, metacognition, and visuospatial abilities. These findings have significant implications for early childhood learning and stimulation, including the development of more differentiated learning approaches, adaptive curriculum design, dynamic assessment methods, utilization of educational technology, and more comprehensive teacher training. Additionally, they open new perspectives in understanding children's cognitive processes and provide a foundation for developing more effective early childhood education theory and practice.

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1. INTRODUCTION

Cognitive development in early childhood is an essential aspect in shaping intelligence and critical thinking abilities that play a crucial role in determining an individual's future developmental trajectory (Pollarolo et al., 2023). This process not only influences a child's intellectual capacity but also forms the foundation for academic and social success. The early childhood period, generally defined as the age range of 0-8 years, is a critical time during which the brain develops rapidly and exhibits high plasticity (Ismail et al., 2017). During this phase, children develop thinking, reasoning, memory, and problem-solving skills that will become the basis for future learning and achievement. Piaget, in his theory of cognitive development, asserts that children in the preoperational stage (2-7 years) begin to develop mental and symbolic representation abilities, which are necessary for abstract and logical thinking (Davidson, 1992).

Recent neuroscientific research has deepened our understanding of the necessity for cognitive stimulation in early childhood for optimal brain structure formation. Studies conducted by Fitzgerald, (2016), Ilyka et al., (2021), and Miguel et al., (2019) reveal that children's experiences and interactions during early life stages have a substantial impact on the formation and strengthening of neural networks in the brain. These findings indicate that adequate and diverse stimulation can shape more complex and adaptive brain structures, thereby supporting optimal cognitive capacity development. Conversely, a lack of stimulation or frequent exposure to negative experiences can impede brain development, potentially resulting in long-term effects on children's learning abilities and behavior (Luby, 2022; Sheridan & McLaughlin, 2016; Duncan et al., 2015). The implications of these findings emphasize the necessity for early intervention and the creation of environments rich in positive stimuli to support optimal brain development in children, which can influence their cognitive and behavioral developmental trajectories throughout their lives.

In the context of cognitive stimulation, puzzle games have long been recognized as an effective tool to support early childhood development. Puzzles not only offer entertainment but also provide a rich platform for learning and developing cognitive skills. According to research conducted by Hawes et al., (2015), children who regularly play with spatial puzzles show improvements in mental rotation abilities and spatial comprehension. These skills are crucial for later development in mathematics and science. Playing puzzles involves various complex cognitive processes, including visual perception, logical reasoning, working memory, and problem-solving (Mulyana & Nurcahyani, 2022). When children attempt to match puzzle pieces, they engage in careful observation, analyzing shapes and patterns, and hypothesizing about where each piece should be placed. This process not only enhances children's fine motor skills but also sharpens their critical and strategic thinking abilities.

Puzzles offer immediate and concrete feedback to children. When pieces don't fit, they must reevaluate and try new strategies. This trial and error process is invaluable in developing perseverance, resilience, and the ability to learn from mistakes (Pusey, 2018). A study conducted by Cui et al., (2021) shows that engagement in puzzle activities at an early age positively correlates with mathematical achievement in elementary school. These findings affirm that skills developed through playing puzzles have significant transfer to other academic domains, especially in aspects of children's cognitive development.

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Although the impact of puzzles on children's cognitive development has been extensively researched, a relatively less explored aspect is the mechanisms by which children develop and apply algorithms and heuristics in the puzzle solving process. In this context, algorithms can be conceptualized as a series of systematic steps implemented to solve a puzzle, while heuristics refer to more adaptive and intuitive problem-solving strategies utilized when precise algorithms are unavailable or less efficient.

In the context of children playing with puzzles, the use of algorithms and heuristics is not consciously recognized or explicitly articulated, but remains an integral part of the problem-solving process. For instance, when a child develops a simple algorithm to complete the edge pieces first before filling in the middle section, this is a systematic approach that can be considered a basic algorithm. On the other hand, the child employs heuristics such as quickly matching colors or patterns to identify fitting pieces, without having to try every possible combination.

The potential relationship between puzzle-playing activities and the development of algorithmic and heuristic abilities in early childhood represents an intriguing yet not fully explored field of research. Several studies have indicated that children possess the capacity to develop and implement complex problem-solving strategies from an early age (Busch & Legare, 2019). For example, research conducted by Armitage et al., (2023) on children's strategies in solving simple arithmetic problems revealed that children spontaneously develop and refine their strategies over time. These findings suggest an innate potential for algorithmic and heuristic thinking in children. However, on the other hand, the problem that arises is that there is not enough evidence to reveal the extent to which the development of algorithms and heuristics honed through puzzle play can be transferred to other problem-solving domains, such as mathematics and logic.

Although these findings provide promising indications, there remains a gap in our understanding of the specific processes involved in the development and application of algorithms and heuristics by children while playing puzzles. How do children develop these strategies? Are there patterns or stages in the development of their algorithmic and heuristic abilities? How do factors such as age, previous experience with puzzles, or the difficulty level of the puzzle influence the strategies used? These questions have not been comprehensively answered in the existing literature. If we can understand how these abilities develop at an early age through activities such as playing puzzles, we may be able to design more effective educational interventions to support children's cognitive development. This could have long-term implications for school readiness, academic achievement, and even future career success.

This research could provide valuable insights into children's cognitive development in general. By studying how children develop and apply algorithms and heuristics in a relatively controlled context such as playing puzzles, we can gain a deeper understanding of how children learn to solve problems and think systematically across various domains. The novelty of this research lies in its specific focus on the process of development and application of algorithms and heuristics by children in the context of puzzle play. While many previous studies have explored the general benefits of puzzles for cognitive development, or have studied the use of algorithms and heuristics in adults or in more formal contexts, there has not been a comprehensive study combining these aspects in the context of early childhood

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development. This research could pave the way for new avenues in the study of cognitive skill transfer.

2. METHODS

This research employs a qualitative approach with a case study method to explore algorithms and heuristics in puzzle-playing activities among young children. The study aims to understand how children aged 4-6 years develop and apply problem-solving strategies while playing puzzles. Research subjects will be selected purposively, involving 10 children aged 4-6 years attending RA Nurud Dhalam in Nyalabu Daya Village, Pamekasan Regency. The selection of subjects considers variations in age, gender, and level of puzzle-playing experience to capture differences and patterns that emerge in the use of algorithmic and heuristic strategies. Data collection will be conducted through participatory observation and in-depth interviews. Observations will be carried out while children play puzzles, focusing on how they identify, organize, and implement solution steps (algorithms) and how they use intuition or spontaneous strategies (heuristics) when facing difficulties. Each observation session will be recorded and documented using field notes and video to capture both verbal and non-verbal interactions. Additionally, interviews with children and teachers will be conducted to understand the thought processes underlying their actions during play. The collected data will be analyzed thematically using content analysis, with the aim of identifying patterns in the use of algorithms and heuristics in children's puzzle-solving processes.

3. RESULTS AND DISCUSSION

3.1. Identification of Algorithms Used by Children

Edge-First Strategy (Completing the Edges First)

One of the algorithms commonly applied by children in puzzle-playing activities is the edge-first strategy. In this approach, children begin the process by identifying and assembling the edge pieces of the puzzle. This strategy emerges as a response to the distinctive characteristics of edge pieces, which typically have one straight side, making it easier for children to recognize and place them. This phenomenon demonstrates that children are capable of applying logical strategies to simplify complex tasks, by completing the easier elements first before moving on to the more challenging central parts of the puzzle. This behavioral pattern reflects the use of a basic algorithm that leverages the most prominent visual elements in the problem-solving process.

The strategy used by the children aligns with the findings of Aisyah, (2021) who observed that children often begin by forming the outer frame of the puzzle as an initial step in the completion process. This approach reflects the child's ability to organize visual and spatial information, which is an essential aspect of cognitive development (Johnson, 2019). The strategy also demonstrates the child's ability to recognize patterns and construct structured steps. After the edge pieces are assembled, they tend to feel more comfortable proceeding to the inner parts of the puzzle because the boundaries are already clearly defined.

Grouping Based on Color or Image

Another algorithm frequently observed is grouping based on similar colors or images. Children appear to group puzzle pieces with similar colors or patterns before attempting to match them. This is demonstrated when children encounter a part of the puzzle depicting a blue sky; they will gather all pieces with blue coloration and attempt to assemble them. This strategy reflects the use of a grouping algorithm, where children automatically divide a large task into smaller, more manageable parts based on visual similarities.

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The application of this algorithm indicates that children are beginning to develop visual analysis skills and task categorization based on specific attributes. This finding aligns with recent research on children's mental representations, as reported by (Peykarjou et al., 2023; Schlegelmilch & Wertz, 2020; Hammer, 2015). These studies demonstrate that children have the capacity to categorize objects based on prominent visual attributes. This grouping process also reflects the development of classification skills, which are fundamental components in the development of children's logical thinking. Thus, the use of the edge-first strategy in puzzle solving not only demonstrates problem-solving ability but also indicates broader cognitive development in terms of visual analysis and categorization.

Systematic Trial and Error

Children also implement a more systematic trial and error algorithm in solving puzzles. In this approach, they methodically attempt to place puzzle pieces in various positions until finding a match. Although this method may appear random, children often modify their strategy by considering previous attempts and avoiding repetition of pieces already tried. This strategy indicates the presence of basic algorithmic thinking, where children repeatedly test hypotheses through structured steps. This systematic trial and error process contributes to the development of children's observation and analysis skills, as they must remember the results of previous attempts to adjust their next steps. While not always efficient, this approach represents a form of logical problem-solving. Mohr et al., (2018), in their theory of children's problem-solving strategies, assert that systematic trial and error is a fundamental stage in cognitive development. Through this process, children learn to organize and evaluate information more effectively, which in turn supports the development of their algorithmic and heuristic thinking abilities.

3.2. Heuristics Used by Children

Search By Shape

One of the heuristics frequently implemented by children in puzzle solving is shape-based search. In this approach, children attempt to match puzzle pieces by searching for suitable components based on the physical characteristics of these pieces. They identify pieces with contours or angles that are compatible with empty spaces in the puzzle. This heuristic heavily relies on children's visual ability and spatial perception in recognizing geometric compatibility. Shape-based search is an intuitive strategy, as children tend to more easily recognize and match prominent shapes with available spaces. This method is also more efficient compared to a pure trial and error approach, as it allows for immediate elimination of pieces that clearly do not fit.

The shape-based heuristic approach applied by children in puzzle solving demonstrates coherence with Gestalt theory of visual perception. This theory emphasizes the presence of form in the process of perceptual organization (Kobourov et al., 2015). Children's capacity to identify and match shapes reflects the development of visuospatial skills, which are fundamental components in spatial cognition (Murias et al., 2019). The implementation of this shape-based heuristic has implications beyond merely facilitating puzzle completion. This phenomenon indicates comprehensive cognitive development, particularly in the domains of visual perception and spatial understanding. The use of this strategy not only demonstrates practical problem-solving ability but also highlights more complex and integrated cognitive development in the early childhood.

Use of Images as Guidance

In the process of puzzle solving, children often utilize images as a heuristic guide. They use visual cues from the already assembled parts of the puzzle to identify and match unplaced pieces. When children observe a formed part of an animal or building image, they search for

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puzzle pieces that potentially complete this visual representation. The use of images as guidance is a manifestation of a visually context-based heuristic. In this approach, children apply available information to predict and determine the next steps in the puzzle-solving process.

The heuristic in this context plays a role in developing children's understanding of the relationships between image components, while simultaneously enhancing their ability to integrate visual information. This approach also demonstrates children's ability to utilize mental representations and compare puzzle pieces with the overall picture. This closely relates to the concept of scaffolding introduced by Vygotsky. In his cognitive development theory, scaffolding describes temporary support given to children to complete tasks they cannot yet perform independently (Yuill & Carr, 2018). In this context, the complete image of the puzzle functions as an external aid, providing a visual framework that facilitates children's problem-solving. Thus, the use of image-based heuristics not only facilitates children in completing puzzles but also reflects more complex cognitive development, involving mental representation abilities, visual integration, and contextual problem-solving.

Elimination of Unsuitable Options

Another finding validated from field research results shows that children use elimination heuristics to simplify the process of selecting puzzle pieces. Children tend to automatically disregard pieces that clearly do not fit with empty spaces, based on differences in either shape or color. This elimination strategy plays a role in accelerating problem-solving by reducing the number of alternatives that need to be considered, thus focusing the child's attention on more relevant options. The use of this elimination heuristic not only reflects children's ability to make quick decisions based on available visual information but also demonstrates cognitive efficiency. This efficiency allows children to avoid time-consuming trial-and-error processes, making the problem-solving process more effective.

3.3. Factors Influencing the Use of Algorithms and Heuristics in Early Childhood

One of the main determinants in the use of algorithms and heuristics by children is age and cognitive developmental stage. Various research results mention that age is often closely related to the maturity of systematic and logical thinking abilities (Murnikov & Kask, 2021; Hoicka et al., 2016). Children in the age range of 3 to 4 years tend to rely more on heuristics, or simple intuitive rules, because the ability to think logically is still in its early stages. At this age, limitations in working memory capacity and abstract thinking ability restrict children in formulating structured and efficient strategies.

Conversely, children aged 5 to 6 years show an increase in the use of algorithms, especially when faced with more challenging tasks such as puzzles. This can be associated with the concrete operational stage according to Jean Piaget's theory, where children begin to develop an understanding of basic logic and cause-effect principles, although still heavily dependent on concrete objects and physical experiences (Madanagopal, 2020). In other words, at this age, children begin to be able to think of systematic solutions to solve problems, although their skills in this regard are still developing. This is evidenced through a study by Li et al., (2017) which found that older preschool children tend to show increased use of rule-based strategies compared to younger children, particularly in the context of tasks that demand planning and problem-solving, such as playing puzzles.

Repeated experience in playing puzzles contributes to the efficiency and effectiveness of children's strategy use. Children with more puzzle experience generally demonstrate a better understanding of structures and patterns typically found in puzzles, allowing them to use algorithms in a more structured manner. For example, they start by assembling the puzzle edges first or grouping pieces based on color or specific patterns. This aligns with the theory

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of transfer of learning, where previous experiences provide a foundation for children to develop more sophisticated and efficient solutions (Huber et al., 2016). Research conducted by Hsu & Wang, (2018) also supports this, where they found that children with more experience in puzzle games are more likely to adopt more complex and algorithm-based solving strategies compared to less experienced children. The trial-error strategy often used by less experienced children tends to be more time-consuming and less efficient, especially when facing more complex puzzles.

Another determining factor in children's choice between algorithms and heuristics is the difficulty level of the puzzle they face. Puzzles with large pieces and easily recognizable images tend to encourage the use of heuristic strategies, where children can complete the puzzle more quickly without having to plan complicated steps. These heuristics utilize intuitive reasoning and simple visual patterns, making it easier for children to find solutions spontaneously. This strategy is more effective for less complex tasks, where little planning is sufficient to achieve results. Conversely, when children are faced with more complex puzzles, both in terms of the number of pieces and image complexity, they tend to use more structured algorithmic strategies.

3.4. Analysis of Algorithms and Heuristics in the Context of Cognitive Development

The use of algorithms and heuristics in playing puzzles provides insight into how children develop logical thinking and problem-solving skills. This phenomenon can be analyzed through previous research findings by Barash et al., (2019), which elaborate on the evolution of children's reasoning through various phases. The edge-first strategy reflects the advancement of conservation capabilities and reversibility of thought, as well as characteristics typical of the concrete operational stage. This strategy demonstrates children's ability to construct systematic thinking patterns and understand cause-effect relationships. More broadly, this heuristic analysis affirms how children gradually develop more efficient and structured approaches when facing problems, as their thinking abilities mature.

The implementation of heuristics such as shape-based search and the use of images as references can be interpreted through the information processing theory framework by Atkinson & Shiffrin, which states that children have mechanisms for encoding, storing, and retrieving visual information (Malmberg et al., 2019). However, this perspective appears too mechanistic and fails to comprehensively capture the complexity of children's cognitive processes. As an alternative Verspoor, (2016) dynamic systems theory offers a more holistic viewpoint by emphasizing how problem-solving strategies are formed from complex interactions between various components of the child's cognitive system and their environment.

The application of systematic trial and error methods by children in solving puzzles can be viewed as a manifestation of executive function development, particularly in aspects of planning and response inhibition (Silva et al., 2022). On the other hand, this approach can also be interpreted through the perspective of metacognition theory by Rhodes, (2019), This theory focuses on children's ability to monitor and evaluate their own cognitive strategies. In the context of puzzle-solving, the use of systematic trial and error indicates a certain level of metacognitive awareness, where children are able to reflect on the effectiveness of their approach and make necessary adjustments. This view raises critical questions about the development of metacognitive awareness in children and how it can be facilitated in the context of game-based learning.

The variations in the use of algorithms and heuristics observed among children challenge assumptions about universal and linear cognitive development. These findings align more

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closely with Vygotsky's sociocultural perspective, which emphasizes the role of social and cultural contexts in shaping cognitive development. This leads to critical theories about how socio-economic, cultural, and environmental factors can influence the development of problem-solving strategies in children. This perspective also raises questions about how educational practices can be designed to address disparities in experience and exposure to problem-solving activities such as puzzles.

Through these various elaborations, these findings lead to the formation of a new critical theory about "distributed cognition in early childhood learning". This theory integrates elements from dynamic systems theory, sociocultural perspectives, and the concept of distributed cognition by Rottschaefer, (2017) to explain how children's problem-solving strategies emerge from complex interactions between internal cognitive processes, manipulation of physical objects (such as puzzle pieces), and social scaffolding from peers and adults. This theory challenges the traditional dichotomy between "in-head" cognition and the external environment, focusing on how cognitive tools like puzzles function as extensions of the child's cognitive system. The implications of this theory extend to the design of learning environments, curriculum development, and reconceptualization of what is meant by "intelligence" in the context of early childhood development.

3.5. Implications of Findings for Early Childhood Learning and Stimulation

The implications of the findings for early childhood learning and stimulation yield positive insights and potentially paradigm-shifting perspectives in early childhood education. Firstly, the understanding of algorithms and heuristics used by children in puzzle-solving provides a foundation for developing more differentiated and responsive learning approaches. This aligns with Vygotsky's Zone of Proximal Development (ZPD) theory, which focuses on providing appropriate support to facilitate children's cognitive development. However, these findings also challenge traditional interpretations of ZPD by focusing on how children can construct their own developmental zones through interactions with physical objects and their social environment. This leads to a new conceptualization of a more flexible and child-centered "dynamic development zone".

Secondly, the implications of these findings for curriculum design and learning environments are substantial. Traditional approaches focused on linear knowledge transmission are replaced by more complex and non-linear learning models. The theory of complexity in education by Ramírez-Montoya et al., (2022) offers a useful framework for understanding how learning environments can be designed to facilitate the emergence of adaptive problem-solving strategies. This leads to the development of an "emergent learning design theory" that integrates principles of complexity theory with insights from studies on children's algorithms and heuristics. This theory asserts the need to create rich "spaces of possibility" in learning environments, where children can explore, experiment, and develop their own strategies.

Thirdly, these findings have implications for assessing cognitive development in early childhood. Traditional outcome-based assessment approaches are increasingly questioned for their relevance in the context of new understandings about the complexity of children's cognitive processes. Instead, there is a growing need for more dynamic and process-oriented assessment methods. The dynamic assessment theory by Bamford et al., (2022) offers a promising framework, but needs to be expanded to include analysis of algorithms and heuristics used by children in problem-solving. This leads to the development of a "cognitive algorithm assessment theory," which focuses on identifying and analyzing problem-solving strategies used by children, rather than just the end results of these processes.

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Fourthly, the implications of these findings for the role of technology in early childhood learning are substantial. Understanding the algorithms and heuristics used by children can inform the development of more sophisticated adaptive learning technologies. However, this also raises critical questions about the potential impact of technology on children's cognitive development. The instrumentation theory by Alqahtani & Powell, (2018) offers a useful perspective for understanding how technological tools can become an integral part of children's cognitive processes. This leads to the development of a "cognitive-technology co-evolution theory" that explores how interactions between children and learning technologies can reciprocally shape children's cognitive development.

Finally, the implications of these findings for teacher training and professional development are substantial. New understandings about the complexity of children's cognitive processes demand new approaches in preparing early childhood educators. The pedagogical content knowledge theory by Willermark, (2018) needs to be expanded to include a deeper understanding of children's cognitive algorithms and heuristics. This leads to the development of a "pedagogical algorithm competence theory" that focuses on teachers' ability to identify, understand, and facilitate the development of children's problem-solving strategies.

4. CONCLUSION

Based on the research results presented, it can be concluded that young children demonstrate the ability to develop and apply algorithms and heuristics when playing puzzles. Common strategies used include the edge-first approach, grouping based on color or image, and systematic trial and error. Frequently utilized heuristics include shape-based search, using images as guidance, and elimination of unsuitable options. Factors such as age, previous experience with puzzles, and puzzle difficulty level influence children's strategy selection. Analysis shows that the use of these algorithms and heuristics reflects complex cognitive development, involving executive functions, metacognition, and visuospatial abilities. These findings have implications for early childhood learning and stimulation, including the development of more differentiated learning approaches, adaptive curriculum design, more dynamic assessment methods, utilization of learning technologies, and more comprehensive teacher training. This research opens new perspectives in understanding children's cognitive processes and offers a foundation for developing more effective and responsive early childhood education theory and practice.

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6. AUTHORS' NOTE

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7. REFERENCES

Aisyah, A. (2021). Pengaruh permainan puzzle terhadap kemampuan daya ingat anak

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kelompok B. *Incrementapedia: Jurnal Pendidikan Anak Usia Dini*, *3*(1), 22–25. https://doi.org/10.36456/incrementapedia.vol3.no01.a3848

Alqahtani, M. M., & Powell, A. B. (2018). Teachers' instrumentation of a collaborative dynamic geometry environment. *Horizontes*, *36*(1), 172–183. https://doi.org/10.24933/horizontes.v36i1.649

Armitage, K. L., Suddendorf, T., Bulley, A., Bastos, A. P. M., Taylor, A. H., & Redshaw, J. (2023). Creativity and flexibility in young children's use of external cognitive strategies. *Developmental Psychology*, *59*(6), 995–1005. https://doi.org/10.1037/dev0001562

Bamford, C. K., Masso, S., Baker, E., & Ballard, K. J. (2022). Dynamic assessment for children with communication disorders: A systematic scoping review and framework. *American Journal of Speech-Language Pathology*, *31*(4), 1878–1893. https://doi.org/10.1044/2022_AJSLP-21-00349

Barash, J., Brocas, I., Carrillo, J. D., & Kodaverdian, N. (2019). Heuristic to Bayesian: The evolution of reasoning from childhood to adulthood. *Journal of Economic Behavior & Organization*, *159*, 305–322. https://doi.org/10.1016/j.jebo.2018.05.008

Busch, J. T. A., & Legare, C. H. (2019). Using data to solve problems: Children reason flexibly in response to different kinds of evidence. *Journal of Experimental Child Psychology*, *183*, 172–188. https://doi.org/10.1016/j.jecp.2019.01.007

Cui, Y., Zhang, D., & Leung, F. K. S. (2021). The influence of parental educational involvement in early childhood on 4th grade students' mathematics achievement. *Early Education and Development*, *32*(1), 113–133. https://doi.org/10.1080/10409289.2019.1677131

Davidson, P. M. (1992). Genevan contributions to characterizing the age 4 transition. *Human Development*, *35*(3), 165–171. https://doi.org/10.1159/000277148

Duncan, N. W., Hayes, D. J., Wiebking, C., Tiret, B., Pietruska, K., Chen, D. Q., Rainville, P., Marjańska, M., Ayad, O., Doyon, J., Hodaie, M., & Northoff, G. (2015). Negative childhood experiences alter a prefrontal-insular-motor cortical network in healthy adults: A preliminary multimodal rsfMRI-fMRI-MRS-dMRI study. *Human Brain Mapping*, *36*(11), 4622–4637. https://doi.org/10.1002/hbm.22941

Fitzgerald, B. (2016). The importance of early brain development. *Journal of the Georgia Public Health Association*, *6*(2). https://doi.org/10.21633/jgpha.6.210

Hammer, R. (2015). Impact of feature saliency on visual category learning. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00451

Hawes, Z., Moss, J., Caswell, B., & Poliszczuk, D. (2015). Effects of mental rotation training on children's spatial and mathematics performance: A randomized controlled study. *Trends in Neuroscience and Education*, *4*(3), 60–68. https://doi.org/10.1016/j.tine.2015.05.001

Hoicka, E., Mowat, R., Kirkwood, J., Kerr, T., Carberry, M., & Bijvoet-van Den Berg, S. (2016). One ‐ year ‐ olds think creatively, just like their parents. *Child Development*, *87*(4), 1099–1105. https://doi.org/10.1111/cdev.12531

Hsu, C.-C., & Wang, T.-I. (2018). Applying game mechanics and student-generated questions to an online puzzle-based game learning system to promote algorithmic thinking skills. *Computers & Education*, *121*, 73–88. https://doi.org/10.1016/j.compedu.2018.02.002

Huber, B., Tarasuik, J., Antoniou, M. N., Garrett, C., Bowe, S. J., & Kaufman, J. (2016). Young children's transfer of learning from a touchscreen device. *Computers in Human Behavior*, *56*, 56–64. https://doi.org/10.1016/j.chb.2015.11.010

Ilyka, D., Johnson, M. H., & Lloyd-Fox, S. (2021). Infant social interactions and brain development: A systematic review. *Neuroscience & Biobehavioral Reviews*, *130*, 448–469. https://doi.org/10.1016/j.neubiorev.2021.09.001

Ismail, F. Y., Fatemi, A., & Johnston, M. V. (2017). Cerebral plasticity: Windows of opportunity in the developing brain. *European Journal of Paediatric Neurology*, *21*(1), 23–48. https://doi.org/10.1016/j.ejpn.2016.07.007

Johnson, S. P. (2019). Development of Visual-Spatial Attention. In T. Hodgson (Ed.), *Processes of Visuospatial Attention and Working Memory,* (Vol. 41, pp. 37–58). Springer International Publishing. https://doi.org/10.1007/7854_2019_96

Kobourov, S. G., Mchedlidze, T., & Vonessen, L. (2015). Gestalt principles in graph drawing. In E. Di Giacomo & A. Lubiw (Eds.), *Graph Drawing and Network Visualization* (Vol. 9411, pp. 558–560). Springer International Publishing. https://doi.org/10.1007/978-3-319-27261-0_50

Li, W., Cao, B., Hu, L., & Li, F. (2017). Developmental trajectory of rule detection in four- to six-year-old children. *International Journal of Behavioral Development*, *41*(2), 238–244. https://doi.org/10.1177/0165025415620056

Luby, J. L. (2022). Editorial: Environmental conditions for growing healthy children. *Journal of Child Psychology and Psychiatry*, *63*(9), 961–962. https://doi.org/10.1111/jcpp.13674

Madanagopal, D. (2020). Piaget's theory and stages of cognitive development- An overview. *Scholars Journal of Applied Medical Sciences*, *8*(9), 2152–2157. https://doi.org/10.36347/sjams.2020.v08i09.034

Malmberg, K. J., Raaijmakers, J. G. W., & Shiffrin, R. M. (2019). 50 years of research sparked by Atkinson and Shiffrin (1968). *Memory & Cognition*, *47*(4), 561–574. https://doi.org/10.3758/s13421-019-00896-7

Miguel, P. M., Pereira, L. O., Silveira, P. P., & Meaney, M. J. (2019). Early environmental influences on the development of children's brain structure and function. *Developmental Medicine & Child Neurology*, *61*(10), 1127–1133. https://doi.org/10.1111/dmcn.14182

Mohr, H., Zwosta, K., Markovic, D., Bitzer, S., Wolfensteller, U., & Ruge, H. (2018). Deterministic response strategies in a trial-and-error learning task. *PLOS Computational Biology*, *14*(11), e1006621. https://doi.org/10.1371/journal.pcbi.1006621

Mulyana, A., & Nurcahyani, N. (2022). The effect of the puzzle playing method on improving the cognitive development of children aged 4-6 years. *KnE Life Sciences*. https://doi.org/10.18502/kls.v7i2.10354

Murias, K., Slone, E., Tariq, S., & Iaria, G. (2019). Development of spatial orientation skills: An fMRI study. *Brain Imaging and Behavior*, *13*(6), 1590–1601. https://doi.org/10.1007/s11682-018-0028-5

Murnikov, V., & Kask, K. (2021). Recall accuracy in children: Age vs. conceptual thinking. *Frontiers in Psychology*, *12*, 686904. https://doi.org/10.3389/fpsyg.2021.686904

DOI: http://dx.doi.org/10.17509/ cd.v15i2.74701
p- ISSN 2087-1317 e- ISSN 2621-8321

Peykarjou, S., Hoehl, S., & Pauen, S. (2023). The development of visual categorization based on high-level cues. *Child Development*, cdev.14015. https://doi.org/10.1111/cdev.14015

Pollarolo, E., Størksen, I., Skarstein, T. H., & Kucirkova, N. (2023). Children's critical thinking skills: Perceptions of Norwegian early childhood educators. *European Early Childhood Education Research Journal*, *31*(2), 259–271. https://doi.org/10.1080/1350293x.2022.2081349

Pusey, M. (2018). The effect of puzzle video games on high school students' problem-solving skills and academic resilience. *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, 63–69. https://doi.org/10.1145/3270316.3270597

Ramírez-Montoya, M. S., Castillo-Martínez, I. M., Sanabria-Z, J., & Miranda, J. (2022). Complex thinking in the framework of education 4.0 and open innovation—a systematic literature review. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(1), 4. https://doi.org/10.3390/joitmc8010004

Rhodes, M. G. (2019). Metacognition. *Teaching of Psychology*, *46*(2), 168–175. https://doi.org/10.1177/0098628319834381

Rottschaefer, W. A. (2017). How Otto did not extend his mind, but might have: Dynamic systems theory and social-cultural group selection. *Cognitive Systems Research*, *45*, 124–144. https://doi.org/10.1016/j.cogsys.2017.06.001

Schlegelmilch, K., & Wertz, A. E. (2020). *Grass and gravel: Investigating visual properties preschool children and adults use when distinguishing naturalistic images*. https://doi.org/10.31234/osf.io/tgmd3

Sheridan, M. A., & McLaughlin, K. A. (2016). Neurobiological models of the impact of adversity on education. *Current Opinion in Behavioral Sciences*, *10*, 108–113. https://doi.org/10.1016/j.cobeha.2016.05.013

Silva, C., Sousa-Gomes, V., Fávero, M., Oliveira-Lopes, S., Merendeiro, C. S., Oliveira, J., & Moreira, D. (2022). Assessment of preschool-age executive functions: A systematic review. *Clinical Psychology & Psychotherapy*, *29*(4), 1374–1391. https://doi.org/10.1002/cpp.2718

Verspoor, M. H. (2016). The dynamics of a usage-based approach. In J. Daems, E. Zenner, K. Heylen, D. Speelman, & H. Cuyckens (Eds.), *Change of Paradigms—New Paradoxes* (pp. 29–44). DE GRUYTER. https://doi.org/10.1515/9783110435597-003

Willermark, S. (2018). Technological pedagogical and content knowledge: A review of empirical studies published from 2011 to 2016. *Journal of Educational Computing Research*, *56*(3), 315–343. https://doi.org/10.1177/0735633117713114

Yuill, N., & Carr, A. (2018). Scaffolding: Integrating social and cognitive perspectives on children's learning at home. *British Journal of Educational Psychology*, *88*(2), 171–173. https://doi.org/10.1111/bjep.12227

DOI: http://dx.doi.org/10.17509/ cd.v15i2.74701
p- ISSN 2087-1317 e- ISSN 2621-8321