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**Development of Cognitive Abilities:
Design and Implementation of a Digital Tool for Measurement**

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Abstract

This dissertation explores the intersection of cognitive development and digital environments, specifically focusing on how digital tools and robotic agents can facilitate the understanding of Piagetian conservation tasks among children. Building on foundational theories from Piaget and modern cognitive science, the research develops and tests a novel digital platform designed for cognitive assessment. The platform's effectiveness was validated through experiments comparing traditional physical settings with digital and robotic-mediated environments.

In the first study, the platform's capabilities were tested, demonstrating its flexibility and suitability for cognitive development research. The second study examined children's performance on liquid conservation tasks comparing physical and digital environments, resulting in significant findings in cognitive engagement, with implications for digital learning strategies. In the third study, a robotic experimenter was introduced in order to observe potential impacts on task understanding, hypothesizing reduced experimenter bias and greater participant engagement.

Findings indicate that digital environments, particularly those involving robotic agents, offer unique advantages in enhancing cognitive assessment and understanding among children, thus providing new insights for educational practices, cognitive and developmental psychology. These results underscore the potential of technology-enhanced environments in shaping future approaches to cognitive development research.

Keywords:

cognitive development, Piaget conservation tasks, digital environment, socially assistive robotics, virtual learning platform, open research data, machine learning, human–robot interaction

Περίληψη

Η παρούσα διατριβή εξετάζει τον ρόλο των ψηφιακών περιβαλλόντων στη γνωστική ανάπτυξη, εστιάζοντας ειδικότερα στον τρόπο με τον οποίο τα ψηφιακά εργαλεία και τα εκπαιδευτικά ρομπότ μπορούν να διευκολύνουν την κατανόηση των Πιαζετικών δοκιμασιών διατήρησης στα παιδιά. Βασισμένη αφενός στη θεμελιώδη θεωρία του Πιαζέ, και αφετέρου σε σύγχρονες θεωρίες γνωστικής επιστήμης, η έρευνα αναπτύσσει και δοκιμάζει μια καινοτόμο ψηφιακή πλατφόρμα σχεδιασμένη για γνωστικές αξιολογήσεις. Η αποτελεσματικότητα της πλατφόρμας επικυρώθηκε μέσω πειραμάτων που συνέκριναν παραδοσιακά φυσικά περιβάλλοντα με ψηφιακά και ρομποτικά-υποβοηθούμενα περιβάλλοντα.

Στην πρώτη μελέτη, δοκιμάστηκαν οι δυνατότητες της πλατφόρμας, επιδεικνύοντας την ευελιξία της και την καταλληλότητά της για έρευνες γνωστικής ανάπτυξης. Η δεύτερη μελέτη εξέτασε την απόδοση των παιδιών σε δοκιμασίες διατήρησης υγρού σε φυσικά και ψηφιακά περιβάλλοντα, αποκαλύπτοντας σημαντικά ευρήματα στη γνωστική έρευνα, με συνέπειες για τις στρατηγικές ψηφιακής μάθησης. Στην τρίτη μελέτη, παρουσιάστηκε ένας ρομποτικός πειραματιστής για να παρατηρηθούν οι πιθανές επιδράσεις στη κατανόηση της δοκιμασίας, με την υπόθεση ότι θα μειώσει τη μεροληψία του πειραματιστή και θα αυξηθεί η αλληλεπίδραση των συμμετεχόντων.

Τα ευρήματα δείχνουν ότι τα ψηφιακά περιβάλλοντα, ειδικά αυτά που περιλαμβάνουν ρομποτικούς παράγοντες, προσφέρουν μοναδικά πλεονεκτήματα στην ενίσχυση της γνωστικής αξιολόγησης και κατανόησης των παιδιών, προσφέροντας νέες προοπτικές για τις εκπαιδευτικές πρακτικές, τη γνωστική και την αναπτυξιακή ψυχολογία. Τα αποτελέσματα αυτά υπογραμμίζουν το δυναμικό των ψηφιακών τεχνολογιών στη διαμόρφωση μελλοντικών προσεγγίσεων στην έρευνα γνωστικής ανάπτυξης.

Λέξεις Κλειδιά

γνωστική ανάπτυξη, έργα διατήρησης Πιαζέ, ψηφιακό περιβάλλον, κοινωνική υποστηρικτική ρομποτική, εικονική πλατφόρμα μάθησης, ανοιχτά ερευνητικά δεδομένα, μηχανική μάθηση, αλληλεπίδραση ανθρώπου-ρομπότ

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Introduction

In the rapidly evolving landscape of modern education, the interplay between learning, cognition, and technology has become a subject of great interest and significance. Cognitive development and generally the fields of cognitive and developmental psychology are studied and analyzed in depth by many researchers throughout the years (Siegler & Alibali, 2019). One of the most important theories of cognitive development is that of Piaget. It has had a profound impact on our understanding of how children's minds grow and evolve over time. His work on the study of cognitive processes of children and his findings have become a cornerstone of developmental psychology.

Piaget's theory posits that cognitive development occurs through a series of distinct stages, each with its own unique characteristics and milestones (Piaget, 1951,1954; Sanghvi, 2020). The two primary processes that drive this development are assimilation, where new information is incorporated into existing cognitive structures, and accommodation, where existing cognitive structures are modified to fit new information.

Piaget's conservation theory is a fundamental concept in developmental psychology, and it is also central to Piaget's stages of cognitive development. This theory suggests that children reach the ability to grasp conservation at the concrete operational stage (Elkind, 1967; Piaget, 1951,1954). Key experiments involving the conservation of number, length, mass, and liquid volume are used to demonstrate this theory, revealing how younger children often struggle with understanding that the transformation of an object's shape or arrangement does not necessarily mean a change in its quantitative properties. This foundational theory has influenced significantly the understanding of children's cognitive development. Experiments were conducted where, for instance, liquid would be poured from a short, wide glass into a tall, thin glass, and children would be asked if the amount of liquid changed. Younger children typically responded that the quantity had changed, demonstrating a lack of conservation understanding. This concept is crucial in the study of cognitive development, indicating a shift from preoperational to concrete operational stages in a child's thinking, where they begin to understand the world more logically.

Several researchers have investigated the applicability of Piaget's theory of cognitive development. Among his many achievements, Piaget found that children between the ages of 5 and 8 understand the logical idea of conservation. Conservation tasks have received the most extensive investigation of any Piagetian assignment. A given set of achievements coincide with a specific age following Piaget's stages of cognitive development. According to Piaget, children do not develop

meaningful operational skills until they are 7 years old (Babakr et al., 2019). As a result, children start to think rationally and conclusively around the age of 7. Children use tangible representations to address problems throughout this time. They continuously come into contact with new experiences, objects, and words owing to their rapid advances in motor ability and linguistic development. When they are faced with something new, they can either assimilate it into an existing schema by matching it with what they already know or expand their knowledge structure to fit the new scenario, covering the major developmental theories. Many of the children's preexisting schemas will be tested, enlarged, and rearranged during this stage. Conservation presents the most difficulty during the concrete operating phase (Nambeye, 2020).

Whereas some studies often replicated Piaget's original experiments, others expanded on them, and they added additional features and parameters (e.g., Gelman 1969; Kwong See et al., 2012; Light et al., 1979; McGarrigle & Donaldson, 1974). Other studies have explored factors influencing conservation understanding, including age, cultural background, and education (e.g., Goldschmid et al., 1973; Kim, 1987; Nambeye, 2020). Also, contemporary studies have started using conservation experiments with the embodied cognition approach that considers perception, action, and cognition as tightly linked (Lozada & Carro, 2016).

It is important to note that Piaget's theory has faced some criticism over the years, with some researchers arguing that the stages he proposed are too rigidly defined and that cognitive development is a more fluid process (Lourenço & Machado, 1996). Contemporary but also older researchers have indicated that children possess many abilities at an earlier age than was identified by Piaget. Young children may be more capable of thought than originally thought (Gruen, 1965). Most of the critics focus on the methodology of the "clinical method of Piaget." This procedure can cover the real cognitive capacities of young children, putting them into an uncomfortable and even stressful condition facing the experimenter, who is usually an "expert" adult with concrete expectations of them. Children try to recognize the communicative intention of the experimenter from the global condition, that is, the verbal and the nonverbal information, as it is described in cognitive linguistics by relevance theory (Chapelle, 2019). Furthermore, according to critics concerned especially with Piaget's conservation tasks, asking a child a similar question more than once is a blatant indication that the initial response was incorrect. As a result, researchers discovered that some 6-year-olds provided the right response whenever they replicated Piaget's tasks and only posed the question after the transition was performed (Light et al., 1979). Other academics criticized

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Piaget's assignment on quantity conservation, arguing that alterations made by adults led children to perceive that the modification was just as significant. Therefore, researchers developed an experiment on conservation of number that was comparable to Piaget's (McGarrigle & Donaldson, 1974). The researchers confused the counts whenever they stretched out the column of counters using the "Naughty Teddy Bear," making the shift appear unintentional. Over 62% of children responded affirmatively when asked if the candies in the first and second rows were comparable, higher than the response rate of less than 15% from Piaget's research.

Despite the criticism that it faced, Piaget's work has a lasting impact on the field of developmental psychology. His insights continue to influence our understanding of how children's minds grow and evolve. Other experiments conducted by academics such as Elkind highlighted the validity and importance of Piaget's research on American children between the ages of 5 and 6 (Elkind, 1967; Watanabe, 2022). These findings supported Piaget's theories on conservation tasks, showing that the capacity for conservation dramatically rises with age. Thus, various research has been conducted on conservation and the age that children become aware of it.

None of the aforementioned studies and existing research compares the execution of Piaget's conservation tasks in a physical environment with the execution in a digital environment. Thus, the rationale for comparing digital and physical environments in the context of conservation tasks lies in understanding how different environments influence a child's cognitive development and learning processes. This comparison can reveal insights into how children perceive, interact with, and learn from digital versus physical stimuli, thereby informing educational strategies and developmental theories in the contemporary, technology-oriented world. This is especially important since recent studies have highlighted the profound impact that technological advancements have had on the ways in which individuals acquire knowledge and develop cognitive abilities (Carroll, 1998; Dror, 2008). Furthermore, the advent of digital technology has transformed the way individuals perceive and interact with the world (Kostaki et al., 2019), a change that is also profoundly evident in the field of child development. With the increasing ubiquity of digital devices in children's lives, it becomes imperative to understand how interactions with virtual environments influence cognitive development (Sung et al., 2016; Zhang & Nouri, 2018).

Virtualization has become more common in recent generations as open participation in the digital revolution has risen (Huamaní, 2014). Virtual applications for developmental study with children, on the other hand, have gotten very little consideration and the methods used to execute

such cognitive developmental studies are still lacking the inclusion of technology, such as the use of virtual and automated platforms or even the inclusion of automated robots.

One key way in which technology has transformed the educational landscape is through the emergence of electronic books (e-books). Digital technology is an essential component of contemporary culture and society, and the use of academic electronic books has been shown to have a positive impact on undergraduate students' achievement in higher education (Alsalhi et al., 2020).

According to (Alsalhi et al., 2020), e-learning platforms have become widespread, providing learners with the flexibility to acquire knowledge and understanding through a variety of teaching sources at their convenience.

Another key aspect is the role of mobile technology in fostering higher-order thinking skills. Research suggests that the academic use of mobile technology can directly influence students' higher-order thinking skills, in addition to their learning effort and active engagement in courses (Kim et al., 2020). Digital technology in modern life has led to the emergence of a generation of students who have grown up in a digitally rich environment, potentially developing new ways of learning through the pervasive presence of these technologies. Further studies have highlighted the potential of mobile technology in improving students' higher-order thinking skills, which include cognitive skills related to the use of digital technology for information management, communication, and social functioning. The creation of a technology-enriched classroom environment has been shown to have a positive effect on the acquisition of these higher-order thinking skills, as teachers have reported significant differences between the traditional classroom and the technology-enriched setting (Ahmad et al., 2020; Hopson et al., 2001; Kim et al., 2020).

Furthermore, the proliferation of access to and use of information communication technologies has had positive impact on education delivery strategies, as schools and universities have extended their delivery modes to include fully online and other forms of blended modalities to support the traditional face-to-face approach (Alsalhi et al., 2020; Barclay et al., 2018). Also, as the COVID-19 outbreak diminished social interaction, leading to the closure of many developing institution research facilities in 2020, scientists started to look for alternative ways of executing cognitive development experiments, among these ways the most promising one is the use of virtual research techniques (Gijbels et al., 2021), since it allows the execution of psychological experiments without requiring a direct social interaction and at the same time the participants are not influenced by the physical presence of the experimenter, which could affect negatively their behavior.

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Considering this digital transition, the shift from in-person to virtual research is particularly challenging and recent research studying manipulation, proposed even tools of detecting manipulators among digital platforms users (Fedushko et al., 2019). This scientific challenge is of great importance for the psychologists of cognitive development as well, due to lack of equipment used for recording critical aspects of experiments. Acknowledging this, it is imperative for researchers to contribute to the field by providing tools that enable performing different and regulated virtual cognitive development experiments in children.

However, in order for these regulated virtual cognitive experiments to be executed and delivered to children, novel and sophisticated virtual platforms are required. Those platforms should be capable of parametrizing the experiment structure, e.g., its questions, answers and interface, while also providing innovative ways of interaction between the experimenter and the children. An important feature of those platforms is the gamification of the whole process, in order to attract children's interest and therefore optimize the process by obtaining the best possible results. Such virtual learning/experimentation platforms are extensively described and presented in the literature (e.g., Bri et al., 2009; Georgouli, 2011; Kliziene et al., 2021). However, existing virtual learning/experimentation platforms are not customizable enough and most of them are outdated and they do not integrate modern technologies, like automated humanoid robots and machine learning.

Robots nowadays are becoming sharper and more advanced nearly every day. Robotic systems may soon be moving from the production line into our residences and even taking care of the children, thanks to recent developments in artificial intelligence and software algorithms. Nonhumanoid and mainly humanoid Socially Assistive Robots are used to improve children's creativity, motivation, and social skills (Ali et al., 2019; Masson et al., 2017). Harvard University researchers have also entered the field of child-friendly robotics (Rubenstein et al., 2015). They started developing a cheap robot in 2014 that could be readily controlled utilizing an application and a basic programming system. Any institution might utilize such robotics to inspire students to learn to program. Future generations will see more and more robots in daily life. It has been demonstrated that engaging students with robots in the classroom increases understanding. According to Solace Shen, a Cornell University psychologist specializing in developing young children and experiments on robot-human interrelations, contemporary research indicates that children could benefit from communicating with robotics (Bennington-Castro, 2017), and they can learn by teaching robots,

improving linguistic, reading, writing, reasoning, and other cognitive capacities (Jamet et al., 2018). It is possible that among the first jobs that child-friendly robots will do is helping preschool instructors. Researchers are investigating the potential use of robotics in classrooms with children as part of studies (Leite et al., 2012).

Another important aspect of robotics is their interaction with children with special needs. According to extensive literature available (Daniela & Lytras, 2019; Papakostas et al., 2021), children with special needs are drawn to robotics because they are less complicated and unpredictable than individuals, less frightening, endlessly patient and constant in their voice quality and attitude, and extremely configurable and adaptive to the requirements of individual children. Most of these values can be transferred to typically developed children and ease the adjustment period for experiments and provide more accurate results.

Organization of this Thesis

The “Cognitive Development” and “Technology in Psychology and Learning” chapters formulate the Background section, which presents related studies and research associated with the subjects discussed and analyzed throughout the thesis.

Next is the “Digital Tool for Measurement” chapter that presents in details the architectural decisions and implementation details of the novel virtual platform that was developed in order to be used to host and enable the execution of all the experiments.

The first study presented in the thesis is focused on the validation of the aforementioned virtual platform. Details about the platform are described in depth and a basic functionality test is performed, by using three different modes of execution in a proof-of-concept experiment to showcase the possible use cases of the virtual platform. The experiment chosen is based on Piaget’s conservation tasks, which is among the most popular experiments in cognitive development area. The scientific hypothesis concerning the high functionality of the virtual platform was formulated. At the same time the results of the chosen experiment will be presented and analyzed in order to further reinforce and empower the significance and importance of the virtual platform in the area of modern psychology experimentation and measurement.

In the second study, a novel dimension of Piaget’s theory of conservation was explored by juxtaposing children’s interaction with a liquid conservation task in two distinct environments: the digital and the physical. The comparison of digital and physical environments in understanding liquid

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conservation provides a unique lens through which the impact of digital environments on cognitive development can be examined. This study, therefore, seeks to bridge the gap between traditional developmental theories and the contemporary digital context in which today's children are immersed. The comparison performed in this research is not only a matter of academic interest but has practical implications in areas ranging from educational technology to parenting strategies in the digital era.

In the third study, the conservation concept is studied using the conservation tasks based on the well-known Piagetian conservation tasks of liquid and mass, but with a substantial shift: the introduction of a robotic experimenter instead of a human. The hypothesis is that using a robot experimenter would aid in knowledge and understanding of the conservation concept, eliminating the human experimenter bias as previous academics have noted. Another objective of this research was to identify possible associations between the acquisition of the general concept of conservation and three more specific concepts, identity, compensation, and reversibility.

Finally, in the last chapter the results and implications of all three studies are discussed and analyzed.

CHAPTER 1: Cognitive Development

1.1 Introductory Elements in Cognitive Development

The study of cognitive development has been a central focus in the field of psychology, with researchers seeking to understand the processes by which individuals acquire, process, and apply knowledge (Siegler & Alibali, 2019). Two primary cognitive-developmental theories have emerged, each with its own unique perspective on the question of how cognition changes over time.

The structuralist theory, as exemplified by the work of Jean Piaget (Piaget, 1951,1954,1973) and Heinz Werner (Werner & Kaplan, 1950; Werner & Wapner, 1952), is concerned with the organization of behavior and how it evolves with development (Collins, 1984). The researchers of the structuralist theory have explored the ways in which individuals construct and restructure their understanding of the world, moving through a series of cognitive stages characterized by distinct patterns of thought and problem-solving.

In contrast, the functionalist theory that is influenced by behaviorism (Moore, 1996) and information processing (Simon, 1979), focuses on the underlying processes that drive behavioral change. Researchers in this theory investigate the specific mechanisms and cognitive processes that enable individuals to acquire, store, and manipulate information, and how these processes develop over time.

While these two theories have often been presented as distinct and even opposing, there is growing recognition that they may be complementary in their approach to understanding cognitive development. Researchers in both theories have expanded their focus to include a range of behaviors and cognitive processes, moving beyond the traditional emphasis on knowledge acquisition to consider the broader implications of cognitive development for individuals' understanding of the world and their ability to engage with it effectively (Collins, 1984).

1.2 Cognitive Development in Infancy

Cognitive development during infancy, a crucial period of human growth and maturation, has been the focus of extensive research in the field of developmental psychology. The study of infant cognition has revealed the competence and active engagement of the developing mind from a very early age (Paterson et al., 2006). Infants demonstrate an intuitive analysis of the statistical regularities in the speech sounds they hear, laying the foundation for language acquisition. This suggests that infants possess an innate capacity to extract patterns and make sense of the complex

sensory information they encounter, a process that lays the groundwork for more advanced cognitive abilities.

In addition to their language-learning abilities, infants and toddlers also develop implicit theories to explain the actions of objects in their environment and the behavior of people they interact with, which form the basis for causal learning and a deeper understanding of the physical and social worlds (Allen et al., 2015). This innate drive to seek explanations and make sense of their environment is a strong indication of early cognitive development. Moreover, the ability to engage in shared experiences and learn from others is a testament to the social and interactive nature of cognitive development in infancy.

The research on cognitive development in infancy has significant implications for our understanding of human cognition and learning. These findings challenge the traditional view of the infant as a passive recipient of information. Instead, they reveal the infant as an active learner, capable of extracting patterns, forming theories, and benefiting from social interaction. This has shed light on the remarkable competence and active engagement of the developing mind. Infants demonstrate an impressive capacity for language acquisition, causal reasoning, and social learning, which lays the foundation for more sophisticated cognitive abilities (Garton, 1995). These insights have profound implications for our understanding of human cognition and the ways in which we can foster the cognitive growth and development of young children.

1.3 Cognitive Development in Early Childhood

Cognitive development in early childhood studies the transformations in a child's mental capacities, including their ability to perceive, learn, remember, and problem-solve. During this formative period, children display an astonishing competence, actively engaging with their environment and constructing new knowledge through exploration and discovery (Asmussen et al., 2018).

This is intrinsically linked to the maturation of other domains, such as language and physical-motor skills, creating a complex and intertwined domain of human development.

Cognitive development in young children can be understood through the lens of various research viewpoints. This early cognitive development sets the stage for further advancements in areas such as language and mathematics (Perry & Dockett, 2008).

Effective learning activities have a significant impact on enhancing cognitive development in early childhood. Through exploration, play, and interaction with their surroundings, children acquire

new knowledge and enhance their problem-solving abilities (Spencer & Darvizeh, 1981). This cognitive growth not only benefits the child's immediate learning but also lays the foundation for their future academic, personal and social success.

By studying the crucial role of cognitive development in early childhood, researchers and early care professionals have made progress in understanding the developing mind. This knowledge has direct implications for the design and implementation of educational programs and learning environments that foster the optimal cognitive growth of young children (Amalia & Khoiriyati, 2018).

1.4 Cognitive Development in Middle Childhood

Middle childhood is the period between the ages of 6 and 12. This period presents a critical stage of cognitive development, where children undergo significant changes and advancements in their thinking abilities, problem-solving skills, processing of temporal information and overall intellectual capacity (Samartzi, 2011). This phase is characterized by a global shift in cognition, motivation, and social behavior, with children becoming more self-aware, reflective, and able to consider the perspectives of others (Del Giudice, 2014; Schonert-Reichl et al., 2013). During this crucial life stage, children's personalities, behaviors, and competencies consolidate into forms that often persist into adolescence and adulthood, as highlighted by recent research. One of the key developments during this period is the emergence of more logical thinking, reasoning, and problem-solving abilities, as described by Piaget's theory of cognitive development. While preschool children are often tied to the concrete and readily perceptible characteristics of tasks, the thoughts of children aged 6-12 become more fully logical and systematic, allowing them to engage in more complex intellectual endeavors and tackle increasingly sophisticated problems.

Additionally, middle childhood is a time when children's understanding of themselves and others becomes more nuanced and multifaceted. They start developing social relationships, learn essential life skills, and actively use outdoor spaces for play and exploration. This period is also marked by a shift in children's motivation and social behavior, as they become less egocentric and better able to consider the feelings and perspectives of others (Schonert-Reichl et al., 2013). Researchers have also highlighted the importance of recognizing the culturally defined tasks associated with this stage of development, as children work to master academic skills, such as reading, writing, and arithmetic, while also developing a stronger sense of right and wrong and the

capacity to act in accordance with higher levels of social understanding (Del Giudice, 2014; Schonert-Reichl et al., 2013).

The transition to middle childhood has been described as a "switch point" in the development of life history strategies, with the underlying hormonal mechanism of adrenarche playing a crucial role in this process (Del Giudice, 2014). The various psychological developments that occur during this stage are not only significant in their own right but also have lasting implications for an individual's cognitive, social, and emotional well-being throughout their lifespan.

1.5 Cognitive Development, Learning Styles and Cultural Influences

In general, cognitive development is a fundamental aspect of human growth and learning that encompasses the intricate processes by which individuals acquire, process, and apply knowledge, skills, and understanding. This dynamic process is influenced by a variety of factors, including biological characteristics, environmental stimuli, and cultural contexts (Gauvain et al., 2011; Wattad & Chen, 2023).

One critical component of cognitive development is the concept of learning styles, which refers to the preferred ways in which individuals perceive, process, and retain information. Effective learning activities that cater to diverse learning styles can significantly contribute to the enhancement of cognitive development, especially in early childhood (Amalia & Khoiriyati, 2018).

This approach to cognitive development highlights the role of more experienced cultural members, practices, institutions, and artifacts in guiding children's development of knowledge and thinking skills (Gauvain et al., 2011). This perspective acknowledges that cognitive development is not merely an individual phenomenon, but a dynamic interplay between the child and their learning and cultural environment.

Moreover, the notion that cognitive development continues throughout an individual's lifespan challenges the traditional view of cognition as a static entity (Wattad & Chen, 2023). Formal learning and education can serve as mediating factors, influencing the learning process and the individual's ability to navigate the challenges encountered during cognitive development.

Piaget's seminal theory of cognitive development outlines a series of distinct stages through which children progress. This theory provides a foundational framework for understanding the process by which an individual's mental capabilities evolve and mature over time and they are shaped by the cultural context in which they occur (Rabindran & Madanagopal, 2020). As researchers have

delved deeper into the nuances of cognitive development, it has become increasingly clear that the influence of culture cannot be overlooked. The cultural approach to cognitive development emphasizes the crucial role that the cultural environment plays in shaping an individual's cognitive abilities and thought processes. This perspective acknowledges that the practices, institutions, and artifacts of a particular culture serve as scaffolding for children as they develop their knowledge and thinking skills. Cross-cultural studies have been instrumental in highlighting the ways in which cultural factors can influence the pace and trajectory of cognitive development (Thomas & Fam, 1984). One of the key insights of the cultural approach is the recognition that cognition is not an isolated individual construct, but rather a distributed phenomenon that is deeply embedded within the social and cultural contexts in which it occurs. This shift in perspective has important implications for how researchers approach the study of cognitive development, as it calls for a more holistic and contextual understanding of the process that takes into account the complex interplay between the individual and their cultural environment.

1.6 Cognitive Development and Socioeconomic Status

The relationship between socioeconomic status and cognitive development has been the subject of extensive research, revealing a complex interplay between environmental, biological, and sociocultural variables (Nießen et al., 2020). Emerging evidence suggests that childhood socioeconomic status influences neural development, which may contribute to the well-documented socioeconomic status related disparities in academic achievement (Rosen et al., 2018). Extensive research in the sociology of education has found a strong support for a positive association between family socioeconomic status and academic achievement. Higher socioeconomic status as reflected in the income-to-needs ratio was associated with higher parent-reported achievement, working memory performance, and cognitive stimulation in the home environment (Rosen et al., 2018).

Socioeconomic status is one of the most widely studied constructs in the social sciences. Several ways of measuring socioeconomic status have been proposed, but most include some quantification of family income, parental education, and occupational status (Bradley & Corwyn, 2002). Research shows that it is associated with a wide array of health, cognitive, and socioemotional outcomes in children, with effects beginning prior to birth and continuing into adulthood.

1.7 Interventions to Enhance Cognitive Development

It is widely accepted that cognitive development in young children is a crucial aspect of their overall growth and well-being. Cognitive development is closely intertwined with the development of other domains, such as language and physical-motor skills, making it a critical focus for early childhood interventions.

One effective approach to enhancing cognitive development in young children involves engaging them in a variety of learning activities which can stimulate children's curiosity and problem-solving abilities. This type of active exploration can have a profound impact on the development of children's mindset and thinking capabilities. In addition to engaging learning activities, research has also highlighted the importance of providing a nurturing and supportive environment for young children (Chua et al., 2017). Caregivers and educators who foster an environment that encourages curiosity, exploration, and problem-solving can significantly contribute to the cognitive development of the children in their care (Amalia & Khoiriyati, 2018).

Furthermore, recent advancements in the understanding of early cognitive development have led to the recognition of the importance of tailoring interventions to the unique needs and developmental stages of individual children. By implementing personalized strategies that cater to the specific strengths and challenges of each child, caregivers and educators can maximize the effectiveness of their interventions and foster optimal cognitive growth.

Through the implementation of engaging learning activities, the provision of a supportive and nurturing environment, and the tailoring of interventions to individual needs, caregivers and educators can unlock the incredible potential of young minds and set the stage for lifelong learning and success (Allen et al., 2015; Amalia & Khoiriyati, 2018).

1.8 Implications for Education and Parenting

As our understanding of cognitive development has evolved, it has become increasingly clear that this area of study holds profound implications for both education and parenting (Lanjekar et al., 2022), as the experiences and environments children are exposed to can have a significant impact on their cognitive growth and overall well-being. Researchers have highlighted that cognitive development is a remarkably complex and interrelated process, with various aspects of a child's development, such as emotional regulation, attention, and memory, all playing a crucial role in their ability to learn and engage with new information. This realization has important consequences for

those who care for and educate young children, as it underscores the need for a comprehensive and holistic approach to supporting cognitive development (Kuhn, 1979a).

This emphasizes the importance of educators and parents being attentive to the unique cultural backgrounds and experiences of the children in their care, and tailoring their approaches accordingly.

The fact that learning is an active and multifactoral process, challenge the traditional notions of children as passive recipients of knowledge, and instead positions them as active participants in their own learning and development (Sharp et al., 1979).

In light of these insights, the implications for education and parenting are profound. Educators and caregivers must be equipped with a deep understanding of cognitive development, and must be prepared to create learning environments and activities that nurture and support the cognitive growth of the children in their care (Gauvain et al., 2011). This may involve, for example, designing curricula that explicitly address the development of cognitive skills such as reasoning, attention, and memory, while also acknowledging the cultural context and individual needs of each child (Allen et al., 2015).

Similarly, for parents, the research on cognitive development underscores the crucial role they play in shaping their children's cognitive growth. By providing a nurturing and stimulating environment, while being responsive in their children's needs, parents can significantly contribute to their children's cognitive and overall well-being (Amalia & Khoiriyati, 2018).

As educators and parents strive to support the cognitive growth of the young people in their care, it is essential that they remain attuned to the latest research and insights in this field, and are prepared to adapt their approaches accordingly.

1.9 Some Directions in Future Cognitive Development Research

As the field of cognitive development continues to evolve, researchers are increasingly exploring new frontiers in understanding the complex processes that shape the human mind from infancy to adulthood. One promising direction involves the relationship between cognitive development and emotional dynamics. By studying this connection, researchers can gain a more holistic understanding of how children's social-emotional experiences influence the development of their mental faculties, and how these faculties, in turn, shape their social and emotional lives (Collins, 1984).

Another area of growing interest is the relationship between brain changes and cognitive development. As neuroimaging and other neuroscientific techniques become more advanced, researchers are able to examine the neural underpinnings of cognitive development with greater precision. This can shed light on how structural and functional changes in the brain contribute to the acquisition of new cognitive skills and the refinement of existing ones (Dunn, 2000).

A third promising direction in cognitive development research is the role of informal teaching and other modes of social interaction in shaping cognitive growth. While formal schooling is a well-established influence on cognitive development which has been largely studied, researchers are currently recognizing the importance of the social interactions that take place outside the classroom, such as parent-child exchanges, peer interactions, and community-based learning (Fischer & Bullock, 1984). Indeed, the nature and effects of schooling and literacy on cognitive development remain a crucial area of research. As children progress through the educational system, their cognitive capacities are challenged and expanded in a myriad of ways. Researchers continue to investigate how different educational approaches, curricula, and pedagogical techniques impact the trajectory of cognitive development, and how these impacts may vary across different cultural and socioeconomic contexts (Striano & Reid, 2006). By pursuing these and other emerging directions in cognitive development research, scholars can work towards a more comprehensive and dynamic understanding of the human mind, paving the way for more effective interventions and educational practices that support the cognitive growth and flourishing of individuals from all backgrounds (Hausfather, 1996).

An additional direction in future research of cognitive development is the role of technology, which also has emerged as a pivotal area of this thesis, offering both challenges and opportunities for researchers and educators alike. Digital platforms, interactive games, and socially assistive robotics have transformed how children learn and engage with cognitive tasks, providing environments that are tailored, adaptive, and interactive. These technologies can enhance cognitive processes by scaffolding learning, offering immediate feedback, and fostering problem-solving skills through gamified experiences. Moreover, the integration of artificial intelligence and machine learning in educational tools allows for highly personalized learning journeys, catering to individual cognitive developmental trajectories. The interaction between technology and cognitive development extends beyond academic skills, influencing children's attention, memory, and even social-emotional capacities. As such, researchers are increasingly investigating how prolonged

technology use shapes the development of critical thinking, creativity, and social interaction in children. By exploring the potential and limitations of these technologies, future studies can provide insights into designing interventions that harness technology to support holistic cognitive growth, while mitigating its possible adverse effects on developmental outcomes.

1.10 Main Cognitive Development Theoretical Approaches

1.10.1 Piaget's Theory

Piaget's Cognitive Development Theory, proposed by the renowned Swiss psychologist Jean Piaget, is a framework that has profoundly influenced our understanding of how children's cognitive abilities evolve over time (Huitt & Hummel, 2003; Piaget, 1951,1954). This theory suggests that individuals progress through distinct stages of cognitive development, each marked by unique characteristics and abilities (Sanghvi, 2020).

At the core of Piaget's theory is the idea that children actively construct their own knowledge and understanding of the world through their experiences and interactions with their environment (Rabindran & Madanagopal, 2020). This process of knowledge construction is driven by two key mechanisms: assimilation, where new information is integrated into existing cognitive structures, and accommodation, where existing cognitive structures are modified to adapt to new information. Piaget also made the assumption that children are naturally motivated to learn and that their cognitive development occurs in a prescribed order, regardless of external influences.

Piaget's theory outlines four distinct stages of cognitive development: the Sensorimotor stage, the Preoperational stage, the Concrete Operational stage, and the Formal Operational stage (Feldman, 2004; Piaget, 1962).

Piaget's has influenced numerous fields, including education, psychology, and cognitive science (Huang, 2021; Mielonen & Paterson, 2009). By recognizing the active role children play in constructing their own knowledge, Piaget's theory has lead educational practices to emphasize hands-on learning, discovery, while emphasizing the importance of creating environments that foster children's natural curiosity and engagement (Haley & Good, 1976).

1.10.1.1 Stages of Cognitive Development

Piaget's theory outlines four primary stages of cognitive development (Piaget, 1962, 1976).

The first stage, known as the sensorimotor stage, spans from birth to around two years of age and is characterized by the child's reliance on sensory experiences and physical interactions to make sense of the world.

The second stage, the preoperational stage, extends from around two to seven years of age. During this stage, the child's thinking becomes more symbolic, as they begin to use language and mental representations to understand and interact with their environment. However, their thinking is still limited by egocentrism, the inability to consider perspectives other than their own.

The third stage, the concrete operational stage, spans from around seven to eleven years of age. In this stage, the child's thinking becomes more logical and organized, as they develop the ability to perform mental operations on concrete objects and events.

The final stage, the formal operational stage, begins around the age of eleven and continues into adulthood. During this stage, the individual's thinking becomes more abstract, hypothetical, and deductive, allowing them to engage in complex problem-solving and reasoning tasks (Rabindran & Madanagopal, 2020). As children progress through these stages, their cognitive abilities become increasingly sophisticated (Arsalidou & Pascual-Leone, 2016).

1.10.1.2 Sensorimotor Stage

The Sensorimotor stage (Piaget, 1962, 1976), the first of Piaget's four stages, which spans from birth to approximately two years of age, is characterized by a child's exploration of the world through their senses and motor skills (Rabindran & Madanagopal, 2020).

During the Sensorimotor stage, infants engage in a series of reflexive behaviors, known as "reflexive schemes," which gradually transition into more complex "primary circular reactions," where they intentionally repeat actions that produce interesting effects (Spencer, 2011). As they progress, they develop "secondary circular reactions," coordinating their actions to achieve desired outcomes, and eventually, "tertiary circular reactions," where they actively experiment with novel behaviors.

During this stage, the child develops an understanding of object permanence, the ability to recognize that objects continue to exist even when they are out of sight (Sanghvi, 2020).

Piaget's emphasis on the child's active engagement with their environment as a key driver of cognitive development is a crucial insight (Spencer, 2011). This active exploration and experimentation, facilitated by the maturation of the child's sensory and motor systems, allows them to construct mental representations of the world, a significant milestone in the Sensorimotor stage.

1.10.1.3 Preoperational Stage

The preoperational stage (Piaget, 1962, 1976) is the second stage in Piaget's theory, which typically spans from 2 to 7 years of age, in which children begin to develop their symbolic thinking and language skills, enabling them to represent the world through mental images, words, and gestures (Rabindran & Madanagopal, 2020). This stage is characterized by several key cognitive abilities and limitations.

One of the defining features of the preoperational stage is the concept of egocentrism, where children view the world primarily through their own perspective and have difficulty understanding the viewpoints of others. As they interact with their surroundings, children in this stage are often focused on their own experiences and may have difficulty comprehending that others may have different thoughts, feelings, or perceptions. However, Piaget's theory suggests that as children progress through this stage, they begin to develop a "theory of mind," which allows them to increasingly understand the intentions, feelings, and perspectives of those around them.

Another important aspect of the preoperational stage is the development of children's ability to use symbols, mental representations, and language to represent their experiences and ideas. As children engage with their environment, they construct meaning and understanding by actively exploring and interacting with their surroundings.

While the preoperational stage marks a significant advancement in children's cognitive abilities, it is also characterized by certain limitations. Children in this stage often struggle with logical reasoning and abstract thinking, tending to focus on the salient features of a situation rather than considering the broader context.

1.10.1.4 Concrete Operational Stage

The third key stage of Piaget's theory is the concrete operational stage (Piaget, 1962, 1976), which typically occurs between the ages of 7 and 11 years. During the concrete operational stage, children begin to demonstrate more logical and organized thinking. They are able to engage in mental operations and problem-solving strategies that were not possible in the previous preoperational stage (Rabindran & Madanagopal, 2020). Notably, children in the concrete operational stage develop the ability of "reversibility," which allows them to think abstractly and understand that actions can be reversed. This represents a significant cognitive advancement, as children are no longer limited to purely concrete, irreversible thinking.

Another key characteristic of the concrete operational stage is the development of identity, compensation, and reversibility. Children now understand that an object or person remains the same over time, despite changes in appearance or context. They can also comprehend that changes in one dimension can be compensated by changes in another, and that actions can be mentally reversed (Huang, 2021). This newfound ability to think logically and reversibly empowers children to tackle more complex problems and scenarios.

The concrete operational stage is also marked by the growth of metacognition, or the ability to think about one's own thought processes (Mielonen & Paterson, 2009).

1.10.1.5 Formal Operational Stage

The formal operational stage (Piaget, 1962, 1976), the final stage in Piaget's theory, is characterized by the ability to think abstractly, logically, and hypothetically (Kuhn, 1979b). During this stage, individuals are able to engage in more complex problem-solving, develop sophisticated reasoning skills, and consider multiple perspectives simultaneously (Rabindran & Madanagopal, 2020).

One of the key features of the formal operational stage is the ability to engage in hypothetical and deductive reasoning. Individuals in this stage can consider abstract concepts, formulate hypotheses, and engage in logical reasoning to test those hypotheses. This represents a significant cognitive advancement from the previous concrete operational stage, where individuals were primarily limited to thinking about concrete, tangible objects and events.

The formal operational stage typically emerges during early adolescence, around the ages of 11 to 15 years old. However, the rate at which individuals progress through this stage can vary, with some individuals developing formal operational thinking earlier or later than others (Shayer et al., 1976).

Research on the formal operational stage has highlighted the importance of environmental factors in the development of this cognitive ability. Differences in cultural and educational experiences can influence the rate at which individuals progress through the formal operational stage, with some individuals developing this cognitive ability more quickly than others.

Finally, it must be noted that research has indicated that not all individuals may fully attain the formal operational stage, and some may remain in the concrete operational stage throughout their lives.

1.10.1.6 Theoretical Foundations of Conservation

Conservation refers to the understanding that the quantity or amount of an object remains the same despite changes in its appearance or arrangement is a significant milestone in a child's cognitive development (Elkind, 1967; Piaget, 1951, 1954; Zimiles, 1963), as it reflects the child's growing capacity for logical reasoning and problem-solving.

Piaget's research revealed that children's understanding of conservation typically develops in a predictable sequence, with the concept of number conservation emerging at an earlier age than that of mass or continuous quantity. His findings challenged the prevailing view that children's cognitive abilities were simply less sophisticated versions of adult thinking, and instead proposed that children actively construct their own understanding of the world through a process of assimilation and accommodation.

According to Piaget's four stages to conservation, it is in the concrete operational stage that children develop the ability to think logically about concrete, observable situations and to understand the concept of reversibility - the idea that an action can be mentally "undone" (Mielonen & Paterson, 2009). This enables them to grasp the equivalency and reversibility involved in conservation tasks, such as recognizing that the amount of liquid in a container remains the same despite changes in its shape or volume (Nelson, 1974).

1.10.1.7 The Role of Conservation in Child Development

Conservation reflects the child's growing capacity for logical reasoning and problem-solving. One of the key findings from Piaget's research is the age at which children develop the ability to conserve. According to Piaget, children typically begin to develop conservation skills around the ages of 5 to 7, with the understanding of number conservation emerging earlier than the conservation of mass or continuous quantity. This finding is supported by studies that have shown that the majority of 5- and 6-year-old children can understand the concepts of equivalency and reversibility involved in the conservation of number. However, the ability to conserve mass and continuous quantity tends to develop later, around the age of 7 or older (Elkind, 1961, 1967; Piaget, 1951, 1954).

The development of conservation skills has profound implications for other areas of the children's development: the ability to conserve is a reflection of this process, as it demonstrates the child's capacity to mentally represent and reason about the world around them, rather than being solely dependent on the perceptual cues of the immediate environment (Rabindran & Madanagopal, 2020).

Furthermore, the development of conservation skills is closely linked to the child's growing ability to engage in logical thinking and problem-solving. As children move from the preoperational stage to the concrete operational stage of Piaget's model, they become increasingly capable of mental operations, such as reversibility and seriation, which underlie the understanding of conservation (Rabindran & Madanagopal, 2020).

Indeed, the ability to conserve reflects the child's growing capacity for logical reasoning and problem-solving, and is a crucial milestone in the overall trajectory of cognitive development.

1.10.1.8 The Development of Conservation Abilities

According to Piaget, in the sensorimotor stage, infants begin to develop an understanding of object permanence, recognizing that objects continue to exist even when they are out of sight. This lays the foundation for the later development of conservation abilities (Elkind, 1961, 1967; Piaget, 1951, 1954). As children progress to the preoperational stage, they develop the ability to mentally represent objects and events, but their thinking remains largely egocentric and focused on the outward appearance of things rather than underlying principles of conservation (Sanghvi, 2020). It is not until the concrete operational stage, typically between the ages of 7 and 11, that children begin to develop the ability to conserve quantity, number, and other properties, despite changes in the physical appearance of the object (Rabindran & Madanagopal, 2020).

One of the classic experiments used to demonstrate the development of conservation abilities is the "water-level" task, in which a child is shown two identical beakers filled with the same amount of water. If one of the beakers is then poured into a taller, thinner container, younger children will often claim that the amount of water has changed, despite the fact that the volume remains the same.

Piaget's research has shown that the ability to conserve is not innate, but rather develops gradually through the child's interactions with the physical world and the mental operations they perform on those interactions.

1.10.1.9 Piaget's Experimental Design and Methodology

To test his theories, Piaget employed a variety of experimental methods, including clinical interviews, observations, and hands-on tasks. Piaget's experiments often involved presenting children with tasks or problems that challenged their current cognitive abilities, allowing him to observe how they adapted and adjusted their thinking to accommodate new information. During the clinical interviews

the children were encouraged to verbalize their reasoning and problem-solving strategies (Elkind, 1961, 1967; Piaget, 1951, 1954).

One of Piaget's most renowned experimental designs were the conservation tasks, which assessed children's understanding of the conservation of quantities, such as liquid or number. In these tasks, children were presented with two equal amounts of a substance (e.g., water in two identical containers) and then one of the quantities was transformed (e.g., the liquid was poured into a taller or shorter container). Depending on the child's stage of cognitive development, they would either recognize that the quantities were still equal (conservation) or believe that the transformation had changed the amount (non-conservation) (Mallon, 1976; Rabindran & Madanagopal, 2020; Sanghvi, 2020).

Through these carefully designed experiments, Piaget was able to identify the distinct stages of cognitive development that children progress through, from the sensorimotor stage in infancy to the formal operational stage in adolescence.

1.10.1.10 *Understanding Reversibility in Conservation*

This capacity for reversibility in conservation, the understanding that changes can be undone, is central to the development of this important cognitive skill (Brainerd, 1972). Early research on this topic has demonstrated the importance of reversibility in children's acquisition of conservation. Recent experiments suggest that the majority of 5-year-olds and 6-year-olds exhibit a strong grasp of the equivalency and reversibility involved in the conservation of number. This indicates that the development of conservation occurs at an earlier age than previously believed (Brekke & Williams, 1975). The ability to conserve mass and continuous quantity usually appears to emerge later, with most children only developing this skill around the age of 7 (Nelson, 1974). This disparity in the age of acquisition suggests that different aspects of conservation may rely on distinct cognitive processes and developmental trajectories.

As noted by (Davidson, 1987), the development of function concepts may provide the foundational knowledge required for the emergence of conservation skills. Furthermore, Piaget's theory emphasizes the role of interaction with the environment in the construction of meaning and learning.

1.10.1.11 *Factors Influencing Conservation Judgments*

According to Piaget, the development of conservation judgments is influenced by several key factors, including maturation, experience, social transmission, and equilibrium (Rabindran & Madanagopal,

2020). Maturation, or the biological unfolding of the child's cognitive capacities, plays a crucial role in enabling the child to grasp the underlying principles of conservation. Experience, or the child's interactions with the physical and social environment, also contributes to the development of conservation judgments, as children build their knowledge through hands-on exploration and observation.

The role of social transmission, or the influence of others such as parents and teachers, is also significant in Piaget's theory. Children learn not only from their own experiences but also from the guidance and instruction provided by more knowledgeable individuals (Barrouillet, 2015).

The concept of equilibrium, or the child's ability to coordinate and balance different cognitive structures, is also central to Piaget's theory. The transition from one stage of cognitive development to the next is driven by the child's attempts to achieve equilibrium, which involves resolving cognitive conflicts and reorganizing their understanding of the world.

The development of conservation judgments has been a subject of extensive research and debate in the field of cognitive psychology (Sanghvi, 2020). Some studies have challenged Piaget's stage-based theory, highlighting individual differences and the influence of learning and experience on the acquisition of conservation judgments (McGarrigle & Donaldson, 1974). Others have sought to refine and expand upon Piaget's work, exploring the various factors that contribute to the development of this cognitive ability.

1.10.1.12 Sociocultural Influences on Conservation

Piaget's research has been a driving force in the study of child development and the design of effective teaching methods for early childhood educators. However, the broader implications of Piaget's work on our understanding of the world have received less attention. Piaget's theory describes development as a process of determining current cognitive competence and influencing what children are capable of learning (Jardine, 1984). Children are viewed as natural scientists who investigate the world and expand their understanding accordingly. Teachers, in this model, are expected to provide resources for children's autonomous learning without interfering with the process (Smith, 1993).

In contrast, Vygotsky's theory emphasizes the importance of the social and cultural context on children's thinking. Vygotsky saw learning as the driving force behind development, with the development of thinking being shaped by the responsive social contexts provided in early childhood

education (Smith, 1993). This perspective suggests that sociocultural factors play a significant role in the acquisition of conservation skills.

Research has shown that constructivism, the broader philosophical approach that encompasses both Piaget's and Vygotsky's theories, can promote creativity and engagement in students (Choi & Lee, 2021). However, the specific influence of sociocultural factors on the development of conservation remains an area of open research.

According to the sociocultural perspective, cognition is not an individual construction but is shaped by society as people participate in culturally relevant activities. This suggests that the development of conservation skills is not a universal skill, but rather a contextually specific process guided by others and mediated by particular cultural tools and artifacts.

Empirical research has been done, examining the application of institutional analyses in order to investigate schooling as a cultural process, the use of interpersonal analyses to understand how interactions promote cognition and learning, and discursive analyses have been exploring the patterns and opportunities in instructional conversation (Palincsar, 1998).

1.10.1.13 *Educational Implications of Conservation*

The development of conservation has important implications for how we approach education and learning (Haley & Good, 1976; Kamii, 1979). Piaget's theory suggests that children construct meaning by interacting with their surroundings, and that the way a child interacts within an environment is what creates learning (Mielonen & Paterson, 2009). Therefore, educational approaches that encourage hands-on, experiential learning, and that allow children to explore and manipulate concrete objects, may be more effective in promoting the development of conservation and other cognitive skills.

Additionally, Piaget's theory suggests that children's cognitive development occurs in a specific sequence, with the concrete operational stage following the preoperational stage. For example, before expecting children to engage in abstract or formal operational thinking, it is important to ensure that they have developed the necessary concrete operational skills, such as the ability to conserve (Mielonen & Paterson, 2009).

Studies have found that a significant proportion of 5- and 6-year-old children were able to understand the concepts of equivalency and reversibility involved in conservation of number, suggesting that this skill may develop earlier than the norm (Nelson, 1974).

Educators should be aware of these developmental differences and adjust their instructional approaches accordingly, providing opportunities for children to engage in a variety of conservation tasks and experiences.

1.10.1.14 *Limitations and Criticisms of Piaget's Work*

Piaget's theoretical framework has been influential in the field of developmental psychology, but it has also faced various limitations and criticisms over the years. One of the primary criticisms of Piaget's work is its lack of a sociocultural dimension. As highlighted in the article "Play, Cognitive Development, and the Social World: Piaget, Vygotsky, and Beyond," Piaget's approach to play and cognitive development did not adequately address the wider sociocultural elements that define and shape the play context (Nicolopoulou, 1993). This oversight has led to a growing influence of Vygotsky's sociocultural theory, which emphasizes the role of social and cultural factors in cognitive development.

Furthermore, as noted in the article "Cross Cultural Methodological Problems in the Study of Singaporean Children's Cognitive Development," (Thomas & Fam, 1984) Piaget's universalistic claims regarding the sequence of cognitive development have been challenged by cross-cultural studies. These studies have found that cultural factors can be determinants in the developmental process, suggesting that Piaget's theory may not be as universal as he had claimed.

Another criticism of Piaget's work is its heavy reliance on observations and interviews, which have been criticized for their potential biases and lack of objectivity. Additionally, some researchers have questioned the validity of Piaget's stage-based model, arguing that cognitive development may be more gradual and less discrete than his theory suggests.

As highlighted in the article "Piaget's stages: the unfinished symphony of cognitive development," (Feldman, 2004) Piaget's stage-based model has also faced criticism for being too vague, too broad, and too dependent on a "miraculous" transition process. To address these concerns, the author suggests revising Piaget's stage theory by shifting stage transitions to the midpoint of each stage, adopting recursive transition processes from neo-Piagetian theories, and embracing decalage as systematic and necessary.

Moreover the apparent lack of correlation in Piaget's conservation experiments is noticed between performance on different conservation tasks. This has led some researchers to question the underlying assumption that these tasks are all measuring the same underlying cognitive structures

or stages. Furthermore, the idea of "horizontal décalages," or inconsistencies in performance across tasks assumed to measure the same stage, has also been a source of concern.

Some researchers have been arguing that the notion of discrete developmental stages may not accurately capture the complexity of cognitive development. Instead, a more recursive process of cognitive development may be more appropriate, as suggested by neo-Piagetian theories.

Researching the issues presented above is essential to further advance our understanding of how children acquire and demonstrate their understanding of conservation principles (Barrouillet, 2015; Feldman, 2004; Sanghvi, 2020; Thomas & Fam, 1984).

1.10.1.15 *Debates Over Conservation Acquisition Age*

One of the key areas of contention in Piaget's theory has been the age at which children develop the ability to conserve quantities, known as conservation. Piaget argued that the ability to conserve quantities, such as the amount of liquid in a container, emerges during the concrete operational stage of cognitive development, which typically begins around age 7 (Rabindran & Madanagopal, 2020). This stage is characterized by the development of logical thought and the ability to mentally manipulate objects and concepts (Rabindran & Madanagopal, 2020). However, the specific age at which children acquire conservation skills has been widely debated.

Earlier research suggested that children do not develop conservation abilities until the age of 7 or 8 (Barrouillet, 2015). However, more recent studies have challenged this view, indicating that some children may develop conservation skills at a younger age. For example, one study found that 84% of 5-year-olds and 94% of 6-year-olds were able to understand the equivalency and reversibility involved in the conservation of number (Nelson, 1974).

1.10.1.16 *Integrating Conservation with Other Cognitive Domains*

The foundational principle of conservation has been extensively studied and integrated into various domains of cognitive psychology. One key area where conservation has been examined is in the development of mathematical understanding. Researchers have found that children as young as 5 and 6 years old are capable of grasping the principles of number conservation, demonstrating an earlier emergence of this concept than previously thought (Watanabe, 2017b). This suggests that early childhood educators should reevaluate their approach to teaching basic mathematical concepts, moving away from rote memorization and toward strategies that foster the construction of one-to-one correspondence between sets of objects.

Conservation has also been linked to the development of literacy skills. Piaget's insights into how children come to understand the concept of quantity can inform instructional methods for teaching reading and writing, as children must grasp the idea of one-to-one correspondence between symbols and their referents. Furthermore, the "reversibility" that accompanies the concrete operational stage allows children to think more abstractly (Commins, 1991; Mielonen & Paterson, 2009; Nelson, 1974).

1.10.1.17 *Practical Relevance of Conservation Studies*

One of the key practical implications of Piaget's conservation studies is their relevance to the field of education (Barrouillet, 2015). By understanding the specific cognitive abilities and limitations of children at different developmental stages, educators can design more effective teaching strategies and learning environments that cater to the unique needs of their students. For instance, the recognition that children in the preoperational stage struggle with conservation tasks has led to the development of teaching methods that focus on hands-on activities and concrete experiences, rather than relying solely on abstract concepts.

Cross-cultural studies, such as the one conducted in Singapore, have provided valuable empirical evidence supporting the universality of Piaget's developmental stages, while also highlighting the potential impact of cultural differences on the pace and expression of these cognitive abilities (Thomas & Fam, 1984). This nuanced understanding of the interplay between biological and environmental factors has further enriched the field of developmental psychology and informed educational practices.

1.10.1.18 *Enduring Legacy of Piaget's Pioneering Work*

Piaget's central thesis was that children are not passive recipients of knowledge, but rather active agents who construct their own understanding of the world through a series of developmental stages. This revolutionary perspective, which contrasted with the prevailing behaviorist view of the time, has had a profound influence on how we think about child development and education. Piaget's theory of cognitive development has provided a framework for understanding the cognitive abilities and limitations of children at different ages, and has informed educational practices aimed at tailoring instruction to the child's level of cognitive maturity (Sanghvi, 2020).

Piaget's work has had a lasting impact on various fields, including developmental psychology, education, and cognitive science. His emphasis on the active role of the child in constructing knowledge has challenged traditional notions of learning and has inspired new approaches to

education that prioritize hands-on, experiential learning and the child's own exploration of the world (Fischer & Hencke, 1996).

1.10.1.19 *Directions for Future Research on Conservation*

As researchers continue to build upon Piaget's foundational contributions, there are several promising avenues for future exploration in the realm of conservation. One area that warrants further investigation is the cross-cultural applicability of Piaget's findings on conservation. While Piaget's theory has been widely tested and validated across diverse cultural contexts, there may be variations in how children from different backgrounds develop this cognitive ability. Expanding research to include more diverse populations, particularly in non-Western settings, could shed light on the universality versus cultural specificity of conservation development (Thomas & Fam, 1984).

Additionally, researchers could explore how variables such as socioeconomic status, educational experiences, and parent-child interactions influence the acquisition of conservation skills. Another promising direction for future research would be to examine the underlying neurological processes involved in conservation. Advances in neuroimaging and cognitive neuroscience could provide valuable insights into the brain mechanisms that support this cognitive capacity.

1.10.2 Vygotsky's Sociocultural Theory

Vygotsky's Sociocultural Theory emerged in the early 20th century. Lev Vygotsky's sociocultural theory has had a profound impact on our understanding of cognitive development and the role of social interactions in learning (Vygotsky, 1987). At the core of Vygotsky's theory is the belief that higher mental functions, such as language, reasoning, and problem-solving, emerge through social interactions and cultural tools.

Vygotsky's theory emphasizes the importance of social interaction and the role of language in cognitive development. According to Vygotsky, language serves as a mediating tool that allows individuals to regulate their own behavior and thinking, as well as to communicate and collaborate with others (Davydov, 1995).

In the context of education, Vygotsky's theory suggests that teachers should create a supportive and interactive social context for learning, where students can engage in shared activities and receive scaffolding to help them achieve their full potential (Kozulin, 2004).

1.10.2.1 Key Principles

Vygotsky's theory posits three key principles that underpin this perspective: the importance of social interaction, the concept of the Zone of Proximal Development, and the emphasis on the process of learning rather than the final product.

The first principle of Vygotsky's theory is the pivotal role of social interaction in the acquisition of knowledge (Topçiu & Myftiu, 2015). Vygotsky argued that higher mental functions, such as problem-solving and critical thinking, have their origins in social activity and are mediated by tools and signs, including language. According to this view, children's learning and development are fundamentally shaped by their interactions with more knowledgeable others, such as parents, teachers, and peers, who guide and scaffold their understanding.

The second key principle of Vygotsky's theory is the concept of the Zone of Proximal Development, which refers to the range of tasks that a learner can perform with the assistance of a more capable individual, but cannot yet accomplish independently (De León, 2012). This zone represents the area of potential development, where learning and growth can occur through the support and guidance of others. By providing appropriate scaffolding within this zone, educators can help students achieve higher levels of understanding and skill, ultimately fostering their cognitive development.

The final principle of Vygotsky's sociocultural theory is the emphasis on the process of learning, rather than the final product. Vygotsky believed that the assessment of learning should focus on the developmental trajectory of the learner, rather than solely on the end result. This perspective underscores the importance of understanding how students arrive at their understanding, rather than simply evaluating their performance against predetermined standards (Choi & Lee, 2021; Hausfather, 1996).

1.10.2.2 Foundations and Approaches

Researchers have explored how the principles of Vygotsky's theory can be applied to the teaching and learning of a second language, highlighting the importance of social interaction, scaffolding, and the Zone of Proximal Development in the language acquisition process (Alharbi, 2023; Lantolf, 1994; De León, 2012; Pathan et al., 2018).

Research has been performed about the Vygotsky's interactionist theory of language acquisition involving collaborative effort involving more experienced individuals (Alharbi, 2023).

Similarly, a critical review of Vygotsky's Sociocultural Theory (Vygotsky, 1987) in the context of second language acquisition underscores the theory's relevance and implications for language learning. The review examines the fundamental concepts of the theory, such as the Zone of Proximal Development, mediation, and scaffolding, and explores how these concepts have been applied and interpreted in the field of applied linguistics.

The application of Vygotsky's Sociocultural Theory in teacher education has also been explored. A study on a reading methods course found that systematic restructuring of the course based on Vygotsky's principles, including the use of a Scaffolded Model, led to significant improvements in the learning outcomes of preservice teachers.

1.10.2.3 The Interplay of Social Interaction and Cognition

According to Vygotsky's theory higher mental functions, such as language, memory, and problem-solving, have their origins in social interactions (Khan, 2005; Moll & Tomasello, 2007). He believed that these cognitive processes are first experienced and internalized through social exchanges before they can be independently performed by the individual. This interactionist view of language acquisition, in particular, has been widely recognized and explored in the field of linguistics and psychology (Alharbi, 2023).

The idea that cognitive growth is not an isolated process has important implications for educational practices, as it suggests that creating a supportive and interactive learning environment is crucial for fostering cognitive development. Educators who embrace Vygotskian principles can design instructional strategies that capitalize on the power of social interaction (Choi & Lee, 2021; Hausfather, 1996).

1.10.2.4 Vygotsky's Perspective on Language and Thought

At the core of Vygotsky's theory is the belief that language and thought are not independent entities, but rather, they are inextricably linked. He claimed that language serves as a crucial tool for cognitive development, enabling children to internalize and make sense of their experiences (Vygotsky, 1987). Vygotsky argued that the path from object to child and from child to object is mediated through another person, emphasizing the crucial role of social interaction in language acquisition.

Research has shown that the application of Vygotsky's principles, such as scaffolding and collaborative learning, can enhance language development in both first and second language acquisition. Vygotsky's perspective on the relationship between thought and language extends beyond the boundaries of natural science, delving into the realm of historical human psychology and

social psychology. His work has been instrumental in shaping our understanding of how social and cultural factors shape cognitive development, with language serving as a critical mediator in this process (Alharbi, 2023).

1.10.2.5 Implications for Education and Instructional Design

Vygotsky argued that higher mental functions, such as problem-solving and critical thinking, have their origins in social activity, and that these functions are mediated by tools and signs (Hausfather, 1996). Vygotsky's notion of the zone of proximal development is particularly relevant to instructional design. According to Vygotsky, learning occurs within this zone, which represents the distance between a student's current level of development and their potential level of development with the guidance of a more knowledgeable other, such as a teacher or peer (Beliavsky, 2006).

This idea has been further developed by scholars such as Jerome Bruner, who introduced the concept of "scaffolding" (Bruner, 2021; Flear, 1990) - the temporary support provided by a teacher or more capable peer to help a student complete a task or develop a new understanding (Beliavsky, 2006). Scaffolding involves gradually withdrawing support as the student becomes more capable, allowing them to take on greater responsibility for their own learning. This approach to instruction has significant implications for how we design learning experiences. Rather than simply delivering content or information, instructional designers should focus on creating opportunities for active engagement, collaboration, and the gradual development of skills and knowledge.

One promising direction in this regard is the use of technology-mediated scaffolding in online and blended learning environments. By providing strategic support, such as prompts, hints, or feedback, instructors can help students navigate the complexities of online learning and overcome the challenges they face within their zones of proximal development.

1.10.2.6 Vygotsky's Legacy and Contemporary Cognitive Psychology

Lev Vygotsky's ideas continue to resonate and influence contemporary research and understanding. The influence of Vygotsky's work can be seen in the growing popularity of constructivist approaches to learning, which emphasize the active construction of knowledge through social interaction and collaboration. Moreover, Vygotsky's theory has also influenced our understanding of the cognitive development of children with neurodiverse learning profiles, such as those with autism spectrum disorder or learning disabilities (Choi & Lee, 2021). The continued relevance of Vygotsky's ideas is evidenced by the extensive body of research that has built upon his work (Choi & Lee, 2021; Hausfather, 1996; Huang, 2021; De León, 2012).

1.10.2.7 Vygotsky's Insights and the Future of Cognitive Science

Vygotsky's insights have challenged the individualistic and often decontextualized approach of earlier cognitive theories, such as those of Jean Piaget (Huang, 2021), by emphasizing the inherently social nature of cognitive development. Despite the growing recognition of Vygotsky's work in the West, his ideas have not yet been fully integrated into the mainstream of cognitive science. As the field continues to evolve, there are promising avenues for further exploration and application of Vygotskian principles, particularly in areas such as the development of neurodiverse learners (Choi & Lee, 2021) and the design of technology-enhanced learning environments. By embracing Vygotsky's insights, cognitive scientists can move towards a more holistic view of the mind as a product of social, cultural, and historical influences.

1.10.3 Vygotsky's Theory of Zone of Proximal Development

The concept of the Zone of Proximal Development has become a fundamental principle in the field of education and cognitive development (Bruner, 1984; Doolittle, 1995). The Zone of Proximal Development, or ZPD, is the area between a learner's current level of understanding and the level of potential development that can be achieved with the guidance and support of a more knowledgeable or skilled individual (Wells, 1999). Vygotsky argued that learning must be in advance of development, and the ZPD enables educators to facilitate this process (Beliavsky, 2006).

The ZPD concept was introduced by Vygotsky in two distinct contexts. One version appeared in a posthumously published collection of essays, where he defined the ZPD as the "distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Wells, 1999). This conception of the ZPD emphasizes the role of assessment and the dynamic nature of intellectual potential, moving beyond the static conception of intelligence represented by IQ scores.

Another perspective on the ZPD emerges from Vygotsky's work on the evolutionary and historical frontiers of human development. In this view, the ZPD is not merely a tool for assessing and facilitating individual learning, but a lens through which to understand the broader processes of human evolution and cultural-historical development. From this angle, the ZPD represents a zone of conflict and tension, where new forms of thinking and behavior emerge and transform existing structures.

1.10.3.1 Understanding the Zone of Proximal Development

Vygotsky argued that learning must precede development (Vygotsky, 1987), and the zone of proximal development provides a framework for understanding how this occurs (Beliavsky, 2006; Bruner, 1984; Doolittle, 1995). By creating a space where learners can engage in tasks that are slightly beyond their current abilities, with the support of a more knowledgeable other, the zone of proximal development enables the internalization of new skills and knowledge, which then become part of the learner's independent development achievement (Beliavsky, 2006). This dynamic process of learning and development is not a unidirectional one, but rather a reciprocal relationship where learning drives development, and development in turn enables further learning.

The concept of scaffolding, as described by Wood, Bruner, and Ross, is closely tied to the zone of proximal development. Scaffolding refers to the temporary support provided by an instructor or more capable peer to help a learner navigate their zone of proximal development and achieve a higher level of understanding or skill. This support can take many forms, such as breaking down a complex task into manageable steps, providing prompts or hints, or modeling desired behaviors.

The zone of proximal development has also been explored in the context of online education, where the instructor's presence and strategic support are crucial in helping students pass through their zones of proximal development.

1.10.3.2 Applying Zone of Proximal Development in Education

The concept of the Zone of Proximal Development holds immense significance in the realm of education. Vygotsky's insights have particular relevance in the context of recent online education (Hall, 2007). As Wood, Bruner, and Ross have articulated, the instructor's presence and strategic support, are crucial in helping students navigate their Zone of Proximal Development and achieve higher levels of self-regulation (Suwastini et al., 2021). Vygotsky's work further emphasizes that educational experiences should be designed to activate a student's "internal developmental processes" through meaningful interactions with their environment.

1.10.3.3 Zone of Proximal Development and Collaborative Learning

The zone of proximal development and collaborative learning are two interrelated concepts that have profound implications for educational practices. Collaborative learning, on the other hand, is a pedagogical approach that capitalizes on the benefits of peer interaction and shared problem-solving. When learners engage in collaborative activities, they have the opportunity to share their

knowledge, perspectives, and problem-solving strategies, enabling them to collectively push the boundaries of their understanding. The synergy between the zone of proximal development and collaborative learning is evident in the ways in which they can reinforce and enhance each other (Beliavsky, 2006; De León, 2012; Suwastini et al., 2021).

1.10.3.4 Zone of Proximal Development and Early Childhood Education

The concept of the Zone of Proximal Development has significant implications for early childhood education (Wells, 1999). This dynamic conception of intellectual potential suggests that a child's true capabilities extend beyond what they can independently accomplish, and can be unlocked through the support of more knowledgeable individuals (Beliavsky, 2006). Vygotsky's work has also been considered alongside the theories of Howard Gardner, another influential figure in educational psychology. Gardner's theory of multiple intelligences aligns with Vygotsky's emphasis on the importance of social and cultural factors in cognitive development, and the need to tailor instructional approaches to address the diverse learning needs of individual students.

1.10.3.5 Limitations and Criticisms of Zone of Proximal Development

One of the primary concerns raised about the Zone of Proximal Development is its potential oversimplification of the learning process (Zeuli, 1986). While the concept highlights the importance of external support and guidance in helping learners progress beyond their current abilities, it may fail to fully account for the multifaceted nature of human development and the complex interplay between individual, social, and environmental factors (Del Río & Álvarez, 2007). Some researchers argue that the Zone of Proximal Development places too much emphasis on the role of the instructor or more knowledgeable other, potentially overlooking the learner's own agency and the dynamic interactions that occur within the learning environment.

Furthermore, the practical application of the Zone of Proximal Development has been criticized for its lack of clear guidelines and the challenges associated with accurately assessing and addressing the evolving needs of individual learners. The concept's reliance on the notion of a "zone" has been questioned, as it may oversimplify the fluid and context-dependent nature of learning, which can vary significantly across different domains, cultures, and individual learners (Del Río & Álvarez, 2007).

Another criticism of the Zone of Proximal Development is its potential to perpetuate certain educational biases and inequalities. Some researchers suggest that the concept may be more

effective in supporting the learning of students from certain cultural backgrounds or socioeconomic status, while neglecting the diverse needs and learning styles of marginalized groups.

Moreover, the Zone of Proximal Development has been scrutinized for its lack of attention to the role of affective and motivational factors in the learning process. Emotions, personal interests, and intrinsic motivation can significantly influence an individual's ability to engage with and progress through their Zone of Proximal Development, but these aspects are often overlooked in the original conceptualization.

Despite these limitations and criticisms, the Zone of Proximal Development remains a influential and valuable framework in the field of educational psychology. Ongoing research and discussions around the concept aims to address these issues (Suwastini et al., 2021).

1.10.3.6 Ethical Considerations in Zone of Proximal Development

The implementation of the Zone of Proximal Development framework raises several ethical considerations that must be carefully navigated by educators and researchers. These ethical considerations include ensuring that the assessments and interventions used to identify and support a student's zone of proximal development do not inadvertently stigmatize or marginalize certain students, and that the support provided is equitable and accessible to all learners, regardless of their background or socioeconomic status. Additionally, educators must be mindful of the potential power imbalances and the risk of undue influence when working within a student's zone of proximal development, and ensure that the learning process remains collaborative and empowering for the student.

By identifying a student's current level of understanding and providing targeted support, educators can help students internalize new knowledge and skills (Beliavsky, 2006). However, the implementation of scaffolding strategies must be approached with care, as there is a risk of creating an overly dependent relationship between the teacher and the student, or of inadvertently reinforcing negative stereotypes or limiting a student's growth (Del Río & Álvarez, 2007; Suwastini et al., 2021).

Furthermore, the increasing use of technology in education has introduced new considerations regarding the ethical use of cognitive scaffolding in digital learning environments. As educators leverage digital tools and platforms to provide personalized, adaptive support to students, they must ensure that these interventions do not perpetuate or exacerbate existing inequities, and

that they respect the privacy and autonomy of the learners (Abdelaziz & Zehmi, 2020; Diaferia et al., 2018; Smagorinsky, 2018; Suwastini et al., 2021).

1.10.3.7 Directions for Future Research in Zone of Proximal Development

With the recent advancements in technology and the increasing diversity of learning environments, there is a need to re-examine and expand our understanding of the zone of proximal development. One promising area of research is the exploration of how the zone of proximal development can be leveraged in online and distance learning settings. In these contexts, the traditional scaffolding provided by an instructor may need to be adapted to the digital environment, incorporating technological tools and virtual interactions to support learners.

Another promising research direction is the exploration of the interplay between the zone of proximal development and the learner's own self-regulatory abilities. As learners progress, they may become more adept at identifying their own learning needs and actively seeking out the necessary support (Chernova & Mustafina, 2017).

1.10.4 Information Processing Theory

The Information Processing Theory supports the notion that the mind functions much like a computer, with distinct stages of information processing that transform sensory inputs into meaningful outputs (Lachman et al., 2015). Cognitive psychologists have dedicated themselves to unraveling the mysteries of this mental architecture, shedding light on the unconscious mental structures and processes that shape our conscious experiences (Kihlstrom, 1987).

Information Processing Theory emphasizes the capacity limitations of the human mind and scientists have been researching to identify these limitations.

The theory has been instrumental in tracing the "time-course" of perceptual processing, from the initial sensory input to the individual's overt response. This level of detail has enabled the construction of precise process models and computer simulations, which have in turn provided deeper insights into the mechanisms underlying human cognition.

Furthermore, in young children, this theory highlights the development of cognitive processes such as attention, memory, and problem-solving (Siegler & Alibali, 2019). Early in life, children's processing capacities are limited, with shorter attention spans and less efficient memory strategies. However, as they grow, their ability to focus, organize information, and retrieve memories improves significantly. For instance, young children rely heavily on rehearsal and visual cues to retain information, gradually developing more sophisticated strategies such as categorization and chunking.

This framework provides insights into how tailored interventions, such as interactive learning tools or gamified educational platforms, can support young children by scaffolding their attention and working memory, aligning with their developmental stage.

1.10.4.1 Key Concepts in Information Processing Theory

One of the key concepts in information processing theory is the notion of "stages of processing." The Information Processing Theory claims that cognition involves a series of steps, beginning with the reception of sensory information, which is then attended to, encoded, stored, and retrieved as needed.

Another important concept is the "locus of capacity limitations." Information processing theorists are interested in understanding what factors constrain the mind's ability to process information efficiently (Shiffrin, 1976). This could include limitations in attention, memory, or the speed of cognitive operations.

The "time-course of perceptual processing" is also a focus of information processing research. Researchers attempt to trace the sequence of events from the initial stimulus input to the final behavioral response, with the goal of constructing detailed process models that can make testable predictions (Pisoni, 2000).

Information processing theory has been critiqued for its overly rigid, computer-like view of the mind and its failure to fully account for the role of context, emotion, and other factors in cognitive processing (Grandjean & Grandjean, 2007; Mayer, 1996; Pisoni, 2000).

1.10.4.2 Stages of Information Processing

The human cognitive system presents a complex and intricate network. This information-processing approach involves a series of distinct stages, each playing a crucial role in our ability to perceive, comprehend, and respond to the world around us (Brayadi et al., 2022; Lindsay & Norman, 2013).

The first stage, sensory registration, involves detecting stimuli such as sights, sounds, and textures, which are particularly salient for young children as they explore their surroundings. At this stage, sensory experiences lay the groundwork for cognitive growth, with young children often relying on multisensory input to understand their environment.

This sensory input progresses to the stage of perception, where young children begin organizing and interpreting raw data to make sense of the world. Perception in young minds is heavily shaped by prior experiences and developing schemas, enabling them to recognize patterns like

familiar faces, shapes, and sounds (Zhang, 2019). These early perceptual abilities are critical for tasks such as language acquisition and object recognition.

Once the information have been perceived, the attention stage is entered, where children's cognitive resources are directed to the most relevant stimuli, though their selective attention is still developing. This stage is crucial for prioritizing information in busy environments and gradually improves as children grow, allowing them to filter distractions and focus on tasks of interest.

Linked to attention is working memory, where children temporarily store and manipulate information, such as recalling instructions or solving simple puzzles. Although limited in capacity compared to adults, young children's working memory steadily improves, supporting more complex problem-solving and language development (Zhang, 2019).

Finally, information that has been processed may enter long-term memory, where it is stored for future use. In young children, long-term memory forms the foundation for learning, helping them retain and build upon knowledge such as vocabulary, social rules, and routines. These stages of information processing are not rigid or isolated; rather, they interact and overlap in a dynamic and interconnected manner, allowing for the efficient and adaptive processing of information. Especially in young children this interconnection reflects the plasticity and adaptability of their developing cognitive systems. This model underscores the importance of providing rich, structured experiences to support children's sensory, attentional, and memory processes during critical developmental periods.

1.10.4.3 Attention and Perception in Information Processing

Attention is the selective process that allows individuals to focus on specific aspects of their sensory input while disregarding others, enabling them to effectively process and make sense of the information they receive. process in young children, enabling them to focus on specific sensory inputs while filtering out distractions, a skill that is foundational for learning and development. At this stage, children's attention systems are still maturing, often driven by a combination of external stimuli, such as bright colors or sounds, and internal motivations, such as curiosity or the desire to explore.

The human brain's perceptive engine, embodied by the brain stem and cerebellum, is responsible for this selective attention process, which is driven by both external stimuli and internal motivations. This selective focus allows individuals to allocate their limited computational resources efficiently, as they can devote more cognitive effort to the parts of a scene or input that are most relevant to their current goals or tasks (Mnih et al., 2014). As children grow, their ability to sustain

attention improves, supporting more complex tasks like problem-solving and learning new words (Simmering et al., 2010).

Attention and perception are deeply intertwined with how young children acquire language, interpret speech, and process visual information. For instance, children use attention to focus on a caregiver's voice in a noisy environment or to track the movement of an object, enhancing their ability to form connections between sensory input and meaning. Inspired by these mechanisms, machine learning models have incorporated attention-like processes to prioritize key features in data, echoing how children focus on salient aspects of their world to build understanding and learn effectively.

1.10.4.4 Memory and Information Processing

The ability of the human mind to store, retrieve, and process information is a cornerstone of their cognitive development. One intriguing aspect of this process is the interplay between conscious and unconscious mental mechanisms. During early childhood, the "cognitive unconscious" plays a vital role in shaping perceptions, memories, and emerging thought patterns. Young children often rely on intuitive, automatic processes to navigate their environments, such as recognizing familiar faces or learning simple routines, which occur largely outside conscious awareness (Kihlstrom, 1987).

However, as our understanding of cognition has evolved, it has become clear that the human mind is not a simple information-processing machine, but a complex system with multiple interconnected components. In young children, the distinction between "System 1" and "System 2" processes becomes particularly relevant. System 1 encompasses the intuitive, automatic responses that dominate early childhood, such as implicit learning of language or categorizing objects based on repeated exposure. In contrast, System 2 represents the deliberate, effortful processes, which emerge gradually as children's cognitive capacities expand, enabling them to solve problems or make reasoned decisions (Dodig-Crnkovic, 2021). This dynamic interaction between unconscious and conscious processes underscores the sophistication of the young mind and its remarkable ability to adapt and grow through early experiences.

1.10.4.5 Encoding and Retrieval in Information Processing

Two important components of the information processing are the encoding and the retrieval of information (Brayadi et al., 2022). The encoding stage, involves the conversion of external stimuli into a form that can be stored and represented within the brain. This stage is influenced by various factors, such as the individual's speech environment and memory capacity. The storage of encoded

information is another critical aspect of the information processing framework. The hippocampus, a region deep within the temporal lobe, receives inputs from various association areas in the neocortex and facilitates the storage of multimodal information. The interplay between the hippocampus and the neocortex allows for the integration and consolidation of diverse sensory inputs, laying the groundwork for the formation of long-term memories.

The final stage, retrieval, involves the ability to access and utilize the stored information when needed. This stage is influenced by factors such as the strength of the initial encoding, the availability of relevant cues, and the individual's cognitive capacity to navigate their internal information landscape. Studies based on the information processing theory, have provided scientists with valuable insights into the ways in which individuals perceive, store, and retrieve information (Pisoni, 2000).

1.10.4.6 Knowledge Representation in Information Processing

A significant area of study in the field of psychology is the concept of knowledge representation, which plays a critical role in the cognitive development of young children. Knowledge representation refers to the cognitive structures and processes that enable individuals to organize, store, and manipulate information about the world around them (Delgrande et al., 2023).

Cognitive structures such as schemas, scripts, and mental models begin to form early and evolve through interactions with their environment. Schemas, for example, allow children to categorize objects (e.g., all four-legged animals as "dogs") and adjust these categories through experiences, a process known as schema accommodation. These structures are built through active engagement with their surroundings, as children transform raw sensory input into generalized, schematic frameworks that help them interpret and predict the world around them.

The organization of these cognitive structures significantly impact how individuals perceive, remember, and reason about information (Punchyk, 2019). For example, research has shown that experts in a particular domain tend to have more highly organized and interconnected cognitive structures compared to novices, which can lead to more efficient information processing and problem-solving abilities.

An equally important aspect of knowledge representation in young children is the role of the cognitive unconscious. Non-conscious mental processes influence much of children's early judgments and decisions, often guiding them in ways they cannot explicitly articulate. For instance, implicit learning mechanisms enable children to pick up on patterns in language or social behavior, shaping

their thoughts and actions without their conscious awareness. These unconscious processes, while less visible, are foundational to the early development of complex cognitive abilities and the refinement of their knowledge representation systems.

1.10.4.7 Problem Solving and Decision Making

The information processing theory provides valuable insights into the cognitive mechanisms underlying problem-solving and decision-making processes. This approach emphasizes the sequential operations and "stages of processing" involved in various cognitive tasks (Heppner & Krauskopf, 1987). These stages, while simpler and less efficient in children compared to adults, are foundational to the gradual development of advanced cognitive skills.

In young children, information processing models trace how perceptual and cognitive processing unfolds over time, offering a quantitative account of how they approach and resolve problems. For example, when solving a puzzle or deciding between play activities, children often rely on trial-and-error methods, which reflect the early stages of developing structured problem-solving strategies. Their decisions are influenced by working memory limitations and an emerging ability to filter distractions, highlighting the importance of external scaffolding and supportive environments in guiding their problem-solving processes.

The traditional models of problem-solving and decision-making often assume a fixed range of possibilities from which the best option can be chosen, but in dynamic environments, both the relevant options and the criteria for decision-making are in flux, rendering formal optimization methods less useful. This is applicable especially in young children because they operate in highly dynamic environments where their knowledge, goals, and options are continually evolving. To address these challenges, researchers have proposed more flexible and adaptive approaches to problem-solving and decision-making, incorporating concepts of bounded rationality and the role of knowledge and strategies in task performance (Heylighen & Vidal, 2008; Lebière & Anderson, 2011).

1.10.4.8 Language Processing and Information Theory

One of the key aspects of language processing is the way in which individuals perceive and interpret linguistic stimuli. Information-processing theory suggests that this process involves a sequence of operations, from the initial sensory input to the final cognitive response. For young children, this process is influenced by their rapidly developing cognitive and neural systems, which enable them to extract meaning from speech patterns and integrate new vocabulary into their understanding of the world.

The intersection of language processing and information theory provides valuable insights into how children acquire language efficiently despite their limited cognitive resources. Neuroimaging studies have revealed the dynamic organization of language-related regions in the developing brain, highlighting how children's early neural networks adapt to support language acquisition. These findings inform the design of more effective teaching strategies, emphasizing the importance of repetition, interactive feedback, and multisensory learning during early childhood to optimize language development (Brayadi et al., 2022; Grandjean & Grandjean, 2007; Iranmanesh et al., 2021; Pisoni, 2000). By understanding how children process linguistic stimuli, researchers and educators can better support young learners as they build the foundational skills for communication and literacy.

1.10.4.9 Cognitive Load and Information Processing

Cognitive load theory states that the human mind has a finite capacity for information processing, and the efficient management of this capacity is crucial for effective learning and problem-solving. The theory suggests that memory has several components, with sensory memory collecting information from the environment and working memory serving as a temporary storage and processing unit. Working memory, however, has a limited capacity, and when it becomes overloaded, it can hinder the encoding of information into long-term memory, which has a virtually unlimited capacity (Van Merriënboer & Sweller, 2005).

Researchers have found that certain instructional approaches can contribute to an increase in cognitive load, leading to suboptimal learning outcomes. For example, complex problem-solving tasks or the presentation of information in a fragmented or disorganized manner can overload students' working memory, making it difficult for them to process and retain the critical information (Sweller et al., 2019). Additionally, the use of strategies such as worked examples, goal-free problem-solving, and the reduction of split-attention and redundancy can help mitigate cognitive load and enhance learning (Tuovinen, 2000).

1.10.4.10 Practical Implications of Information Processing Theory

Information Processing Theory has been pivotal in understanding the cognitive processes involved in speech perception and language learning, particularly in young children, where early developmental stages are critical for building foundational communication skills. By detailing how children encode and decode auditory signals, information processing models help inform the design of speech

recognition assessments and tailor rehabilitation programs that align with a child's developmental capabilities and learning trajectory.

Beyond speech perception, Information Processing Theory has also been extensively applied to the study of learning and education in young children. It helps explain how they collect, organize, and process new information, emphasizing the importance of strategies such as chunking, repetition, and multisensory engagement to enhance learning outcomes. For instance, early educational interventions inspired by this theory can be designed to scaffold children's memory and attention systems, making complex tasks manageable and promoting cognitive growth (Brayadi et al., 2022; Mayer, 1996). This theoretical lens provides a valuable foundation for developing adaptive tools and teaching methods that cater to the unique needs of young learners.

1.10.5 Bronfenbrenner's Ecological Systems Theory

Bronfenbrenner, influenced by the work of Vygotsky and Lewin, introduced this theory in the late 1970s, which has since become a widely adopted approach in the fields of psychology, social work, and education (Bronfenbrenner, 2000).

At the core of Bronfenbrenner's Ecological Systems Theory is the idea that an individual's development is shaped by a series of interrelated systems, ranging from the immediate family to the broader cultural and societal influences. The theory outlines five distinct, yet interconnected, environmental systems that impact an individual's growth and well-being: the microsystem, mesosystem, exosystem, macrosystem, and chronosystem (Bronfenbrenner, 2000).

The microsystem represents the immediate environment in which the individual lives, such as the family, school, or peer group. This system has the most direct and profound influence on the individual's development, as it involves the face-to-face interactions and relationships that shape the individual's experiences and behaviors (Crawford, 2020).

The mesosystem encompasses the interactions and connections between the different microsystems in an individual's life. For example, the relationship between a child's family and their school can have a significant impact on the child's development and well-being.

The exosystem refers to the larger social systems that indirectly influence the individual's development, such as a parent's workplace, the local community, or the media.

The macrosystem encompasses the broader cultural, political, and economic factors that shape the individual's development, such as societal values, beliefs, and norms.

Finally, the chronosystem represents the changes and transitions that occur over the individual's lifespan, including both normative and non-normative events.

The ecological systems theory supports that an individual's development is not solely determined by their personal characteristics, but also by the complex interplay between the various systems that surround them.

1.10.5.1 Microsystems and Individual Development

Bronfenbrenner's Ecological Systems Theory provides a comprehensive framework for understanding how these microsystems, such as family, school, and peer groups, shape the trajectories of individual development (Allen & Bowles, 2012; Bronfenbrenner, 2000; Brummelhuis & Bakker, 2012). The interaction between these microsystems, known as the mesosystem, also plays a crucial role in shaping the developmental outcomes of individuals (Bronfenbrenner, 2000; Brummelhuis & Bakker, 2012).

Microsystems, as described by Bronfenbrenner, are the most immediate and direct environments that impact an individual's growth and development (Bronfenbrenner, 2000; Brummelhuis & Bakker, 2012). These include the family, school, religious institutions, neighborhood, and peer groups, all of which exert a profound influence on the individual's behaviors, attitudes, and overall well-being. The quality of the interactions and relationships within these microsystems can have a lasting impact on an individual's social, emotional, and cognitive development (Brummelhuis & Bakker, 2012).

1.10.5.2 Mesosystems and Interpersonal Relationships

Bronfenbrenner's model emphasizes the significance of mesosystems, which refer to the interconnections between different microsystems, such as the family and school, that collectively shape an individual's development (Bronfenbrenner, 2000).

For instance, a positive relationship between a child's family and school can foster a sense of consistency and support, enabling the child to develop healthier peer relationships and a stronger sense of identity. Conversely, a disconnection or conflict between these microsystems may lead to emotional and behavioral challenges, affecting the child's ability to form and maintain meaningful interpersonal connections (Brummelhuis & Bakker, 2012).

Furthermore, the mesosystem can also be influenced by broader exosystems, such as a parent's workplace experiences or community resources, which can indirectly impact the quality of interpersonal relationships within the child's immediate environment. Immigrant families, for

example, may face unique challenges within their mesosystems, as their cultural values and practices may differ from the dominant societal norms, potentially leading to conflicts and strained interpersonal relationships (Brummelhuis & Bakker, 2012; Crawford, 2020).

1.10.5.3 Exosystems and Environmental Influences

Exosystems are the settings and social structures that indirectly impact an individual's development, even though the individual may not be an active participant within them (Bronfenbrenner, 2000). For example, a child's experiences at home may be significantly influenced by their parent's workplace environments and the demands placed upon them, despite the child not being directly involved in their parent's professional lives.

Studies have demonstrated that factors such as parental job stress, community resources, and societal policies can all exert a profound influence on a child's wellbeing, academic performance, and overall psychos-social functioning (Crawford, 2020). The education system, too, is an exosystem that can shape a child's development, as the experiences, resources, and policies within the broader educational context can significantly impact a student's learning and growth.

1.10.5.4 Macrosystems and Cultural Factors

Another crucial component of Bronfenbrenner's theory is the concept of the macrosystem, which encompasses the overarching cultural, political, economic, and social ideologies that permeate an individual's life (Bronfenbrenner, 2000). These macrosystemic influences can have profound effects on the development and lived experiences of individuals, as they shape the beliefs, values, and norms that are transmitted through various societal institutions and structures.

The macrosystem, as Bronfenbrenner envisioned it, is not a static entity, but rather a dynamic and ever-evolving system that both influences and is influenced by the individuals and subsystems within it (Brummelhuis & Bakker, 2012). For example, the cultural values and beliefs surrounding gender roles, family structures, and educational priorities can significantly impact the developmental trajectories of children and adolescents, shaping their opportunities, expectations, and life choices. Similarly, the broader political and economic conditions of a society can create disparities in access to resources and support systems, ultimately affecting the well-being and development of individuals from different socioeconomic backgrounds.

Bronfenbrenner's theory also emphasizes the importance of understanding the interplay between the macrosystem and the other nested systems, such as the microsystem and the mesosystem (Brummelhuis & Bakker, 2012; Crawford, 2020).

1.10.5.5 Chronosystems and Temporal Dimensions

One critical dimension that Bronfenbrenner later incorporated into his framework is the concept of the chronosystem, which underscores the significance of time and temporal factors in shaping an individual's development.

The chronosystem encompasses the patterning of environmental events and transitions over the life course, as well as sociohistorical circumstances. It recognizes that an individual's development is not isolated from the broader historical and societal contexts in which they are embedded. As Bronfenbrenner's theory evolved, he placed increasing emphasis on the role of proximal processes – the enduring forms of interaction between the organism and its environment – and how these processes are affected by the passage of time (Johnson, 2008).

The introduction of the chronosystem dimension highlights Bronfenbrenner's acknowledgment that human development cannot be fully understood without considering the temporal and historical factors that shape the individual's experiences. This includes the impact of significant life events, such as family transitions, changes in socioeconomic status, or broader societal shifts, all of which can profoundly influence an individual's developmental trajectory.

1.10.6 Theory of Multiple Intelligences

The theory of multiple intelligences, developed by the renowned psychologist Howard Gardner, challenges the traditional view of intelligence as a single, unitary concept based on academic performance or IQ scores. Instead, Gardner proposed that there are multiple forms of intelligence, each with its own unique characteristics and capabilities.

One of the key aspects of Gardner's theory is the recognition that individuals possess different strengths and weaknesses in various areas of intelligence (Alaa'Shdefat et al., 2020). This has led to the idea that instruction should be designed to cater to the diverse learning needs of students, rather than a one-size-fits-all approach (Gardner & Hatch, 1989; Helding, 2009).

1.10.6.1 Rethinking Traditional Intelligence Measures

Traditional measures of intelligence, such as Intelligence Quotient tests, have long been the dominant method for evaluating an individual's cognitive abilities, but they have increasingly come under scrutiny as researchers and scholars question their validity (Hochberg, 2023; Marsh & Iran-Nejad, 1992).

One of the primary criticisms of traditional intelligence measures is that they tend to be heavily weighted towards certain types of logical and analytical abilities, while neglecting other important aspects of intelligence (Hochberg, 2023). For instance, emotional intelligence, which refers to the ability to recognize, understand, and manage one's own emotions as well as those of others, is often overlooked in standard IQ tests. This type of "emotional unintelligence" can have significant implications for an individual's ability to effectively navigate social situations, maintain healthy relationships, and achieve personal and professional success (Gardner, 1987).

There is growing evidence that emotional intelligence, or EQ, may be a more reliable predictor of success than traditional IQ. Studies have shown that EQ can contribute up to 80% of an individual's success, compared to only 20% for IQ. Moreover, emotional intelligence has been linked to effective leadership, as leaders with high EQ are better able to connect with and motivate their teams, manage conflicts, and adapt to changing circumstances (Sternberg, 2018).

In addition to emotional intelligence, a focus on more traditional markers of intelligence, such as rationality, problem-solving, and analytical reasoning, may neglect other important cognitive abilities, such as creativity, adaptability, and social skills. These skills are increasingly valuable in a rapidly changing and interconnected world, where the ability to think outside the box, collaborate with others, and navigate complex social dynamics can be just as important as raw cognitive ability.

As a result, there is a growing call to rethink traditional intelligence measures and to develop more comprehensive and nuanced approaches to evaluating cognitive abilities (Sternberg, 1999).

Gardner's theory of multiple intelligences suggests that traditional academic settings, which often emphasize linguistic and logical-mathematical abilities, may not adequately recognize or nurture the diverse range of intelligences present in students (Gardner & Hatch, 1989). By designing curriculum, instruction, and assessment strategies that cater to multiple intelligences, educators can create more inclusive and enriching learning environments, allowing students to thrive in the areas where they are most gifted.

1.10.6.2 Exploring Diverse Intellectual Abilities

Neuroscience has supported the idea of multiple intelligences, as research has identified distinct neural regions associated with various cognitive processes (Shearer, 2018). This suggests a biological basis for the notion that individuals may excel in specific areas of intellectual functioning, rather than possessing a monolithic form of intelligence. Educators, in turn, have embraced the multiple

intelligences framework, recognizing the need to expand their repertoire of teaching methods and strategies to cater to diverse learners (Alaa'Shdefat et al., 2020).

The concept of naturalistic intelligence, in particular, has gained attention in the context of biology education. Naturalistic intelligence refers to the cognitive capacity to observe, understand, and engage with the natural world, a skill set that is crucial for scientific exploration and conservation efforts.

1.10.6.3 Linguistic Intelligence and Language Processing

Cognitive linguistics has emerged as a prominent field in understanding the relationship between language and the human mind (Croft & Cruse, 2004). Linguistic intelligence, as a construct within the theory of multiple intelligences, suggests that individuals possess unique capabilities in processing and manipulating language. This perspective emphasizes the cognitive and social dimensions of language, moving beyond the traditional focus on grammatical competence. Cognitive linguists have shown that meaning is not inherent within language itself, but rather accessed through the general cognitive processes that allow the human mind to conceptualize experience (Freeman, 2003). This "embodied understanding" highlights the role of analogical reasoning in linguistic phenomena, such as metaphor and metonymy, which have been challenging for logic-oriented theories of meaning (Freeman, 2003).

1.10.6.4 Logical-Mathematical Intelligence and Analytical Thinking

Psychological research has long recognized the importance of logical-mathematical intelligence, which encompasses the ability to reason, analyze, and solve problems in a systematic and structured manner (Qadar et al., 2021). This type of intelligence is closely linked to analytical thinking, a cognitive process that involves breaking down complex information, identifying patterns, and drawing logical conclusions (Bao et al., 2021).

The connection between logical-mathematical intelligence and analytical thinking is well-established in the field of psychology. Researchers have found that individuals with a strong aptitude for logical-mathematical reasoning tend to excel at tasks that require critical analysis, problem-solving, and decision-making. This is because the cognitive skills involved in mathematical and analytical thinking, such as attention to detail, pattern recognition, and abstract reasoning, are often complementary and mutually reinforcing.

Moreover, studies have shown that the development of logical-mathematical intelligence and analytical thinking can be fostered through targeted educational interventions, such as the use of

model problem-based learning in mathematics instruction. By engaging students in hands-on problem-solving activities that challenge them to think critically and logically, educators can help cultivate the cognitive skills that are essential for success in a wide range of academic and professional domains.

Ultimately, the relationship between logical-mathematical intelligence and analytical thinking in psychology highlights the importance of nurturing these cognitive abilities in individuals, as they contribute to the development of critical thinking skills, decision-making capabilities, and problem-solving expertise (Bao et al., 2021; Suryawan et al., 2023; Syafril et al., 2020; Zulkarnain et al., 2020).

1.10.6.5 Spatial Intelligence and Visual-Spatial Reasoning

Spatial intelligence and visual-spatial reasoning play a significant role in various domains, from academic achievement to everyday problem-solving. Spatial cognition encompasses our capacity to process and integrate spatial aspects of our environment, including the analysis of external multisensory information and the manipulation of mental imagery. This review examines the current understanding of spatial intelligence and its underlying neural correlates, as well as its importance in educational and professional contexts.

Spatial cognition is primarily facilitated by the parietal cortex, a brain region that integrates diverse sensory inputs to construct a coherent representation of space (Sack, 2009). Individuals with strong spatial abilities demonstrate enhanced performance in tasks involving object recognition, mental rotation, and spatial navigation (Malanchini et al., 2020). Brain imaging studies have shown that the parietal cortex is activated during a wide range of spatial tasks, suggesting a unitary neural mechanism underlying various spatial skills.

Spatial abilities have been linked to positive developmental, educational, and career outcomes. Individuals with strong spatial skills are more likely to excel in science, technology, engineering, and mathematics fields (Malanchini et al., 2020).

1.10.6.6 Bodily-Kinesthetic Intelligence and Physical Aptitude

Bodily-kinesthetic intelligence refers to the ability to use one's body and physical skills in a highly coordinated and expressive manner. This form of intelligence is often associated with individuals who excel in various physical domains, such as athletes, dancers, and craftspeople, in activities that require fine motor skills, coordination, and a keen awareness of their body's movements and positioning (Daing & Sinocruz, 2022). These individuals often discover information and gain

knowledge through an active, "hands-on" approach, interacting with the physical world in a way that allows them to develop a deep understanding of their own physical capabilities.

Researchers have explored the impact of bodily-kinesthetic intelligence on various aspects of physical performance and academic achievement. For instance, studies have shown that students with strong bodily-kinesthetic intelligence tend to have better study habits and scholastic performance, particularly in subjects that require a physical component, such as physical education. Additionally, the concept of "employability" has been linked to the possession of various forms of intelligence, including bodily-kinesthetic intelligence, as employers often seek individuals with a diverse set of skills and abilities.

1.10.6.7 Musical Intelligence and Rhythmic Abilities

It is well-established that musical abilities are multifaceted, encompassing various cognitive and perceptual skills (Stollery & McPhee, 2002). One particularly intriguing aspect of musical intelligence is its connection to rhythmic abilities. Research has shown that the ability to accurately perceive, internalize, and reproduce rhythmic patterns is a core component of musical aptitude.

Interestingly, the relationship between rhythmic skills and musical intelligence appears to be bidirectional. Studies have demonstrated that individuals with strong rhythmic abilities tend to also exhibit higher levels of musical intelligence, as measured by their performance on various musical tasks (Mertoglu, 2010). Conversely, individuals with greater musical intelligence have been found to possess more advanced rhythmic skills (Stollery & McPhee, 2002).

One possible explanation for this link lies in the shared neural substrates underlying rhythm perception and music processing. Both rhythmic and musical abilities rely on the integration of sensory, motor, and cognitive processes, suggesting that they may be underpinned by common neurological mechanisms.

Moreover, research has suggested that the development of rhythmic abilities during childhood may have a significant impact on the acquisition of mathematical skills. This relationship highlights the broader cognitive benefits that may arise from cultivating rhythmic and musical competencies, particularly in the early stages of development.

1.10.6.8 Interpersonal Intelligence and Social Competence

Interpersonal intelligence and social competence encompass an individual's ability to navigate social situations, empathize with others, and effectively communicate and collaborate. From a broader

societal perspective, interpersonal intelligence and social competence play a crucial role in fostering healthy relationships, productive workplaces, and inclusive communities (Park et al., 2017).

Emotional and social intelligence competencies are crucial determinants of effective performance among managers, leaders, and professionals (Boyatzis, 2011). These competencies enable individuals to sense and understand the needs of customers and employees, manage the emotional labor of their subordinates, and create a positive emotional climate in the workplace (Sadiku et al., 2019). Researchers have found that people in positions of power can "infect" others with their emotional state through the contagion of emotion, underscoring the importance of these competencies in work and social settings.

Classroom teachers, in particular, require a high level of social intelligence, as it helps them anticipate the future behavior of students and employ effective classroom discipline management strategies.

The development of interpersonal intelligence and social competence is not limited to the workplace and academic settings. Longitudinal studies have shown that these competencies can be cultivated sustainably, with significant improvements observed over time. The process of acquiring and applying social-emotional competence is recognized as an integral part of education and human development, and is defined as social-emotional learning (Martinsone et al., 2022).

Key intrapersonal and interpersonal skills that build social-emotional competence include self-awareness, self-management, social awareness, relationship skills, and responsible decision-making. These skills are important in different aspects of life, and they are the best traits to invest in to develop well-being and mental health, moral reasoning, academic performance, and achievement motivation (Boyatzis, 2011; Martinsone et al., 2022; Park et al., 2017).

1.10.6.9 Intrapersonal Intelligence and Self-Awareness

Intrapersonal intelligence is the capacity to understand oneself and one's thoughts and feelings (Caprara & Cervone, 2000). This form of intelligence allows individuals to shape their life circumstances and influence the course of their personal development, as they are able to draw upon their self-knowledge and self-awareness to guide their actions and decisions. Self-efficacy beliefs, for instance, emerge from the interplay between self-referent and situational knowledge, fostering cross-situational coherence in one's appraisal of their capabilities.

Research in psychology has highlighted the centrality of self-referent activities in the causal processes that govern human behavior and experience (Bandura, 1989). Self-generated activities not

only contribute to the meaning and valence of external influences, but also function as important proximal determinants of motivation and action. Consequently, the exploration of the properties, functions, and adaptive significance of the non-consciously generated, self-referential psychological content of the personal narrative has become an area of growing interest.

Contrary to the traditional view that personal awareness and conscious control are the defining features of the self, recent theoretical perspectives have proposed that it is the capacity to share the contents of the non-consciously generated personal narrative stream, rather than personal awareness per se, that confers an evolutionary advantage (Oakley & Halligan, 2017). The ability to selectively communicate ideas, knowledge, and strategies from our internal experiences can underpin the development of socially adaptive behaviors.

1.10.6.10 *Naturalist Intelligence and Environmental Sensitivity*

One form of intelligence is naturalist intelligence - the cognitive potential to process information exhibited by expert naturalists (Hayes, 2009). Naturalist intelligence encompasses the ability to recognize and categorize elements of the natural world, such as plant and animal species, as well as the capacity to observe and understand natural phenomena (McQuaid & Lindsay, 2005). This form of intelligence is closely tied to an individual's sensitivity to and appreciation for the environment. Individuals with a strong naturalist intelligence may be more attuned to the nuances of the natural world, enabling them to better comprehend the complex relationships and interdependencies within ecosystems. This heightened environmental awareness can translate into a greater sense of responsibility and a deeper commitment to conservation efforts.

The concept of naturalistic intelligence, in particular, has the potential to inform the design of undergraduate biology curricula, as it emphasizes the need for well-rounded scientific naturalists who can observe, understand, and engage with the natural world (Malatesta & Quintana, 2006). Fostering naturalistic intelligence in undergraduate biology students can be achieved through various strategies. First, curricula should involve outdoor, inquiry-based projects that immerse students in the natural environment and encourage them to develop keen observational skills. Second, students should be taught to learn how to observe both the natural world and their own learning processes, as these skills are essential to developing expert naturalistic knowledge. By cultivating these abilities, undergraduate biology programs can produce graduates who are not only knowledgeable in their field but also possess a deep appreciation and sensitivity for the environment.

In a study exploring the development of naturalist interest, researchers found that this interest often emerges from a confluence of experiences across the learning ecology, including school, family, and out-of-school learning. The researchers highlight the importance of providing children and youth with opportunities to engage with nature, both independently and under the guidance of experts in fields such as natural history, ecology, and conservation biology. This multifaceted approach to fostering naturalist interest and intelligence can have far-reaching implications for environmental stewardship and conservation efforts.

As humanity grapples with the challenges of the Anthropocene, the need for a populace with strong naturalist intelligence and environmental sensitivity becomes increasingly critical (Hayes, 2009; Hecht et al., 2019).

1.10.6.11 *Existential Intelligence and Philosophical Contemplation*

Existential intelligence and philosophical contemplation encompasses the individual's ability to ponder the fundamental questions of existence, grapple with the paradoxes of life, and navigate the anxieties that often accompany the human experience. Existential intelligence is closely tied to the philosophical tradition of existentialism, which emphasizes the importance of subjective, individual meaning-making. This approach to education and personal growth encourages individuals to confront the harsh realities of life, such as death, rejection, and loneliness, and to forge their own path in the face of these challenges.

The educational implications of this existential approach are profound. As noted in one study, "the teacher has the research task of adequately assessing the value-semantic boundaries of the educational space, taking responsibility for organizing actions and recognizing oneself as a subject of a person who, through actualization experience, goes back to personal and professional growth" (Berberyan, 2019). By fostering an environment that encourages self-awareness, personal truth, and the recognition of one's own voice, educators can help students develop the skills necessary to navigate the complexities of the human condition.

Existentialist education is grounded in the notion that individuals must take responsibility for their own lives and choices. This approach challenges the traditional didactic model of education, where the teacher is the sole purveyor of knowledge, and instead emphasizes the importance of self-discovery and the active engagement of the learner. As one philosopher notes, the aim of existentialist education is "to 'awaken awareness in the learner-existential awareness of himself as a simple subjectivity present in the world'".

The development of existential intelligence requires a willingness to confront the paradoxes and anxieties that are inherent to the human experience. This can be a challenging and often uncomfortable process, as it requires individuals to question their assumptions, beliefs, and values. However, by engaging in this process of self-reflection and meaning-making, individuals can cultivate a deeper sense of purpose and a more authentic understanding of their place in the world.

1.10.6.12 *Integrating Multiple Intelligences Theory with Cognitive Psychology*

The integration of Multiple Intelligences Theory and Cognitive Psychology holds great potential in enhancing our understanding of human cognition and learning (Malatesta & Quintana, 2006). This notion of diverse cognitive abilities challenges the traditional view of intelligence as a unitary construct, and aligns with emerging evidence from Neurobiology suggesting the presence of specialized brain regions corresponding to different modes of information processing.

Cognitive Psychology, on the other hand, focuses on the underlying mental processes that govern our perception, learning, memory, and problem-solving abilities. By synthesizing these two complementary frameworks, researchers can gain deeper insights into the complex interplay between the brain's structural and functional organization, and the various ways in which individuals acquire, store, and apply knowledge (Malatesta & Quintana, 2006; Shearer, 2018).

One key area of intersection lies in the concept of embodied cognition, which suggests that our cognitive processes are inextricably linked to our physical experiences and emotional states (Shearer, 2018). This aligns with Multiple Intelligences Theory's emphasis on the importance of bodily-kinesthetic and interpersonal intelligences, which are often overlooked in traditional educational settings (Hayes, 2009). By incorporating activities and teaching methods that engage these "non-academic" intelligences, educators can create more holistic learning environments that cater to the diverse strengths and preferences of their students.

Additionally, the notion of "make it mean something" in Multiple Intelligences Theory, which emphasizes the importance of connecting learning to personal relevance and significance, resonates with Cognitive Psychology's findings on the role of motivation, context, and meaning-making in effective learning.

Moreover, the idea of "every brain is unique" in Multiple Intelligences Theory is echoed in Cognitive Psychology's recognition of individual differences in cognitive abilities and learning styles. By embracing the synergies between these two frameworks, educators and researchers can develop

more comprehensive and effective strategies for nurturing the full spectrum of human cognitive potential.

1.10.7 Bruner's Theory of Representations

Bruner's theory of representations, formulated by the renowned psychologist Jerome Bruner is based on the notion that humans possess three distinct modes of representation: enactive, iconic, and symbolic (Bruner, 2021; Conway, 2007; Rowland, 1968). The enactive mode of representation involves the use of physical actions and movements to represent and interact with the environment. This mode is typically observed in young children, who rely on hands-on experiences and bodily engagement to explore and comprehend their surroundings. As individuals develop, they transition to the iconic mode, which utilizes visual and spatial representations, such as diagrams, images, and mental models, to organize and communicate their understanding of concepts (Derry et al., 2014). The final mode, known as the symbolic mode, encompasses the use of language, numbers, and other abstract systems to represent and manipulate information.

Bruner's theory is closely aligned with the findings of cognitive research, which suggest that text representation is a multilevel process. Readers not only encode the precise, verbatim form of a text but also construct a network of the propositions or ideas conveyed by the text, as well as the situations to which the text refers. Additionally, representation has been identified as a practical strategy in problem-solving, as it allows individuals to organize, record, and communicate mathematical ideas, as well as model and interpret problems using multiple representations (Rahmah et al., 2019).

1.10.7.1 Cognitive Development and Representations

The three distinct modes of representation according to Bruner are not static, but rather, they evolve and interact with one another as individuals progress through the stages of cognitive development (Rabindran & Madanagopal, 2020). Bruner argued that the ability to move between these different forms of representation is crucial for effective learning and problem-solving.

In addition to the concept of representations, Bruner's theory also emphasizes the importance of the individual's active role in the learning process. Constructivist learning theory, which Bruner's work has significantly influenced, posits that individuals construct their own understanding of the world through their experiences and interactions with their environment.

Bruner's ideas have had a significant impact on the field of education, with his emphasis on the active, constructive nature of learning leading to the development of "process curricula" that

focus on the development of cognitive skills and problem-solving abilities, rather than the simple transmission of information (Cole, 1969).

1.10.7.2 Enactive, Iconic, and Symbolic Representations

The enactive mode, which is the first mode of Bruner's theory, involves representing the world through physical actions and bodily engagement, allowing individuals to interact with their environment in a hands-on, experiential manner (Furth, 1967). This mode is fundamental to early childhood development, as children learn about the world through their senses and by manipulating objects directly.

In contrast, the iconic mode relies on visual or spatial representations, enabling individuals to form mental images and utilize visual-spatial thinking to understand and communicate about their experiences (Mills et al., 2022). This mode allows for more abstract reasoning and problem-solving compared to the enactive mode, as individuals can mentally represent and manipulate information without direct physical interaction.

The symbolic mode, the third mode of Bruner's theory, represents the most advanced form of representation, as it is characterized by the use of language and other abstract symbol systems to represent and manipulate information in an abstract, conceptual way. This symbolic mode allows individuals to engage in higher-order cognitive processes such as abstract thinking, reasoning, and problem-solving, transcending the more concrete and perceptual modes of representation.

By progressing through these three modes, human cognition becomes increasingly flexible, adaptable, and capable of engaging with complex ideas and concepts.

1.10.7.3 Representation and Conceptual Understanding

Bruner's theory of cognitive development emphasizes the role of representation in the formation of conceptual understanding. The process of moving between these three modes of representation is crucial for the development of conceptual understanding. By engaging with the environment through physical actions, constructing mental images, and using symbolic representations, individuals can develop a deeper and more comprehensive understanding of the concepts they are learning.

The importance of representation in conceptual understanding is further supported by research on memory and discourse processing (Singer, 2017). Cognitive theories suggest that readers and learners encode information at multiple levels, including the precise verbatim form of the text, the underlying propositions or ideas, and the situations to which the text refers. This multilevel representation of information allows for more effective retrieval and comprehension.

Furthermore, research on mathematical representation has highlighted the significance of using various forms of representation, such as symbols, graphs, and diagrams, in facilitating conceptual understanding. By encouraging students to construct their own representations of mathematical concepts, rules, and relationships, educators can help them develop a deeper understanding of the underlying ideas.

1.10.7.4 Representation and Educational Technology

Enactive representation involves physical action, iconic representation utilizes visual imagery, and symbolic representation relies on abstract language and mathematics. The effective use of educational technology necessitates consideration of these representational modes. Technological tools can facilitate the translation between these modes, enabling students to engage with content in diverse, meaningful ways. For instance, interactive simulations can provide enactive experiences, while multimedia presentations can leverage iconic and symbolic representations.

Bruner's framework also underscores the importance of scaffolding and sequencing content to support students' cognitive development. Thoughtful integration of technology can enable this progression, guiding learners from concrete to more abstract forms of representation.

Furthermore, emerging technologies such as virtual reality, augmented reality, and 3D platforms hold promise for creating immersive, experiential learning environments that align with Bruner's enactive mode (Araújo, 2019). By allowing students to actively manipulate virtual objects and scenarios, these technologies can foster deeper understanding and knowledge construction (Harmes et al., 2016; Onyango & Gitonga, 2017).

1.10.7.5 Influence of Bruner's Theory on Education

Bruner's theory of cognitive development has had a profound impact on the field of education, shaping the way educators approach teaching and learning. Bruner's theory emphasizes the importance of discovery-based learning, where students actively engage in the learning process and construct their own understanding of concepts (Takaya, 2008).

Bruner's model of instruction has been instrumental in the development of various instructional strategies and frameworks (An, 2021). The emphasis on discovery-based learning is particularly evident in Bruner's work, where he defines instruction as "leading the learner through a sequence of statements and restatements of a problem or body of knowledge that increases the learner's ability to grasp, transform, and transfer what he is learning" (Frew & Klein, 1982). This approach

contrasts with the traditional, more passive approach to learning, where the teacher simply transmits information to students.

Bruner's theory has also influenced the development of the spiral curriculum, which is designed to revisit key concepts repeatedly, allowing students to build upon their understanding over time. This approach aligns with Bruner's belief that helping students gain a firm foundation in primary concepts early on can lead to more effective learning and deeper understanding later in their studies.

Moreover, Bruner's theory has had implications for the development of teacher education programs, as it highlights the importance of considering teachers' personal knowledge and belief systems. This is particularly relevant in the context of educational reforms, where the failure to account for teachers' existing beliefs and experiences can hinder the successful implementation of new instructional approaches (An, 2021; Frew & Klein, 1982; Kleine & Smith, 1989; Warr, 2004).

1.10.8 Papert's Constructionism: Building Cognitive Structures

Papert's theory of constructionism (Papert, 1973, 1984, 1996), which emerged as an extension of Jean Piaget's constructivism, offers a powerful framework for understanding how individuals construct knowledge and develop cognitive structures (Alanazi, 2016). Constructivism, at its core, states that learners are active agents in the process of learning, constructing their own understanding of the world through interaction with their environment and prior experiences (Ültanır, 2012). Papert took this idea a step further, emphasizing the importance of the learner's active engagement in the creation of tangible artifacts, such as computer programs or physical models, as a means of fostering deep learning and the development of cognitive structures. By actively creating and manipulating these artifacts, learners are able to explore, experiment, and engage with the subject matter in a more meaningful and immersive way, leading to a deeper understanding and the formation of robust cognitive structures that can be applied to various contexts.

One of the key principles of Papert's constructionism is the idea that learning is a social and collaborative process, where learners engage in shared experiences and exchanges of ideas with their peers and mentors (Alanazi, 2016; Mascolo et al., 1998; Wu, 2021).

1.10.8.1 Developmental Stages and Cognitive Growth

Papert, a pioneer in the field of educational robotics, believed that when children could communicate with computing devices using their mathematical knowledge and skills, they would find learning more concrete and natural. One of the key aspects of Papert's approach was his emphasis on the importance of assimilation and accommodation in effective learning, similar to the work of Jean

Piaget (Rabindran & Madanagopal, 2020). Piaget's theory of cognitive development describes children as "natural scientists" who investigate the world and thereby broaden their understanding. However, Papert's work diverged from Piaget's in its greater emphasis on the role of the social and cultural context in shaping children's thinking (Smith, 1993).

Papert envisioned creating computing devices with which young learners could command and communicate using their mathematical knowledge and skills. This belief was rooted in Papert's view that learning to program a computer could fundamentally change the way other learning takes place. One of Papert's key concepts, known as "body syntonicity," suggested that the body should work in parallel with objects to illuminate powerful ideas (Peppler et al., 2023).

This idea of the body as part of the learning environment has been expanded upon in more recent work on "material syntonicity," which examines the new possibilities that emerge at the intersection of body syntonicity and the tools and materials used in learning (Peppler et al., 2023).

Papert's approach to educational robotics and computing has been further explored in a systematic review of the literature on developing computational thinking in young learners. This review suggests that robotics activities can be effectively adopted to develop computational thinking skills, and offers insights into effective curriculum design for these activities (Ching & Hsu, 2024).

1.10.8.2 Contributions to Cognitive Development

Papert believed that when children could communicate with a computing device using math, they would find math learning more concrete and natural (Papert, 1996). This idea, known as body syntonicity, takes into account the body as part of the constellation of materials in a learning environment by designing maps or parallels between the body and the objects being manipulated.

Papert's work has had a significant impact on the field of early childhood education, as evidenced by the paper "Early Childhood Educare: Seeking a theoretical framework in Vygotsky's work." The paper argues that Vygotsky's theory, which emphasizes the importance of the social and cultural context on children's thinking, should be given more consideration in early childhood education compared to Piaget's theory, which focuses more on the individual's cognitive development (Smith, 1993). Moreover, Papert's ideas have been influential in the field of educational robotics, as discussed in the paper "Educational Robotics for Developing Computational Thinking in Young Learners: A Systematic Review." (Ching & Hsu, 2024).

1.10.8.3 Papert's Perspective on Learning

Papert's approach stands in contrast to more traditional, "instructionist" models of education, where the focus is on the transmission of information from teacher to student (Efgivia et al., 2021a). Papert argued that such teacher-centered models fail to account for the subjective and socially-situated nature of learning. Instead, he advocated for learning environments that empower students to take an active role in their own education, exploring their interests and constructing personalized understandings (Pundir & Surana, 2016). Papert's perspective has had a significant influence on the field of educational technology, inspiring the development of tools and environments that enable learners to engage in hands-on, project-based activities (Ültanır, 2012).

Overall, Papert's constructionist learning theory offers a compelling alternative to traditional, teacher-centered models of education. By recognizing the active, subjective, and socially-situated nature of learning, Papert's perspective has the potential to transform the way we approach the education of the 21st century learner (O'Loughlin, 1992; Pundir & Surana, 2016; Sharkey & Gash, 2020).

1.10.8.4 The Importance of Play in Learning

At the heart of Papert's theory is the belief that children can learn and acquire knowledge more effectively through engaging in open-ended, exploratory play, rather than through traditional, didactic instruction. One of the key principles of Papert's theory is the idea that children learn best when they are given the opportunity to explore and experiment, without the fear of failure. This approach, known as "mathematical play," allows students to develop their own conjectures and hypotheses, which in turn lays the foundation for deeper mathematical learning. Papert's theory also highlights the significance of social interaction and collaboration in the learning process. Through play, children can engage in social pretend play, which not only promotes cognitive development but also fosters social competence, such as self-regulation and cooperation (Nicolopoulou et al., 2009).

However, implementing a play-based approach in the classroom can present certain challenges. As some studies have shown, factors such as inadequate resources, space constraints, uncertainty about the teacher's role, and insufficient knowledge and skills can hinder the successful enactment of play-based pedagogy (Khalil et al., 2022; Nicolopoulou et al., 2009). Despite these challenges, the transformative power of play in education remains a crucial aspect of Papert's theory. As Vygotsky and Vivian Paley have demonstrated, integrating play-based activities into the

curriculum can engage children's enthusiasm while also providing scope for their own initiative and creativity (Nicolopoulou et al., 2009).

1.10.8.5 Papert's Influence on Educational Technology

One of Papert's key contributions was the development of the Logo programming language, which allowed children to control and direct a virtual "turtle" on a computer screen (Papert, 1985; Solomon et al., 2020). This approach, known as "learning through programming," encouraged children to explore mathematical concepts through hands-on experimentation and problem-solving.

The use of educational robotics, for example, has been shown to be an effective means of developing computational thinking skills in young learners. Similarly, the integration of computer software into the teaching of initial reading and writing has been found to enhance student engagement and learning outcomes (Sahin & Özenç, 2021).

However, as Papert's work has been widely adopted, some critical perspectives have emerged. Researchers have noted the need to balance the emphasis on "learning to learn" with more traditional teaching methods, highlighting the potential for a problematic opposition between teaching and learning.

1.10.8.6 Microworlds: Simulated Learning Environments

Microworlds is a concept introduced by Papert. Microworlds are simulated environments that provide learners with a self-contained domain to interact with and explore, often through the lens of specific subject matter or skills (Fjællingsdal & Klöckner, 2017). One key aspect of microworlds is their ability to immerse learners in a highly interactive and engaging learning experience. Virtual reality based learning environments, in particular, have been leveraged to teach micro-systems related topics, enhancing the overall learning experience for students. As the power of personal computers and associated hardware has advanced, the graphical fidelity and realism of these simulated worlds have also improved, blurring the line between what is considered a traditional learning environment and what can be achieved through technology-aided education (Hamilton et al., 2020).

Microworlds are often described as promoting self-regulated learning, where learners are encouraged to obtain information and skills on their own volition, rather than being passive recipients of instruction (Hamilton et al., 2020). The potential of microworlds in education extends beyond traditional classroom settings. Websites such as Boardgamegeek.com have been established to allow individuals to review, trade, discuss, and chat about tabletop gaming, which can be considered a form of microworld that offers educational and learning opportunities (Fjællingsdal &

Klößner, 2017). In this context, educational games can be viewed as microworlds, where the high degree of immersion into the subject matter can contribute to the acquisition of knowledge and skills.

The use of virtual reality and other immersive technologies in the creation of microworlds has been a subject of growing interest in the field of education. Researchers have explored the acceptability and potential of the metaverse, a collective virtual space that combines virtual reality, augmented reality, and other emerging technologies, as a platform for educational experiences (Chua & Yu, 2024).

As the COVID-19 pandemic has accelerated the transformation of learning environments, the role of microworlds and metaverse-based educational experiences has become increasingly relevant. Educators and researchers have recognized the value of these simulated learning environments in providing engaging and immersive educational experiences, even in the face of physical distancing and remote learning requirements (López-Belmonte et al., 2023; Chua & Yu, 2024).

1.10.8.7 Papert's Vision for the Future of Education

Papert's vision for the future of education centered on the idea that computers could serve as powerful tools for learning, enabling students to engage in more interactive, personalized, and emotionally-driven educational experiences (Castellan, 1987). Papert believed that by harnessing the capabilities of computers and emerging technologies, educators could develop new pedagogical strategies that would better cater to the diverse needs and learning styles of individual students, allowing for more personalized and engaging learning experiences. This would empower students to take a more active role in their education, fostering deeper understanding and a greater sense of ownership.

Moreover, Papert envisioned a future where educational technology would transcend the traditional boundaries of the classroom, enabling students to connect with a global network of peers and resources. This vision of a more interconnected and collaborative learning environment would allow students to engage in problem-based learning, where they could tackle real-world challenges and develop critical thinking skills required in a rapidly changing world (Araújo, 2019; Hedley & Ellsworth, 1992; Motamedi, 2019).

Papert's ideas have gained significant traction in recent years, as educators and policymakers have increasingly recognized the potential of technology to transform the educational landscape. As the world continues to evolve, Papert's visionary perspective on the future of education remains highly relevant and influential (Araújo, 2019; Hamilton et al., 2020; Krug, 2004; Sahin & Özenc, 2021).

1.10.9 The Theory of Connectionism

According to the theory of connectionism, the human mind operates through a network of interconnected units, similar to the neural connections in the brain, rather than through a serial processing of information as in classical computational models (Walker, 1990). The connectionist approach emphasizes the importance of the brain's ability to learn and adapt through the strengthening and weakening of connections between these units, known as nodes or neurons. This dynamic process allows the mind to recognize patterns, encode memories, and engage in complex cognitive tasks without the need for a rigid, rule-based system.

One of the key aspects of connectionism is its emphasis on the role of associative learning, where the strength of the connections between nodes is modified based on the frequency and temporal proximity of their activation (Plunkett et al., 1997). Empirical research has provided strong support for the connectionist approach, with studies demonstrating the brain's ability to learn and represent information in a distributed and parallel fashion (Frankland & Bontempi, 2005). These findings have prompted a shift in cognitive science towards more biologically plausible models of the mind, with the goal of better understanding the underlying mechanisms of human cognition and learning.

1.10.9.1 Connectionist Approaches to Cognition

Connectionism has challenged the traditional view of the brain as a "serial" information processor, instead highlighting its ability to process information in a more parallel and distributed manner (Peterson, 1997). One of the significant contributions of the connectionist paradigm is its ability to account for the brain's remarkable capacity for learning and adaptation. This paradigm is particularly relevant to understanding cognitive development in young children, whose brains are highly plastic and adaptive during early developmental stages. Connectionist models have demonstrated how complex cognitive functions—such as language, memory, and problem-solving—can arise from the dynamic interactions of large numbers of simple processing units, without the need for pre-programmed symbolic rules. For example, these models have demonstrated how children can learn patterns, such as phonemic structures in language or the principles of object permanence, through repeated exposure and interaction with their environments.

In the context of young learners, connectionist theories align with developmental research emphasizing the importance of experiential learning and neural adaptation. Digital platforms and interactive tools that mimic connectionist processes, such as machine learning algorithms, are

increasingly being employed in educational settings to replicate this adaptive, distributed processing. These tools allow for tailored learning experiences, providing young children with opportunities to engage in exploratory problem-solving and iterative feedback loops that resemble the trial-and-error learning patterns inherent in connectionist systems. By modeling how young brains dynamically process and adapt to information, connectionism offers insights into designing educational interventions that nurture foundational cognitive skills in early childhood.

1.10.9.2 *Connectivism and Networked Learning*

Connectivism, as a learning theory, has gained significant attention in the digital age. Its emphasis on the importance of technological mediation in the learning process has made it particularly relevant in oppressed societies, where traditional educational models may be less accessible or effective (AlDahdouh, 2021). By leveraging digital tools and networks, learners in these contexts can engage in information-seeking behaviors that transcend geographical and political boundaries, opening up new avenues for knowledge acquisition and sharing.

Research has shown that connectivism can be effectively applied to diverse educational contexts, from writing pedagogy to professional development programs for English language instruction. In writing pedagogy, for example, connectivism can be used to facilitate international collaborations and intercultural learning, where students leverage digital tools and networks to engage in knowledge-sharing and problem-solving activities.

Similarly, in the context of professional development for English for Specific Purposes instructors, connectivism can inform the design of online learning environments that foster social interaction, collaborative problem-solving, and the co-construction of knowledge.

Connectivism, with its emphasis on the importance of networks, information flows, and the distributed nature of knowledge, offers a promising foundation for developing a more robust e-learning theory. Furthermore, it provides a valuable lens through which to explore developmental phenomena, such as Piagetian conservation, language development, and categorical reasoning in young children (Shultz, 1998). At its core, connectionism models cognitive processes as emergent from the dynamic interactions of simple processing units, akin to the neural connections in the brain. This framework aligns with how young children acquire and adapt cognitive skills through repeated exposure and interaction with their environments.

One particularly relevant example of connectionism's application is its ability to model phenomena like shape bias, as studied by Samuelson (Samuelson et al., 2008). Shape bias reflects a

developmental tendency in young children to generalize names of objects based on their shape, a behavior that emerges from the statistical regularities children encounter in their environment. Connectionist models, such as neural networks, can simulate this behavior by mapping repeated input patterns (e.g., shapes and object names) to output predictions (e.g., naming or categorization). Over time, these models demonstrate how exposure to consistent associations can lead to generalized biases, such as a preference for shape over other features like size or color.

1.10.9.3 Emergent Properties of Connectionist Networks

Connectionism, as a theoretical framework, offers a compelling account of how the brain's neural networks might give rise to the complex and multifaceted nature of perception and learning. Connectionist networks, also known as artificial neural networks, are computational models inspired by the structure and function of the human brain (Dodig-Crnkovic, 2021). These models consist of interconnected nodes, akin to neurons, that process and transmit information through weighted connections, reminiscent of synapses (Ramabaja, 2021). Connectionist models, inspired by this adaptive capacity, simulate how repeated interactions can strengthen or weaken connections between nodes, mirroring how children learn from reinforcement and feedback. For example, as children explore their world, they develop perceptual and cognitive abilities—such as recognizing shapes, understanding object permanence, or learning language—through the iterative strengthening of neural pathways. These processes parallel how artificial neural networks adjust their weights during training, offering a computational analogy for understanding cognitive development (Schlesinger & McMurray, 2012; Shultz, 2013).

Recent advancements in neural network architectures have been largely inspired by the functional organization of various regions in the brain, such as the visual cortex (Roberts et al., 2019). This is particularly relevant to young children, whose sensory and motor interactions with their environment play a critical role in shaping cognitive development. For instance, early visual processing in children involves identifying patterns, recognizing objects, and distinguishing features—tasks that artificial neural networks have been modeled to perform. Such models offer insights into how children integrate sensory information to form mental representations of their surroundings, supporting the development of key cognitive skills like spatial reasoning and conservation.

However, the field of deep neural networks has often overlooked the topological aspects of neuronal networks, which have been a subject of extensive research in the field of neuroscience.

Neuroscientific research into the developing brain suggests that the organization and plasticity of neural networks in young children differ significantly from those in adults. By incorporating these developmental principles, connectionist models could provide a more nuanced understanding of how children acquire and refine cognitive abilities over time.

The human brain supports a wide array of learning and memory systems, many of which are highly active and adaptable during early childhood. Some of these systems—such as procedural learning and associative memory—are well-understood, while others, like episodic memory development, remain areas of active research. Understanding these underlying principles can serve as a crucial blueprint for developing more sophisticated artificial intelligence systems. By aligning connectionist principles with the unique developmental trajectories of children's brains, researchers can enhance the design of adaptive educational technologies, creating tools that support learning in ways that mirror natural cognitive development.

1.10.9.4 Perception and Connectionism

The nature of perception is not solely dependent on the bottom-up processing of incoming sensory data, but is also profoundly influenced by top-down mechanisms reflecting an individual's past experiences and prior knowledge. This notion of perception as an inference process, rather than a direct translation of external stimuli, has gained significant traction in the field of psychology, with researchers drawing from the principles of Bayesian inference and estimation theory to develop more mathematically rigorous models of perceptual processing (Moutoussis, 2016).

The children's brains continuously integrate new information with existing mental models to refine their understanding of the world. Research into early visual development highlights a functional dichotomy within the brain's visual systems, with one pathway specialized for recognizing objects and patterns, while another supports motion detection and spatial awareness. For young children, the interplay between these pathways and the balance of bottom-up and top-down processes is crucial for tasks such as learning to identify shapes, navigating environments, and forming object permanence. Understanding this dynamic interplay provides valuable insights into how perception evolves during childhood, informing educational and developmental strategies that align with the unique characteristics of children's visual and cognitive systems.

1.10.9.5 Limitations and Criticisms of Connectionism

Connectionism, as a theoretical framework within cognitive psychology, has faced a range of criticisms and limitations that have been the subject of ongoing debate and discussion within the

field. Connectionist models have been criticized for their limitations in capturing the hierarchical and symbolic nature of human thought processes, which are essential for higher-order cognitive functions such as language, reasoning, and problem-solving (Frankland & Bontempi, 2005).

While connectionist models have shown promise in simulating certain aspects of learning and memory, they have struggled to replicate the abstract and generative capabilities of the human mind. Critics argue that the distributed and parallel processing approach of connectionism falls short in explaining the systematic and compositional nature of human cognition, which often involves the manipulation of abstract symbols and rules. This limitation has led some researchers to question the adequacy of connectionism as a comprehensive theory of human intelligence and to explore alternative frameworks that can better account for the complexity of human cognitive abilities.

Another criticism of connectionism is its perceived inability to adequately capture the role of conscious and unconscious mental processes in human cognition. Connectionist models have been criticized for their focus on the automatic and implicit aspects of cognition, which can neglect the important role of conscious deliberation, reasoning, and metacognitive processes in human decision-making and problem-solving (Piccinini & Scarantino, 2011).

As the field of cognitive science continues to evolve, the debate between proponents of connectionism and classical information-processing models remains an active area of research and discussion.

1.10.10 Social Cognition and Mental States in Children

Research suggests that the development of social cognition, which encompasses processes like understanding others' emotions, perspectives, and intentions, begins early in life and undergoes significant changes throughout childhood. Infants demonstrate an emerging grasp of intentionality and others' intentions, which further develops during the preschool years with the emergence of metarepresentation - the ability to understand that others have their own thoughts, beliefs, and desires that may differ from one's own (Callanan et al., 1993).

The mapping of young children's growing comprehension of the links between people's mental states, such as desires and beliefs, and their subsequent actions has become a dominant focus in cognitive developmental psychology (Wellman, 2017). This body of work has challenged previous notions about childhood realism, demonstrating that even very young children possess surprisingly sophisticated understandings of the nonmaterial and abstract nature of mental entities.

As children progress through early and middle childhood, their theory of mind - the ability to attribute mental states to others and understand how these states influence behavior - becomes increasingly sophisticated..

Researchers have highlighted several key issues in the study of social cognition and mental state understanding in children. These include the examination of individual differences, the need to differentiate between various aspects of social understanding, and the relationship between these cognitive developments and children's social relationships and emotional experiences (Callanan et al., 1993; Conte et al., 2019; Dunn, 2000; Wellman, 2017).

1.10.10.1 *Analyzing Children's Thinking Processes*

Jean Piaget and Lev Vygotsky, have made significant contributions to the field of analyzing children's thinking processes. Contrary to previous beliefs, research indicates that children as young as 12-18 months are able to recognize that people have inner mental states that guide their behavior. This early grasp of the connection between mental states and action sets the stage for more sophisticated developments in theory of mind that occur in the preschool years, as children become increasingly adept at reasoning about the beliefs, desires, and intentions of themselves and others.

The preschool period marks another key developmental milestone in children's understanding of mental states. During this time, children progress from an implicit to an explicit comprehension of internal psychological phenomena. They develop the capacity for metarepresentation, allowing them to think about their own and others' thoughts in an increasingly abstract and sophisticated manner (Wellman, 2017). This transition is a crucial component of the broader development of theory of mind, which has important implications for children's social understanding and interactions. Children's implicit awareness of others' intentions and goals gives way to an increasingly sophisticated explicit understanding of mental phenomena, with important consequences for their social and cognitive development (Conte et al., 2019; Grazzani et al., 2018).

1.10.10.2 *Investigating Social Cognition in Early Development*

The development of social cognition, the ability to understand and reason about the mental states of others, is a crucial aspect of human (Allen et al., 2015). Recent advancements in the field have revealed the remarkable competence and insight that infants and young children possess in their intuitive understanding of the social world around them.

Infants and toddlers are remarkably adept at deriving implicit theories to explain the actions of objects and the behavior of people, forming the foundation for causal learning and more

sophisticated understanding of the physical and social worlds (Allen et al., 2015). This capacity for intuitive analysis and theory-building is not limited to the physical domain, but extends to the social realm as well. Infants and young children are also highly responsive to the actions and words directed to them by other people, a capacity that may be the foundation for their ability to benefit from culturally transmitted knowledge.

Recent research has also highlighted the fundamental connections between self and other in the development of children's social cognition, moving away from the earlier tendency to describe children's social understanding as an intra-psychological phenomenon. The study of early social cognitive development has been an active and rapidly evolving field, with researchers drawing from various disciplines to achieve a more robust understanding of the nature and parameters of human social cognition.

One key area of interest in this field has been the study of individual differences in mind-reading and emotion understanding, and the broadening of the age range and cultural groups within which these are studied. Researchers have also grappled with the question of how the various aspects of cognitive development brought under the general label of 'social understanding' should be differentiated, and the critical question of how these developments in cognition relate to children's social relationships and emotional experiences - both as antecedents and as sequels (Dunn, 2000).

1.10.10.3 *The Role of Representations in Child Cognition*

The interplay between representations and child cognition is a fundamental aspect of developmental psychology, highlighting the intricate process by which children construct and manipulate mental models to navigate their world. Representation, the ability to create internal mental images or schemas, is a crucial component of cognitive development, enabling children to form, store, and retrieve information about their experiences (Craik & Bialystok, 2011).

Recent research has delved into the specific role of representations in children's understanding of complex systems, such as robotics. Scholars have found that even young children possess the capacity to reason about and formulate sophisticated theories regarding technological systems, provided they are given the opportunity to engage with and construct their own mental representations. This suggests that fostering children's representational abilities can enhance their learning and problem-solving strategies, as they are able to draw upon their internal models to make sense of new information.

Piaget's groundbreaking theory of cognitive development provides a framework for understanding the trajectory of representational skills in children. As children progress through the stages of sensorimotor, preoperational, concrete operational, and formal operational thinking, their ability to internalize and manipulate mental representations becomes increasingly sophisticated (Rabindran & Madanagopal, 2020). During the preoperational stage, for instance, children begin to develop the capacity to hold an object in mind while perceiving another, a crucial step in the emergence of symbolic thinking and predication.

The development of a "theory of mind," or the ability to attribute mental states to oneself and others, is closely tied to the growth of representational capacities. As children acquire the computational resources to model and simulate the mental processes of those around them, they are better equipped to predict and explain the behaviors of others (Gordon & Olson, 1998). This interplay between representation and social cognition highlights the integrative nature of child development, where various domains of understanding coalesce to support the child's holistic engagement with their environment. The role of representations in child cognition is multifaceted, encompassing the formation of mental models, the capacity for symbolic thinking, and the development of social-cognitive skills.

1.10.10.4 *Problem-Solving Processes in Children*

Problem-solving is a fundamental cognitive process that allows individuals to navigate and address various challenges they encounter throughout their lives. Problem-solving is extremely important in education, as it serves as a bridge between theory and practice, and reflects a student's overall preparedness and training (Salmina & Sorhina, 1982). The literature suggests that problem-solving is a multifaceted skill that can be viewed as a goal, a method, and a cognitive process (Merriënboer, 2013). As a goal, problem-solving should not be limited to well-structured problems but should encompass real-life problem-solving scenarios. As a method, problem-solving has certain limitations for novice learners, and providing appropriate support is crucial for helping them develop these essential skills (Samartzi & Kazi, 2010; Samartzi & Pavlou, 2009).

Examining the developmental trajectory of problem-solving skills, researchers have found that cognitive development and problem-solving ability are closely interrelated, especially after the age of 11, when formal operational abstract thinking becomes possible. Intellectually gifted children have been shown to possess advanced cognitive abilities, which appear to facilitate the development of more sophisticated interpersonal and intrapersonal problem-solving skills. Researchers have also

identified various aspects of problem-solving that can be taught and learned, including the development of cognitive strategies (Gagné, 1980). These strategies are often task-specific, and there is a need to distinguish between more general "executive" type strategies and those that are more domain-specific.

1.10.10.5 *Causal Inferences and Logical Reasoning in Children*

The ability to draw causal inferences and engage in logical reasoning is a crucial cognitive skill that develops during childhood. General reasoning ability is closely related to the children's capacity for logical reasoning (Liu et al., 2018). The development of causal inferences and logical reasoning in children is a multifaceted process that is influenced by a range of cognitive, social, and environmental factors. For example, left-behind children, or those who have been separate from their parents due to factors like migration, may face unique challenges in this area, as they may receive less direct interaction and conversation with their caregivers.

Research on informal reasoning among high school students suggests that while learners may be able to apply formal logic to well-defined problems, the actual process of scientific reasoning often involves a more informal, intuitive approach that draws on personal experiences and beliefs. This highlights the complex nature of human reasoning (Crépault & Samartzi, 1989; Huang, 2021; Liu et al., 2018; Samartzi, 1992; Wu & Tsai, 2007).

1.10.11 *Relevance Theory in Developmental Psychology*

Relevance theory is a prominent framework in cognitive science which has garnered significant attention in the field of developmental psychology, as it offers a comprehensive approach to understanding the cognitive processes underlying language acquisition and usage. This theory, proposed by Sperber and Wilson, states that human communication is guided by the search for relevance, where individuals strive to optimize the cognitive benefits they derive from an utterance while minimizing the cognitive effort required to process it (Wilson & Sperber, 2012).

In the context of child development, relevance theory provides insights into how children navigate the complexities of language learning and usage. As children engage in social interactions, they actively seek out the most relevant information to further their understanding of the world around them. This process is driven by their innate tendency to maximize the relevance of the information they receive, which in turn shapes their language development and pragmatic skills (Shuo & Chen, 2018).

1.10.11.1 *Cognitive Processes and Relevance*

The interplay between cognitive processes and the concept of relevance in communication and information processing is a multifaceted and intriguing area of study. At the heart of this intersection lies the fundamental question of how individuals perceive and judge the relevance of information, and the cognitive mechanisms that underlie this complex decision-making process (Vervaeke & Ferraro, 2013).

Relevance, as a construct, has been conceptualized in various ways, with researchers highlighting its multidimensional nature. Cognitive relevance, in particular, refers to the degree to which a given piece of information satisfies the user's informational needs, including perceived informativeness, novelty, and quality. Situational relevance, on the other hand, is associated with the user's interpretation of the task at hand, while motivational relevance encompasses the individual's intent and goals, as well as the level of satisfaction experienced.

The relationship between cognitive processes and relevance judgments has been the focus of extensive research. Cognitive approaches to relevance emphasize the role of the user's mental representations, decision-making strategies, and information-processing capabilities in determining the perceived relevance of information (Huang & Soergel, 2013). This perspective underscores the subjective and contextual nature of relevance, as individuals may differ in their cognitive appraisal of the same information based on their unique knowledge, goals, and situational factors.

The cognitive processes involved in relevance judgments are varied and complex, ranging from selective attention, memory retrieval, and information integration to higher-order reasoning and decision-making. These processes are influenced by a range of factors, including the user's prior knowledge, task demands, and personal preferences (Chen & Xu, 2005).

Researchers have also explored the relationship between cognitive processes and the different types of relevance. For instance, studies have shown that cognitive relevance is closely tied to the user's ability to comprehend and mentally integrate the information, while situational relevance is more closely linked to the user's interpretation of the task and its context (Chen & Xu, 2005; Kiili et al., 2008).

1.10.11.2 *Relevance and Pragmatic Skills Development in Child Clinical Psychology*

Child clinical psychology is a specialized field that focuses on the assessment, diagnosis, and treatment of psychological and behavioral issues in children and adolescents. One of the key aspects of this field is the development of pragmatic skills, which are the practical, real-world skills that

enable individuals to effectively navigate social and interpersonal situations. Researchers have emphasized the need for comprehensive training programs that not only address cognitive and emotional issues but also target the development of practical, everyday skills (Prinstein & Roberts, 2006). These skills, which include communication, problem-solving, and social interaction, are crucial for children's overall well-being and success in various life domains.

Interestingly, a growing body of research has explored the relevance of socioemotional skills development in child clinical psychology (Puerta et al., 2016). These studies have highlighted the significant impact that socioemotional skills can have on a range of outcomes, from academic performance to health and employment. For example, one study found that children's social competence in kindergarten, as assessed by their teachers, was strongly associated with their later outcomes in adulthood, including educational attainment, employment status, and mental health.

To address the need for pragmatic skills development, researchers have proposed various intervention programs and strategies. One approach, known as Developmental Social Skills Training, has been shown to be effective in improving social skills in children with a range of developmental and behavioral challenges (Bracegirdle, 1990). These programs typically involve teaching specific social skills, such as initiating and maintaining conversations, understanding social cues, and managing emotions, through a combination of direct instruction, modeling, and practice.

While the existing research on pragmatic skills development in child clinical psychology is promising, there are still several limitations and challenges to consider. One key issue is the need for a more comprehensive understanding of the specific skills and behaviors that constitute "pragmatic competence" and how they can be accurately assessed. Additionally, there is a need for more rigorous, longitudinal research to evaluate the long-term effectiveness of these intervention programs and their impact on children's overall well-being and life outcomes.

1.10.12 Embodied Action and Cognition

The concept of embodied action and cognition (Foglia & Wilson, 2013) has gained significant traction in the field of cognitive science, challenging the traditional view of the mind as a detached, disembodied system. Embodied cognition states that our mental processes are inextricably linked to our physical experiences and interactions with the world around us (Mills et al., 2022).

One key aspect of embodied cognition is the recognition that perception and action are closely intertwined (Fierro, 2012). Rather than viewing the mind as a passive recipient of information, embodied cognition suggests that our cognitive abilities are shaped by our ability to actively engage

with the environment through our senses and bodily movements. This perception-action cycle is a fundamental component of how we make sense of and navigate the world.

Embodied cognition has important implications for various domains, including clinical psychology. For example, in the context of schizophrenia, researchers have explored how disturbances in bodily experience and self-awareness may contribute to the development and maintenance of the disorder. Similarly, the embodied nature of cognition has been recognized in the field of virtual reality, where the immersive and multimodal nature of the experience can significantly impact the way individuals make meaning and represent information. Furthermore, the embodied approach to cognition has been applied to the realm of mathematics, where researchers have explored how physical and sensorimotor experiences can support the development of mathematical understanding (Tran et al., 2017; Tschacher et al., 2017).

1.10.12.1 *Theoretical Foundations and Key Concepts*

One key aspect of embodied cognition is the importance of self-generated movements and felt sensations in learning and conceptual development. This is in contrast to the emphasis on abstract symbol manipulation that characterized earlier cognitive science. Scholars such as Dewey and Montessori have long emphasized the significance of "learning by doing," recognizing the crucial role of kinesthetic action as a building block for conceptual understanding.

Recent research in neuroscience and cognitive science has provided further evidence for the embodied nature of cognition. Bodily variables such as facial expression, gestures, body movement, and posture have been shown to influence a wide range of mental processes, including affects, emotions, motivation, and brain activity. This underscores the bidirectional, perception-action cycle that is central to embodied cognition, where behavior consists of a succession of adaptive motor reactions to changes in the environment, which in turn affect subsequent actions.

The implications of embodied cognition are particularly significant for understanding cognitive development in children. Young children's cognition is deeply rooted in their physical interactions with the world, and their ability to perceive, think, and engage in intelligent behavior is profoundly shaped by their self-generated movements and felt sensations (Gibbs, 2005).

1.10.12.2 *Embodied Cognition and Information Processing*

The perception-action cycle, in which behavior consists of a succession of adaptive motor reactions to changes in external and internal environments, is a key aspect of the approach of embodied cognition. The integration of embodied cognition with information processing models has the

potential to provide a more comprehensive understanding of human cognition and its underlying mechanisms. The info-computational approach, which incorporates scientific knowledge about the processes in nature and translates them into the language of natural info-computation, offers a promising avenue for this endeavor.

The implications of embodied cognition for the design and use of technologies, such as virtual reality, are particularly intriguing. The recognition that meaning making is deeply grounded in multisensory processes and bodily experience suggests that technologies that facilitate immersive, embodied interactions may have significant potential for enhancing multimodal meaning making and representation (Dodig-Crnkovic, 2021; Mills et al., 2022; Tran et al., 2017; Tschacher et al., 2017).

1.10.12.3 *Embodied Perception and Sensorimotor Integration*

The importance of the body for information processing is emphasized by the evidence from neuroscience and embodied cognition research, which suggests that even abstract concepts contain sensorimotor ingredients. Bodily variables, such as facial expressions, gestures, body movement, and postures, have been shown to influence a wide range of mental processes, including affects, emotions, motivation, attitudes, brain activity, reflexes, and neuroendocrine events. This indicates that perception and cognition are not isolated from the physical embodiment of the human experience, but rather are deeply integrated with the sensory and motor systems of the body.

The implications of embodied cognition for understanding the affordances of virtual reality technologies for multimodal meaning-making and representation are significant. In virtual reality, meaning-making becomes immersive, involving the full sensorium of the user, rather than being limited to abstract, disembodied cognitive processes. Furthermore, research has shown that mental models or representations of the surrounding environment can be constructed using both visual and non-visual information, suggesting that the body's sensorimotor integration plays a crucial role in spatial awareness and navigation (Shioiri et al., 2018).

1.10.12.4 *Embodied Problem-Solving and Decision-Making*

Traditionally, the mind has been viewed as a separate entity from the physical body, operating as a symbol-manipulating system that processes information in an abstract and disembodied manner. However, the embodiment approach challenges this view, positing that the mind is inextricably linked to the body and its interactions with the world. Embodiment theories suggest that all human cognition, including abstract thought, is grounded in multisensory processes and bodily experiences (Mills et al., 2022).

As Bishop notes, decision-making is at the heart of the teaching process, and the rationality and emotions of the mathematics teacher are considered two sides of the same coin (De Simone, 2019). Embodied cognition implicates a perception-action cycle in which behavior consists of a succession of adaptive motor reactions to changes in external and internal environments. These actions produce changes in those environments that in turn affect subsequent actions, continuing a dynamic loop. The importance of embodiment is further highlighted in the context of virtual reality technologies. Virtual reality allows for immersive, multimodal meaning-making, where the body's interactions with the digital environment become central to the cognitive process.

1.10.12.5 *Embodied Development in Young Children*

The concept of embodied development is especially important for young children. Recent research has highlighted the significant benefits of incorporating embodied learning strategies into educational settings, particularly for young children in preschool and elementary school. The idea is that by engaging the whole body in the learning process, children are able to build stronger, more durable representations of the concepts and skills they are acquiring. (Gibbs, 2005) This is supported by the notion that learning is a comprehensive activity involving both the mind and the body, with kinesthetic action serving as a crucial foundation for conceptual development. By actively engaging the body in the learning process, young children can better internalize and apply the knowledge and skills they are acquiring, leading to more meaningful and lasting learning outcomes (Lozada & Carro, 2016).

Evidence from a range of studies suggests that embodied learning approaches are particularly well-suited for supporting the development of mathematical thinking and problem-solving skills in young children. These studies have shown that by incorporating physical movement, gestures, and manipulation of objects into mathematical activities, children are able to more effectively grasp and apply fundamental mathematical concepts, such as number sense, spatial reasoning, and problem-solving strategies (Oers, 2010; Tran et al., 2017).

1.10.12.6 *Implications for Education and Pedagogy*

By recognizing the integral role of the body in shaping our mental processes, the embodied action approach has significant implications for how we approach education and pedagogy, calling for a more holistic and experiential approach to learning. The approach challenges the traditional view of learning as the passive acquisition of knowledge, and instead suggests that active engagement and physical interaction with the world are crucial for the construction of conceptual knowledge. This

idea is reflected in the educational philosophies of thinkers like John Dewey and Maria Montessori, who emphasized the importance of "learning by doing" and the integration of kinesthetic and tactile experiences into the learning process (Gibbs, 2005). This approach is particularly relevant in the context of subjects like mathematics, where studies have shown that embodied cognition can support mathematical thinking and problem-solving through the use of non-digital and digital approaches that leverage the body's percept-action cycle (Tran et al., 2017).

The implications of embodied action for education and pedagogy are multifaceted. For instance, the acknowledgment that the mind is embedded in the body suggests that teaching and learning should incorporate opportunities for physical movement, gestures, and tactile exploration, as these can enhance cognitive development and the retention of information (Gibbs, 2005; Tschacher et al., 2017). The embodied action perspective highlights the need for a more holistic and personalized approach to education, one that considers the unique physical, emotional, and cultural factors that shape an individual's learning experiences (Sani et al., 2021; Tschacher et al., 2017).

1.10.12.7 Challenges and Limitations in Embodied Action and Cognition

The field of embodied action and cognition also presents a number of challenges and limitations that must be carefully considered (Kosmas & Zaphiris, 2018). One of the primary challenges in embodied action and cognition is the difficulty in capturing the full complexity of the body-environment-cognition interplay.

Another key limitation of the embodied approach is the difficulty in establishing clear causal relationships between bodily variables, such as facial expressions, gestures, or postures, and their influence on cognitive processes and mental states. While numerous studies have demonstrated correlations between bodily and cognitive phenomena, untangling the precise mechanisms underlying these relationships remains an ongoing challenge.

Additionally, the embodied approach has been criticized for its potential to oversimplify the complex interplay between the body, environment, and cognition. The perception-action cycle, in which behavior is understood as a succession of adaptive motor reactions to changes in the environment, may not fully capture the nuanced and often non-linear nature of human cognition and behavior. Despite these challenges, the embodied action and cognition paradigm has made important contributions to our understanding of human behavior and experience.

1.10.12.8 *Interdisciplinary Collaborations in Embodied Action and Cognition*

Researchers in the field of embodied cognition have explored a wide range of applications, from the treatment of mental health disorders, such as schizophrenia, to the design of educational interventions that leverage the body's role in learning and problem-solving (Mills et al., 2022; Tschacher et al., 2017). In the context of multimodal meaning-making, for example, the affordances of virtual reality technologies have been examined, as they offer the potential for immersive, embodied experiences that can shape the ways in which individuals engage with and construct meaning from digital environments (Mills et al., 2022).

The growing body of research in embodied cognition has also highlighted the importance of interdisciplinary collaboration, as different fields bring unique perspectives and methodologies to the study of the mind-body connection. By integrating insights from neuroscience, psychology, education, and computer science, among other disciplines, researchers have been able to develop a more comprehensive understanding of the complex and dynamic interplay between our physical and cognitive experiences.

As this field continues to evolve, it will be essential for researchers to maintain and deepen these interdisciplinary collaborations, leveraging the diverse expertise and theoretical frameworks of their colleagues to push the boundaries of our understanding of the embodied nature of human cognition (Guckelsberger et al., 2021; Tran et al., 2017).

1.10.12.9 *Embodied Cognition and Augmented Reality*

The relationship between embodied cognition and augmented reality is a fascinating area of study that has garnered increasing attention in the fields of psychology, neuroscience, and human-computer interaction (Carmigniani et al., 2011). Augmented reality technology, which blends digital information with the user's physical environment, provides an intriguing lens through which to explore the implications of embodied cognition. By superimposing virtual elements onto the real world, augmented reality has the potential to extend and augment our bodily experiences, potentially influencing our cognitive processes in unexpected ways.

One key aspect of this relationship is the role of multisensory integration in both embodied cognition and augmented reality. Standard cognitive science has traditionally focused on the abstract abilities of the mind, often treating the physical body as a separate and lesser entity. However, embodiment theories have highlighted the crucial role that multisensory processes and bodily experiences play in shaping our cognition and meaning-making. Similarly, the seamless blending of

visual, auditory, and even haptic cues in augmented reality can create a more immersive and embodied experience for the user, potentially influencing their perceptions, emotions, and decision-making (Stanney et al., 2009; Yin et al., 2021).

CHAPTER 2: Technology in Psychology and Learning

2.1 Virtual Platforms in Psychology

Face-to-face contacts have historically been used when participating in research environments. However, with recent advancements in technology, virtual platforms have been introduced in the field of psychology, aiming to transform the way mental health services are delivered, offering greater accessibility, flexibility, and reach for both practitioners and clients. This shift is reshaping traditional therapeutic practices and opening up new opportunities for research, engagement, and personalized care in the field of psychology (Bocanegra & Gallup, 2018). These virtual platforms include, but are not limited to, teletherapy, online counseling, virtual support groups, and mobile apps, like chatbots (Koumaras et al., 2018), that facilitate a range of psychological services, from assessment and diagnosis to therapy and self-help tools. Virtual platforms are a great tool for research in psychology, not only bridging geographic barriers but also facilitating a controlled meeting in which the researcher-observer can note any situations or challenges that arise and adapt as required (Wu & Kraemer, 2016).

The fact that experimental methods involving children are often more complicated than those involving adults is undoubtedly among the main factors for the sluggish adoption of virtual research in future developments. Considering age-specific visual attention, one of the biggest challenges for early childhood, developmental specialists are figuring out how to engage individuals, reduce distractions, and incentivize involvement effectively. Relationship between even a patient and a therapist might aid in keeping the child's attention (Gijbels et al., 2021). Even though the job is automated, formative research investigations, particularly those focusing on audio or visual processing, might gain from collected data (Adams et al., 2018). In a controlled meeting, the researcher-observer can note any situations or challenges that arise and adapt as required.

Although interpersonal relations over a screen are generally regarded as "obliterated" and cannot entirely substitute in-person encounters, executing virtual experiments facilitate remote execution, thus providing ease of access and improving participation and involvement (Naseer et al., 2019). Furthermore, the simultaneous entrance of a foreigner, such as a researcher, and a new location, such as the facility, in the experimental process might conflict with the integrity of collecting data in research related to children. Virtual platforms eliminate those new variables by enabling the

child to interact with a machine in the comfort of its own environment, thus mitigating the aforementioned risks.

2.1.1 Social Learning Theory and Virtual Classrooms

Social Learning Theory, as proposed by Albert Bandura (Bandura, 1977), supports that individuals can learn new behaviors by observing others. This theory emphasizes the importance of the learner developing their own knowledge or information gained from observing models in their surrounding environment (Manik et al., 2022). The learner organizes this observed information into detailed codes, which can then be repeated and refined through real-time feedback.

In the context of virtual classrooms, Social Learning Theory can be particularly relevant. Virtual environments have the unique ability to alter the social dynamics of learning by transforming social interactions. For example, studies have shown that by breaking the rules of spatial proximity that exist in physical space, students can learn more effectively by being in the center of the teacher's field of view and by being closer to the teacher.

Moreover, the introduction of virtual co-learners, who can serve as either model students or distracting students, can significantly impact the learning abilities of participants. These findings suggest that virtual environments have the potential to enhance the social dynamics of learning by manipulating the spatial and social factors that influence the learning process (Bailenson et al., 2008; Manik et al., 2022; Zimmerman & Kleefeld, 1977).

To design effective virtual classrooms, it is crucial to incorporate active learning approaches and cooperative/collaborative learning methodologies that encourage social interaction and engagement among students (Camilleri & Camilleri, 2022). The use of video conferencing technologies can facilitate online interactions, provided that students actively participate and engage with the learning materials and their peers.

2.1.2 The Role of Technology in Enhancing Learning Abilities

Technology has become an integral part of our daily lives, and its role in enhancing learning abilities has been a subject of significant interest and research in recent years (Carroll, 1998; Kuhlenschmidt & Kacer, 2010). The integration of technology into the educational system has had a profound impact on both students and educators (Zhang, 2014). Technology can be leveraged to create more engaging and interactive learning experiences, which can lead to improved comprehension and retention of information. For instance, the use of multimedia presentations, interactive simulations, and virtual

reality can help students better visualize and understand complex concepts, ultimately enhancing their learning abilities (Carroll, 1998).

Moreover, the availability of online resources and educational platforms has provided students with greater access to knowledge, enabling them to explore topics beyond the confines of the traditional classroom. This increased accessibility has empowered students to take a more active role in their learning, fostering a sense of autonomy and self-directed learning.

The impact of technology on learning abilities extends beyond the classroom. Social media technologies, in particular, have emerged as powerful tools for adult learners to engage in continuous learning and professional development (Alsaadat, 2018). These platforms allow for the exchange of knowledge, the formation of learning communities, and the ability to access a wealth of information on a wide range of subjects.

Furthermore, the advent of digital textbooks and academic e-books has revolutionized the way students access and interact with educational content. These digital resources offer a level of flexibility and convenience that traditional print materials cannot match (Alsobhi & Alyoubi, 2019; Bhat, 2023; Carroll, 1998; Van et al., 2021).

2.1.3 Impact of Technology on Cognitive Development in Children

In the rapidly evolving digital landscape, the influence of technology on child development has become a topic of increasing interest and concern among researchers, educators, and parents. While some early studies raised alarm about the potential detrimental effects of technology on children's cognitive abilities, more recent research suggests a more nuanced and complex picture (Shanmugasundaram & Tamilarasu, 2023). The initial concerns centered around the idea that technology could potentially isolate children from crucial face-to-face interactions, hindering their social and emotional growth and impeding mental development.

However, subsequent studies have challenged this notion, revealing that the appropriate and balanced use of technology can, in fact, enhance the cognitive development of children in various ways. Technology-enabled communication and collaboration can facilitate social interaction and emotional intelligence, when implemented thoughtfully. As such, the impact of technology on child development appears to be multifaceted, requiring a more detailed understanding and careful consideration of the context and mode of usage.

One of the key areas where technology has played a transformative role is in the educational system. The rapid technological advancements have created a significant gap between traditional

teaching methods and the learning needs of modern children, who are often referred to as "digital natives" (Kivunja, 2014). To address this, educational institutions have been incorporating various digital tools and platforms, such as interactive whiteboards, educational apps, and online learning resources, to enhance the learning experience. These technological interventions have been found to have a positive impact on children's academic performance, cognitive abilities, and engagement with the learning process. Additionally, the use of technology in the classroom has enabled more personalized and adaptive learning, catering to the unique needs and learning styles of individual students. This has led to improved learning outcomes and a more engaging and stimulating educational environment for children.

Another aspect of the technology-driven cognitive development in children is the role of digital entertainment, such as video games and interactive media. While initial concerns centered around the potential for video games to be a distraction or to promote sedentary behavior, recent research has revealed that certain types of video games can actually enhance cognitive skills, such as problem-solving, spatial awareness, and decision-making (Bavelier et al., 2010; Giacomo et al., 2017; Lieberman et al., 2009; Sahin & Özenç, 2021). These games often require players to engage in strategic planning, hypothesis testing, and pattern recognition, which can transfer to real-life problem-solving and critical thinking abilities.

Furthermore, the integration of physical activity and interactive technology, such as motion-controlled games or virtual reality experiences, can also contribute to the cognitive development of children by promoting physical, social, and emotional well-being, all of which are essential for holistic mental growth (Bavelier et al., 2010).

2.1.4 Technological Innovations in Cognitive Assessments

The field of cognitive assessments has undergone a remarkable transformation in recent years, driven by the rapid advancements in technology. Artificial intelligence has emerged as a powerful tool, enabling the development of assessment methods that are more personalized, adaptive, and efficient than traditional paper-and-pencil tests (Javed et al., 2023).

Technological innovations have not only improved the delivery and scoring of cognitive assessments, but they have also expanded the scope of what can be measured. Computerized approaches to assessment, the ability to implement life-like scenarios in a controlled virtual environment, and teleneuropsychology offer promise for expanding available approaches to cognitive remediation and self-monitoring (Adams et al., 2017). Furthermore, computational models

are increasingly being used to integrate neuroimaging into the assessment process, allowing for the development of neuropsychological assessments with greater accuracy and targeted testing.

These technological advancements have the potential to revolutionize the way cognitive assessments are conducted, providing a more comprehensive understanding of an individual's cognitive abilities and functioning. The integration of artificial intelligence into the assessment process has been a significant development in the field of cognitive assessment (El Msayer et al., 2024). However, the deployment of AI in education also raises significant ethical concerns. Issues such as algorithmic bias and the opacity of AI decision-making processes pose risks of perpetuating inequalities and affecting assessment outcomes.

To address these concerns, various stakeholders, including educators, policymakers, and organizations, have developed guidelines to ensure the ethical use of AI in education (Bulut et al., 2024). These guidelines emphasize the importance of transparency, fairness, and accountability in the development and deployment of AI-based assessment tools.

The use of online proctoring technologies during the COVID-19 pandemic has also sparked a renewed debate on the ethical implications of such technologies. These technologies raise concerns about academic integrity, privacy, and the autonomy of students, as they can be perceived as a form of "Big Brother" surveillance (Coghlan et al., 2021).

2.1.5 Online Educational Resources and Cognitive Engagement

In the digital age, the landscape of education has undergone a profound transformation, with the proliferation of online educational resources becoming an increasingly integral component of the modern learning experience. Researchers have explored the far-reaching impact of these digital tools on cognitive engagement, examining the ways in which they have reshaped the fundamental dynamics of teaching and learning (Mollenkopf et al., 2020).

The digitalization of educational content has led to the emergence of a diverse array of innovative online resources, ranging from interactive multimedia platforms to sophisticated cloud-based learning management systems. These technological advancements have not only expanded the accessibility and availability of educational materials but have also introduced a wealth of new avenues for fostering student engagement. The seamless integration of these resources into the learning process has the potential to cultivate greater cognitive engagement, as students are presented with dynamic and highly interactive platforms that cater to a wide spectrum of learning styles and preferences (Montebello, 2014).

Moreover, the integration of artificial intelligence algorithms and techniques into e-learning platforms has further enhanced the capacity for personalized and adaptive learning experiences (Arun Kumar et al., 2022). These intelligent systems are capable of analyzing student data, identifying individual strengths and weaknesses, and tailoring instructional content and delivery to meet the unique needs of each learner.

2.1.6 Gamification of Learning and Cognitive Skill Development

The integration of gamification has emerged as a promising approach to enhance learner engagement, motivation, and cognitive skill development (Busarello et al., 2016; Sailer & Homner, 2020). Gamification, defined as the incorporation of game-like elements into non-game contexts, has been widely adopted in various fields, including education, to create more engaging and immersive learning experiences (Sanmugam et al., 2014).

The existing literature suggests that gamification can have a significant impact on learners' motivation and engagement. Specifically, the introduction of game-based elements, such as points, leaderboards, and badges, can help to foster a sense of achievement, competition, and progress, which can ultimately lead to increased learner involvement and a more enjoyable learning experience (Rahman et al., 2018). Moreover, research indicates that well designed gamification can also contribute to the development of cognitive skills, such as problem-solving, critical thinking, and decision-making. The application of gamification in education has been explored across various disciplines, including science, mathematics, and physical education.

A systematic review of the literature on gamification in science education revealed that the implementation of game-like elements can facilitate scientific thinking and enhance students' motivation to engage with scientific concepts (Kalogiannakis et al., 2021). Similarly, a study on the gamification of physical education found that the integration of playful elements can positively impact students' motivation and academic performance (Férriz-Valero et al., 2020).

Despite the promising findings, the research also suggests that the effectiveness of gamification in learning and cognitive skill development is not always straightforward. The design and implementation of gamified learning environments must be carefully considered to ensure that the game-based elements are meaningful, aligned with learning objectives, and tailored to the needs and preferences of the target audience.

2.1.7 Educational Games and Cognitive Skill Acquisition

Educational games have long been a topic of interest in the field of cognitive psychology, as researchers seek to understand the potential benefits of integrating gameplay into the learning process. Several studies have shown the positive effects of video games on various cognitive processes, such as perception skills, visual and spatial abilities, short-term memory, attention, and reaction time (Stafford & Vaci, 2022). Moreover, there is increasing evidence that using games to train and educate is an effective approach, as the development of the game world has penetrated fields beyond just entertainment .

The advent of computer technology has brought new possibilities to the field of game-based learning. With the unprecedented processing power and graphic technology of computers, modern educational games can represent, simulate, and contextualize knowledge from a wide range of academic disciplines.

One of the main benefits of online gaming in education is that it can make learning fun. Many students struggle to stay engaged in traditional learning environments, but online games can capture their attention and motivate them to keep learning. By incorporating game mechanics like achievements and rewards, these games can help students stay motivated and engaged in their learning (Azizah & Irsyadi, 2020; Cheng & Milikich, 2023; Huo, 2019).

In a study exploring the use of educational games for learning the Arabic language in a modern Islamic boarding school, researchers found that the development of educational games assisted the learning process and improved the learning outcomes of students (Azizah & Irsyadi, 2020). Similarly, a review of the impact of COVID-19 on the gaming industry and lesson delivery highlighted the potential of educational games to help students of all ages learn and develop important skills (Cheng & Milikich, 2023).

2.1.8 Immersive Environments for Cognitive Skill Transfer

Immersive environments for cognitive skill transfer refer to the use of virtual reality (VR), augmented reality (AR), or mixed reality (MR) environments designed to help individuals learn and apply cognitive skills in real-world situations (Yang & Liu, 2022). The latest advancements in virtual and augmented reality technologies have opened up new ways for the exploration of immersive environments and their potential impact on cognitive skill development and transfer. Immersive virtual reality and augmented reality have demonstrated significant promise in enhancing learning

and training across a wide range of domains, from military applications to professional skills development (Checa & Bustillo, 2020).

One of the key advantages of immersive environments is their ability to provide a deeper level of engagement and presence, which can lead to more effective knowledge retention and skill acquisition. By surrounding the learner with digital content and allowing them to interact with it in a natural and intuitive manner, these technologies can create a sense of embodiment and immersion that is difficult to replicate with traditional learning methods. This enhanced level of engagement has been shown to improve the learner's understanding and application of complex concepts, as well as their ability to transfer these skills to real-world settings (Back et al., 2020).

The benefits of immersive collaborative learning in CAVE-based virtual reality have been well-documented. These environments allow learners to interact with educational content in a shared, virtual space, fostering a sense of community and collaboration that can further enhance the learning experience. Similarly, the integration of virtual and augmented reality with gamification elements and interactive features can significantly increase learner involvement and motivation, leading to improved learning outcomes (Grigoreva & Grigorev, 2023).

As the cost of VR and AR technologies continues to decrease, the prospects for their widespread implementation in educational and training settings have become increasingly promising. The ability to "expand" the learning environment through augmented reality and to provide a visually and spatially immersive experience through virtual reality can address the limitations of traditional e-learning approaches, such as the effect of distraction and the lack of a true sense of presence (Grigoreva & Grigorev, 2023).

2.1.9 Augmented and Virtual Reality in Cognitive Training

Augmented reality (AR) overlays digital content onto the real-world environment, allowing users to interact with both virtual and physical elements (Lorusso et al., 2018). Virtual reality (VR), on the other hand, completely immerses the user in a computer-generated environment, providing a more immersive and interactive experience.

Integrating these technologies into teacher education programs is crucial, as it equips pre-service teachers with the necessary skills and knowledge to effectively utilize AR and VR in their classrooms. Recognizing the potential of these technologies, educator preparation programs can provide opportunities for pre-service teachers to practice their skills, explore new teaching methods, and build confidence in using these innovative tools.

These technologies can be leveraged to create engaging and interactive learning experiences, particularly in the realm of problem-solving, pragmatic, and cognitive development. By designing AR and VR-based integrated systems, educators can empower students to develop critical thinking skills, enhance their understanding of complex concepts, and foster a deeper engagement with the learning process. These immersive technologies can provide engaging and interactive learning experiences, even in remote or hybrid learning environments (Boletsis & McCallum, 2014; Cho et al., 2002).

The research in this field has demonstrated the potential of AR and VR to enhance cognitive training, learning outcomes, and student engagement. As highlighted in a recent study, the learning technique based on augmented reality technology has been shown as an active learning method, as it allows for the efficient conversion of acquired information into long-term memory (Gaol & Prasolova-Førland, 2022). Furthermore, the educational values of AR and VR are not solely based on the use of technologies, but rather on how they are designed, implemented, and integrated into formal and informal learning settings (Lorusso et al., 2018).

2.1.10 Behaviorism and Online Learning

Behaviorism, as a psychological perspective, emphasizes the role of external environmental factors in shaping and modifying behavior (Reimann, 2018). In the context of education, behaviorist learning theory has played a significant role, particularly in the design and implementation of traditional classroom-based instruction (Qasem, 2015).

With the advent of online learning, educators have had to reevaluate the applicability and relevance of behaviorist principles in this new learning environment. Behaviorism, with its focus on observable behavior and the use of reinforcement and punishment to shape learning, has been widely applied in the development of online instructional materials and assessment strategies (Phillips, 2012; Qasem, 2015; Reimann, 2018).

One of the key aspects of behaviorism that has found relevance in online learning is the concept of programmed instruction. This approach involves breaking down learning content into small, manageable steps and reinforcing correct responses. The use of online collaboration and discussions can also be viewed through the lens of behaviorism.

However, the shift to online learning has also raised questions about the limitations of a purely behaviorist approach. Constructivist learning theory, which emphasizes the active role of the learner in constructing knowledge, has gained increasing attention in the context of online education (Efgivia et al., 2021b).

The integration of behaviorist and constructivist principles in the design of online learning environments has become a subject of ongoing research and discussion. Researchers have explored the potential tradeoffs between classical conditioning, learning by imitation, and learning by doing in the online education system.

2.1.11 Challenges and Considerations for Implementing Technology-based Learning Strategies

The integration of technology-based learning strategies into academic settings has been a double-edged sword, presenting both opportunities and challenges (Lucas, 2017). On one hand, technology can enhance student engagement, personalize learning experiences, and improve educational outcomes. On the other hand, these strategies have been accused of promoting digital divide, have raised online safety concerns, and present a possible risk of over-reliance on screens.

One of the key considerations is the impact of technology integration on student learning outcomes. While numerous studies have demonstrated the positive impact of technology on learning, the effectiveness of these strategies depends on thoughtful implementation and addressing the associated challenges. Successful technology integration requires not only the availability of hardware and software but also the development of digital literacy skills among both educators and learners (Marín & Castaneda, 2023; Martin & Grudziecki, 2006).

Addressing the digital divide is another critical factor in ensuring equitable access to technology-based learning. Disparities in access to technology and digital resources can exacerbate existing educational inequalities, further marginalizing underserved communities. Additionally, the integration of technology in the classroom can introduce potential distractions and privacy concerns (Beland & Murphy, 2016). Educators must strike a balance between leveraging the benefits of technology and mitigating the risks of overreliance on screens and potential data privacy issues (Haduong et al., 2015). By addressing these considerations, educational institutions can harness the power of technology to enhance student learning and foster a more equitable and engaging educational landscape.

2.2 Human-Robot Interaction in Learning and Psychology

In the rapidly evolving landscape of technology, the integration of robots into various aspects of human life has become increasingly prevalent, particularly within the realms of learning and psychology. As intelligent machines become more sophisticated and accessible, the need for effective human-robot interaction strategies has become paramount, as these interactions can

significantly impact how individuals learn, perceive, and interact with their environment. The integration of robots in learning environments, such as classrooms and educational settings, has the potential to enhance the educational experience by providing personalized instruction, adaptive learning, and interactive engagement (Semeraro et al., 2023). Similarly, the application of robots in psychological research and therapies can lead to breakthroughs in understanding human behavior, cognition, and emotional responses (Shleibik et al., 2024).

The development of human-robot teaming capabilities is a crucial aspect of this integration, as it allows for the dynamic collaboration between humans and robots, leveraging the strengths of both to navigate complex situations more efficiently (Shleibik et al., 2024). This collaboration involves the robot's ability to adjust its level of autonomy to match the needs of the task and the human team members, creating a more seamless and effective partnership. An example of this is a study on human-robot collaboration in industrial settings highlighted the importance of ensuring safe interaction, designing intuitive user interfaces, and combining the strengths of robots and human workers to achieve efficient collaboration (Villani et al., 2018).

Another review on human-robot collaboration and machine learning emphasized the significance of building cognitive models that can collect inputs from the environment and the user, and then translate them into information that the robot can use to tune its own behavior and improve the joint performance with the user (Semeraro et al., 2023).

2.2.1 Computer and Tablet Interaction with Children and Learning

In our digital era, the integration of computer and tablet technologies into the learning process has become a topic of growing interest and scrutiny. Today's children, often referred to as "digital natives," are immersed in a world where these devices are ubiquitous, presenting both opportunities and challenges for educators and parents alike (Bittman et al., 2011).

The potential benefits of incorporating computer and tablet technologies into children's learning are well-documented. These devices can provide interactive and engaging educational content, facilitate personalized learning experiences, and open up new avenues for exploration and discovery. Moreover, the mobility and accessibility of tablets and computers allow learning to take place anytime and anywhere, empowering children to take an active role in their educational journey (Kwok et al., 2016).

Research suggests that children can learn new facts equally well from interactive media compared to traditional face-to-face instruction (Kwok et al., 2016). The reactivity, interactivity, and

portability of these technologies offer significant advantages over traditional learning methods, such as allowing for tailored content and progressive learning experiences. Furthermore, the use of educational software in teaching initial reading and writing has been shown to help children control their learning experiences by providing concrete experiences and facilitating the engagement of multiple sensory organs (Sahin & Özenç, 2021).

Despite these promising findings, concerns have been raised regarding the potential risks and drawbacks of extensive computer and tablet use by children. To address these concerns, it is crucial to strike a balance between the integration of technology and the preservation of traditional learning methods.

2.2.2 The Need for a Robotic Experimenter

With robots, children, especially those with Autistic Spectrum Disorder (ASD), demonstrate enhanced social skills, as evidenced by increased emulation and collaborative concentration. One of the most important features of using robotics with children is to keep them engaged in extended sessions (Michaud et al., 2007) and therefore keeping their attention focused on particular social skills (Prescott & Robillard, 2021). One of the reasons why children like interacting with robotics is that such agents are basic in look and conduct, straightforward, and not as daunting as people may be in high social complexity (Marchetti et al., 2022). The research on Social Assistive Robots (SAR) psychotherapy for children, especially those with ASD, is vast and it helps researchers classify trials based on the type of robotics utilized and the interactions that are happening. Considering these, the virtual platform could enable researchers to expand the research with experiments in children beyond those with ASD. Researchers believe robotics may induce observable behavioral reactions to stimulations and create the same stimulation for diverse participants (Prescott & Robillard, 2021). It is important to note that robots might aid in collecting quantitative measurements of children. In the long term, the robot's activities might be converted into quantifiable measurements that might be used for further analysis.

In principle, empirical research shows that using robots with children has beneficial outcomes. Irrespective of the sort of robots utilized, researchers discovered that such gadgets could be helpful as mediating devices throughout unpleasant therapies or merely during a child's hospitalization (Marchetti et al., 2022). Furthermore, such studies reveal that robots benefit children and caretakers by reducing parental worry and assisting professionals during certain operations (Pivetti et al., 2020). However, as previously stated, these findings have drawbacks, the most

significant of which are the limited number of persons, the cultural differences, the varied robot characteristics, and the aging nonuniformity, all of which will have to be considered in a forthcoming related study. Most of the drawbacks are addressed in the virtual platform presented here by providing an open and online platform that has interfaces and the ability to support multiple remote controlled robotic experimenters.

According to literature, there are two general types of SARs (Feil-Seifer & Mataric, 2005): non-humanoid and humanoid. In this study, only humanoid robots are considered, since they are beneficial not only for movement therapy but also for their pleasant interpersonal characteristics (Marchetti et al., 2022). Moreover, humanoid robots with limbs, arms, feet, and heads enable broader interaction and improve children's motivation due to the innately social and educational character, as highlighted by numerous researchers. Studies on cognitive development pointed out the role of robots in transmission of social cues (Masson et al., 2017) as well as in children's general learning ability (Jamet et al., 2018).

2.2.3 The Integration of Robotics in Educational Settings

The integration of robotics in educational settings for children has emerged as a critical area of research and exploration, as educators and policymakers seek to harness the potential of technology to enhance the learning experience and prepare students for the demands of the 21st century (Anwar et al., 2019). Numerous studies have investigated the impact of educational robotics on academic and social skills, with a growing body of evidence suggesting the potential benefits of this approach.

A systematic review of studies on educational robotics highlights the steady increase in the number of investigations in this field, with researchers examining the use of educational robots in both formal and informal learning environments to enhance K-12 students' interest, engagement, and academic achievement in various STEM (Science, Technology, Engineering, Mathematics) disciplines (Ferrada et al., 2020). The review suggests that while there is evidence for the general benefits of educational robotics, there is a need to better understand the specific advantages that can be achieved through the implementation of robotics in educational settings.

Another review explores the educational potential of robotics in schools, presenting a synthesis of the available empirical evidence on the effectiveness of robotics as an educational tool. The review identifies the potential contribution of incorporating robotics as an educational tool, including its ability to enhance learning, and defines future research perspectives concerning educational robotics.

While the existing research highlights the promise of educational robotics, it is important to note that the integration of this technology is not a panacea and needs careful consideration and the use of best practices and strategies (Anwar et al., 2019; Benitti, 2012).

2.2.4 Human-Robot Teamwork in STEM Education

The most recent advancements in robotics and artificial intelligence have opened up exciting opportunities for their integration into the field of STEM education. Robots can serve as valuable educational tools, complementing human teachers and enhancing the learning experience for students (Afari & Khine, 2017).

One of the key benefits of incorporating robots in STEM education is the ability to provide hands-on, experiential learning (Sapounidis & Alimisis, 2020). Interactive robots can capture the attention of students, particularly those who might not have previously considered STEM fields, and spark their interest in these subjects. Robotics-based STEM learning designs have been shown to foster students' competence in applying interdisciplinary knowledge to solve problems, a crucial skill in the modern world (Darmawansah et al., 2023). Furthermore, robots can be employed to create a more inclusive learning environment. Interactive robots can be designed to facilitate inclusion, such as when co-designed with students with various abilities, including those with visual impairments. By reducing stereotypes about STEM fields and making them more accessible, robots can contribute to increasing diversity in higher education.

However, the effective implementation of human-robot teaming in STEM education requires careful consideration. To achieve efficient collaboration, several challenges need to be addressed, such as ensuring safe interaction between humans and robots, and designing intuitive user interfaces that allow human operators to easily program and interact with the robotic systems (Villani et al., 2018).

2.2.5 Fostering Social-Emotional Development with Robots

Another particularly intriguing area of exploration is the potential impact of social robots on the social-emotional development of children. The research suggests that social robots can play a significant role in fostering children's social-emotional skills, if designed and implemented effectively. While some studies have raised concerns about the potential for children to develop unhealthy relationships with robots, the overall evidence suggests that social robots can be valuable tools in

supporting children's social-emotional growth, particularly when used in conjunction with adult involvement and guidance (Jeong , 2017; Pashevich, 2022).

One key consideration in this field is the need for robots to present engaging personalities and respond dynamically to the needs of their young users. Social robots that are capable of effectively interacting with children and adapting to their individual needs have been shown to positively impact children's social behaviors and affect. Additionally, the presence of adult involvement in the human-robot interaction has been found to be crucial, as it can help guide children's understanding of the robot's role and prevent the development of unhealthy power dynamics (Cameron et al., 2016; Kahn et al., 2013).

2.2.6 Personalized Learning Experiences with Robotic Tutors

One promising development of robotics is the use of robotic tutors to provide personalized learning experiences for students. Intelligent Tutoring Systems (Baillifard et al., 2023) have emerged as a powerful tool in this regard, capable of selecting and adapting learning activities in real-time to cater to the unique needs of each individual student (Belfer et al., 2022).

The research on implementing learning principles with personal AI tutors has demonstrated the ability of these systems to effectively model human learning processes and enhance academic performance. By incorporating AI-driven curriculum plans and intelligent tutoring systems, educators can offer students personalized learning experiences that are grounded in the principles of learning sciences, addressing the challenges associated with implementing effective learning strategies (Leyzberg et al., 2018).

These AI-powered educational technologies, such as intelligent tutoring systems and AI-based curriculum plans, have the potential to enhance educational outcomes and provide engaging learning experiences for young people (Baillifard et al., 2023; Hasse et al., 2019). Adaptive curricula and contextual bandits have been shown to lead to superior completion rates and significantly improved student engagement when compared to other approaches, unlocking new opportunities for learning experience personalization.

While AI tutors and coaches have traditionally been designed to be in control of the educational process, the realities of today's world require a different approach that provides students with more agency and opportunities to set their own goals, build on their own interests, and develop their own strategies. Incorporating learner agency is vital in students' development, helping them

cultivate the initiative, motivation, self-confidence, and creativity needed to contribute meaningfully to their communities (Hasse et al., 2019; Resnick, 2024).

2.2.7 Ethical Considerations in Human-Robot Interaction

As the integration of robots and artificial intelligence into our daily lives becomes increasingly ubiquitous, it is paramount to examine the ethical implications that arise from these developments. One crucial aspect to consider is the ethical duty we hold as creators of sentient beings, both natural and artificial. The concept of imbuing robots with a basic understanding of morality and the ability to make ethical judgments is a complex issue. While fiction has explored the notion of robots refusing to comply with unethical demands, the feasibility of implementing such capabilities in real-world robotics remains a subject of ongoing research and debate (Malle & Scheutz, 2019).

The field of "socially cognizant robotics" advocates for a human-centric approach that synthesizes technical and social science methods, empowering stakeholder participation in shaping AI-driven robot behavior at all levels (Dana et al., 2023). This approach recognizes the need to balance traditional technology-based metrics with critically important, yet challenging to measure, human and society-based metrics.

Finally, the issue of trust in robots is a crucial consideration. Recent advancements in psychometrics, trustworthy systems, robot-ethics, and deep learning may provide a pathway towards the creation of truly autonomous, trustworthy social robots (Kok & Soh, 2020).

2.2.8 Impacts of Robotics on Child Development and Cognition

The progress in the field of artificial intelligence has been a driving force behind the development of increasingly sophisticated robots. The level of intelligence exhibited by the most advanced robots is currently at par with that of a very young child, and researchers argue that further integration of AI and robotic research will lead to even more rapid progress (Bogue, 2014).

The influence of robotics on child development and cognition can be both positive and negative. On the one hand, studies have shown that children who interact with robots exhibit a high degree of creativity, and wearable machines can enhance the expression ability of adolescents with autism spectrum disorders (Lai et al., 2023). According to research, the application of artificial intelligence in education can promote the development of social abilities in children. However, the frequent use of intelligent electronic devices has also been found to have a negative impact on adolescents' interpersonal relationships and social adaptability.

One of the key concerns raised by researchers is the potential for children to develop a master-servant relationship with robots, which could lead to detrimental developmental outcomes (Kahn et al., 2013).

2.2.9 Overcoming Challenges in Human-Robot Collaboration

The robots used in human-centric environments are designed to assist and collaborate with human users, particularly in tasks that may be inconvenient or challenging for individuals to perform independently. However, the successful adoption of collaborative robots has been hindered by concerns over safety and the need for intuitive user interfaces (Villani et al., 2018).

To address these challenges, researchers have explored various strategies to facilitate user-specific, adaptable safety controllers that can enhance the user's trust and comfort in working alongside robots (Prabhakar & Billard, 2022). One key aspect is the development of robust perception systems that can accurately detect and track changes in the dynamic environment, allowing the robot to adapt its behavior accordingly. This is particularly crucial in unstructured environments, where robots must possess a deep understanding of the task at hand and the ability to respond to unpredictable changes in the surroundings (Ortenzi et al., 2021).

Moreover, the design of intuitive user interfaces has emerged as a critical component in fostering effective human-robot collaboration (Złotowski et al., 2015). By enabling human operators to easily program and interact with the robot, these interfaces can leverage the complementary skills of both humans and robots, allowing them to work together seamlessly and efficiently (Villani et al., 2018).

Another critical factor in the successful adoption of collaborative robots is the need for safety measures that can protect human workers from potential harm. Researchers have explored various approaches, such as collision detection and human action recognition, to develop reliable safety monitoring systems that can ensure the well-being of human workers in close proximity to the robot.

2.2.10 Evaluating the Long-Term Effects of Robotic Interventions

In recent years, the use of educational robots in K-12 settings has gained increasing attention, with studies suggesting their potential to enhance students' computational thinking, STEM attitudes, and academic achievement (Benitti, 2012; Xia & Zhong, 2018; Zhang et al., 2021). However, the long-term effects of these robotic interventions remain unclear.

Robotic technologies have been implemented in various educational contexts, from after-school programs to integrated classroom activities. While some studies have found positive effects on student engagement and learning outcomes, others have reported no significant improvements. This calls for a more comprehensive understanding of the long-term impact of educational robotics.

A systematic review by (Benitti, 2012) examined the available empirical evidence on the educational effectiveness of robotics as a teaching tool. The authors found that educational robotics often acts as an element that enhances learning, but this is not always the case, as some studies have reported no improvement in learning. Similarly, a review of the literature on K-12 educational robotics highlighted the need to determine the specific benefits that have been achieved through robotics implementation (Anwar et al., 2019).

To address this gap, researchers have begun to investigate the long-term effects of robotic interventions in education and psychology. These studies aim to explore the lasting impact of robotics-based learning on students' cognitive, social, and emotional development, as well as on their academic performance and engagement.

Additionally, researchers have explored the potential of robotic technologies to support interventions in the field of psychology, particularly in areas such as autism spectrum disorder, social skills training, and cognitive rehabilitation. These studies suggest that the use of robots can foster social interactions, improve emotional regulation, and enhance cognitive functioning in various clinical populations.

2.2.11 Blending Traditional and Technological Approaches

The integration of technology in educational institutions has generated an active learning process that combines face-to-face instruction with online components, known as "blended learning" (Irum et al., 2020). Blended learning has been widely adopted across higher education, with some scholars referring to it as the "new traditional model" or the "new normal" in course delivery (Dziuban et al., 2018).

The term "blended learning" denotes the mixing of various educational approaches and methods, including the adaptation of new information and knowledge technologies. Blended learning programs can provide better opportunities for interactive learning between teachers and students, offer pedagogical flexibility and interaction, and deliver teaching and learning in a more cost-effective and meaningful manner (Tayebnik & Puteh, 2013).

Blended learning combines online and face-to-face instructional approaches, with each component complementing the other through careful tailoring. Practices of blended learning have been widely accepted in educational networks, providing students with more engaging and effective instruction that is customized to their needs (Listiana & Jaharadak, 2019).

However, the adoption of technology into face-to-face teaching that initiates the emergence of the online component has raised some concerns (Tayebnik & Puteh, 2013). Students, teachers, and blended learning institutions have faced various challenges in using technology in blended learning environments (Rasheed et al., 2020). Nonetheless, the integration of traditional and technological approaches in education and psychology has become a new norm, with the potential to enhance student performance and experiences.

2.2.12 Robotics and the Transformation of Learning Environments

Experts predict that artificial intelligence will be the main driver behind the significant virtual shift in the way we learn, communicate, and conduct educational activities (Ojha et al., 2023). The rapid infusion of diverse AI technologies, such as Natural Language Processing, Deep Learning, and immersive experiences enabled by Virtual Reality and Augmented Reality, has marked a significant shift in pedagogical approaches. These technologies, powered by the vast amount of data available, have the potential to revolutionize the educational landscape, providing personalized learning experiences, high-quality feedback for students, and supporting teachers in assessment activities (Zhang & Aslan, 2021).

The integration of robotics and AI-driven solutions in education has the potential to contribute to the effectiveness, equity, and cost-efficiency of educational systems. Robotics can serve as a bridge between the physical and digital realms, enabling innovative ways of engaging students and enhancing their learning experiences (Pantelimon et al., 2021). As the educational landscape evolves, the role of robotics in transforming learning environments is gaining significant attention. The rapid advancements in this field present both opportunities and challenges for educators, policymakers, and the broader educational community.

2.2.13 Robotics and Embodied Cognition in Learning

One of the key principles underlying the use of robotics in education is the concept of embodied cognition, which posits that cognitive processes are deeply rooted in the physical, sensorimotor interactions with the environment (Benitti, 2012). This perspective suggests that by incorporating

physical, hands-on experiences with robotic systems, learners can develop a more intuitive and holistic understanding of the concepts they are exploring (Benitti, 2012).

The intersection of robotics and embodied cognition has indeed emerged as a captivating area of research, offering profound insights into the complexities of human learning and the potential for innovative approaches to instruction (Kuniyoshi et al., 2007). The recent surge of interest in Educational Robotics has prompted a re-examination of the field, as researchers seek to uncover the expected learning outcomes and the various platforms available for leveraging these technologies (Evripidou et al., 2020). A systematic review of the literature on K-12 educational robotics reveals a consistent trend of increasing implementation and a growing body of evidence supporting the general benefits of these tools in providing impactful learning experiences. Furthermore, a separate study delves deeper into the specific contributions of robotics in schools, identifying its potential to enhance learning across a wide range of academic domains (Benitti, 2012).

2.3 Machine Learning in Psychology

Machine learning (ML) is increasingly being applied in psychology to understand and improve human learning and cognition. Researchers are using machine learning to study brain activation patterns related to learning scientific concepts, providing insights into how the brain learns abstract concepts (Mason & Just, 2016). Such research typically involves analyzing behavioral data, speech patterns, or even physiological signals to gain insights into the cognitive and emotional development of children (Jacobucci & Grimm, 2020).

Additionally, artificial neural networks are employed in order to help psychologists and teachers understand developmental stages, identify students with dyslexia and other learning difficulties and tailor educational interventions (Sailer et al., 2023). It has also been used to analyze eye-tracking data for understanding reading comprehension and mind-wandering (D'Mello et al., 2020). Moreover, it is being utilized to predict mental health problems, such as loneliness, depression, and anxiety, by analyzing psychological and sociodemographic traits (Altschul et al., 2021).

All those use cases suggest that the general trend in the field indicates that machine learning is increasingly being applied and it can provide innovative ideas that may have taken considerable time for humans, in part because it is less constrained by limits on available knowledge and biases (Bartlett et al., 2023).

However, concerns about machine learning techniques are mainly about the “black box” results they produce (Elhai & Montag, 2020; Guidotti et al., 2018). The learning algorithms can predict outcomes successfully with great accuracy, but they do not provide the causal or explanatory information that traditional methods generate and require. This is not essentially bad in psychology as contemporary researchers have argued that: “psychology’s near-total focus on explaining the causes of behavior has led much of the field to be populated by research programs that provide intricate theories of psychological mechanism, but that have little (or unknown) ability to predict future behaviors with any appreciable accuracy” (Yarkoni & Westfall, 2017).

2.3.1 Artificial Intelligence in Cognitive Skill Prediction

Artificial intelligence is capable of simulating human intelligence processes, such as reasoning, knowledge, planning, learning, communication, perception, and even problem-solving, which makes it a powerful tool for talent cultivation and assessment. One of the key applications of AI in cognitive skill prediction is the utilization of machine learning algorithms (Matsuda et al., 2007). These algorithms can process large amounts of data and uncover patterns that may not be readily apparent to the human eye, enabling more accurate predictions of an individual's cognitive abilities (Zhao et al., 2023). AI-based systems can also be tailored to provide personalized learning and assessment experiences, enhancing the overall effectiveness of the talent cultivation process (Kumar, 2019).

The application of AI in cognitive skill prediction has been on the rise, with researchers and practitioners exploring various techniques to optimize its implementation. For instance, deep learning models have been employed to analyze player performance data in the sports industry, enabling the prediction of outcomes, the identification of patterns, and the formulation of strategies that might not be evident to human experts.

2.3.2 Applying AI and ML Techniques in Cognitive Psychology Experiments

The field of cognitive psychology has long been dominated by traditional experimental methods, relying heavily on observational studies and controlled laboratory settings to understand the complex inner workings of the human mind. However, the rapid advancements in artificial intelligence and machine learning have opened up new avenues for cognitive psychologists to explore, offering a powerful set of tools and techniques that can complement and enhance their research efforts (Sinha et al., 2018).

One of the key areas where AI and ML have made significant inroads in cognitive psychology is the study of human cognitive abilities. Researchers have begun to leverage machine learning algorithms to analyze large datasets of human cognitive performance, uncovering patterns and insights that were previously inaccessible through traditional methods. This has led to a better understanding of the underlying cognitive processes that drive human decision-making, perception, and memory, among other cognitive functions (Agrawal et al., 2023).

For instance, a recent study has demonstrated the potential of using AI and ML techniques to support human instruction and learning (Mozer et al., 2019). By harnessing the power of predictive modeling and real-time feedback, these technologies can help tailor the learning experience to the individual needs of students, optimizing the delivery of content and the selection of appropriate learning activities.

Similarly, the application of AI and ML in cognitive psychology experiments has the potential to revolutionize the way researchers collect, analyze, and interpret data. Through the use of advanced pattern recognition algorithms and data mining techniques, researchers can uncover previously hidden relationships and insights within their experimental data, leading to a more nuanced and comprehensive understanding of the cognitive processes under investigation (Bhatt et al., 2023). Furthermore, the integration of AI and ML into cognitive psychology research can also enhance the scalability and efficiency of experimental methods. By automating data collection and analysis, researchers can conduct larger-scale studies, gather more detailed and precise measurements, and respond to research questions more quickly, ultimately accelerating the pace of discovery in the field.

The synergistic relationship between AI, ML, and cognitive psychology is not without its challenges, however. Ensuring the ethical and responsible use of these technologies, addressing issues of algorithmic bias, and maintaining the rigor and validity of experimental methods are all critical considerations that must be carefully addressed as this field continues to evolve (Maghsudi et al., 2021; Mozer et al., 2019). By embracing the emerging technologies of AI and ML techniques, cognitive psychologists can unlock new insights, enhance the precision and scalability of their research, and ultimately deepen our understanding of the human mind (Ma & Jiang, 2023; Yu et al., 2017).

2.3.3 Leveraging AI-Driven Data Analysis in Cognitive Psychology Research

Cognitive science, which encompasses both psychology and computational approaches, has been instrumental in driving the development of AI systems that can emulate and even surpass certain human cognitive abilities. Perception, a fundamental cognitive function, has been a particularly fruitful area of collaboration between cognitive science and AI (Kuzior & Kwilinski, 2022). By studying and emulating the various processes involved in human perception, AI researchers have been able to develop more robust and efficient computer vision and pattern recognition systems. This cross-pollination of ideas has led to significant improvements in the performance and resource efficiency of AI systems, while also providing cognitive psychologists with new tools and techniques to investigate the complexities of human perception.

The synergy between cognitive science and AI extends beyond perception. Researchers have also explored the potential of AI-driven data analysis to support and enhance human instruction and decision-making (Jiao et al., 2024). By leveraging AI algorithms to monitor and individualize the microorganization of learning and teaching activities, cognitive psychologists can gain deeper insights into the cognitive processes that underlie human learning and memory. This integration of AI-driven data analysis can help cognitive psychologists better understand the nuances and individual differences in how people acquire, retain, and apply knowledge.

As the popular media's interest in AI has primarily focused on autonomous systems that may replace human roles, the subfield of AI that aims to empower and augment human cognitive abilities has often been overlooked. However, this human-centered focus holds immense promise for advancing our understanding of the human mind and cognition, while also improving the tools and techniques available to cognitive psychologists.

2.3.4 Integrating Machine Learning Models into Cognitive Behavior Studies

In recent years, the integration of machine learning models into cognitive behavior research has emerged as a promising approach to deepen our understanding of these processes (Forstmann & Wagenmakers, 2015; Maia & Frank, 2011; Laureiro-Martinez, 2014). Machine learning algorithms have the potential to uncover patterns and relationships within large, multimodal datasets that may be difficult for human researchers to detect (Sui et al., 2020). By leveraging the power of these algorithms, researchers can develop predictive models that can forecast cognitive and behavioral

outcomes with greater accuracy, potentially leading to more effective interventions and improved mental health outcomes.

One of the key advantages of using machine learning in cognitive behavior studies is the ability to personalize diagnoses, prognoses, and treatment plans. By analyzing individual-level data, such as neuroimaging, genetic, and clinical information, machine learning models can identify unique patterns that may be indicative of specific cognitive or behavioral profiles. This personalized approach to mental health research and clinical practice holds the promise of more tailored and effective care for individuals struggling with mental health challenges (Chekroud et al., 2021).

However, the integration of machine learning into cognitive behavior research is not without its challenges. Concerns have been raised about the potential for systematic overestimation of model performance and methodological inconsistencies in the field. To address these issues, researchers have called for the development of clear guidelines and best practices for the application of machine learning in psychiatric and psychological research (Schwartz et al., 2021).

Nonetheless, the existing literature provides encouraging evidence for the potential of machine learning to enhance our understanding of cognitive behavior. Studies have demonstrated the ability of machine learning models to predict cognitive function, symptom severity, personality traits, and emotion processing from neuroimaging and other biological data.

2.3.5 Innovations in Cognitive Research through AI and ML

Researchers have now leveraged the powerful pattern recognition and data processing capabilities of AI to uncover new insights into these fundamental cognitive functions. This approach, known as "cognitive science-inspired AI," has the potential to lead to improved performance and efficiency in AI systems, as they can be designed to emulate the principles and strategies employed by the human brain (Looks & Goertzel, 2006).

In this regard, the work of (Agrawal et al., 2023) provides a comprehensive review of how AI can benefit from the principles of cognitive science, particularly in the realm of perception. Furthermore, the integration of AI and ML has also enabled researchers to develop systems that can support and enhance human instruction. These systems, which leverage interdisciplinary research from fields such as cognitive neuroscience, psychology, and theoretical computer science, have the potential to revolutionize the way we learn, remember, perceive, and make decisions. As the field of cognitive research continues to evolve, the synergistic integration of AI and ML will undoubtedly play

a crucial role in unlocking new discoveries and driving innovative solutions to complex cognitive challenges.

2.3.6 Automating Cognitive Data Processing with AI and ML Algorithms

As the volume and complexity of cognitive data continue to grow, the need for efficient and scalable data processing solutions has become increasingly urgent. Traditional manual data processing approaches have become inefficient and unsustainable, leading researchers and practitioners to explore the potential of AI and machine learning algorithms to automate and streamline cognitive data processing tasks (Taye, 2023).

One of the key challenges in automating cognitive data processing is the reliance on human-generated labels and annotations. Many data-intensive applications that leverage machine learning and AI techniques require an initial dataset annotated by humans, which can be a time-consuming and resource-intensive process. Researchers have proposed the development of "active-learning-as-a-service" systems that can efficiently manage the data labeling process, enabling the continuous improvement of machine learning models through targeted data collection and annotation (Huang et al., 2022).

Another important area of research is the development of algorithmic or information processing abstractions that can effectively model and simulate natural processes. This includes the integration of formal methods and tools for modeling and simulation, as well as the creation of cognitive tools that can leverage and extend the reach of human intellect in scientific discovery.

Recent advancements in automated data processing and feature engineering for deep learning and big data applications have also shown promise in streamlining cognitive data processing tasks (Xiong & Proctor, 2018). These techniques have the potential to simplify the design of machine learning systems and reduce the manual effort required in data preprocessing and augmentation.

As noted in (Huang et al., 2022), real-world AI applications often face more complicated scenarios that cannot be adequately addressed by a model-centric approach. In such cases, researchers must dedicate significant time and effort to data preparation, including data labeling, error detection, and monitoring for data distribution drift.

The integration of AI and machine learning algorithms will play a critical role in enabling more efficient, scalable, and effective solutions that can keep pace with the ever-increasing demands of data-driven research and discovery (Alonso, 2019; Berens et al., 2023; Honavar et al., 2016).

2.3.7 Machine Learning Approaches to Cognitive Skill Development

Traditionally, the study of cognitive skills has been dominated by theories and models rooted in psychology and neuroscience. However, the influence of pattern recognition and statistical methods during the 1990s led to a decreased interest in directly mapping human thought processes. Instead, the focus shifted towards using historical data to better predict unobserved outcomes, a core principle of machine learning.

With the exponential growth in the volume of data generated by both individuals and organizations, machine learning has become increasingly integral to the field of cognitive skill development. Researchers have explored the potential of machine learning techniques, such as deep learning and Gaussian processes, to create cognitive architectures that can mimic and potentially enhance human-like cognitive abilities (Garrido-Merchán & Molina, 2020).

One of the key advantages of using machine learning in cognitive skill development is the ability to generate synthetic data for training and testing cognitive models. This allows for more comprehensive testing and validation of cognitive theories, as well as the development of personalized learning and training programs. Furthermore, machine learning algorithms have demonstrated their capability in identifying patterns and relationships within complex data, which can be leveraged to better understand the underlying mechanisms of cognitive skill development.

As the field of machine learning continues to evolve, the integration of these techniques with cognitive science and psychology is expected to yield groundbreaking insights and advancements in our understanding and enhancement of human cognitive abilities (Abdellaoui et al., 2020; Liu et al., 2017; Lu et al., 2023).

2.3.8 Ethical Considerations in Applying AI to Cognitive Research

The application of AI in cognitive research also raises crucial ethical considerations that must be thoroughly examined and addressed. One of the primary ethical concerns is the potential for AI-driven cognitive research to infringe on individual privacy and autonomy. As AI systems become increasingly adept at analyzing and interpreting vast amounts of personal data, there is a heightened risk of sensitive information being accessed, misused, or even manipulated without the individual's knowledge or consent. This issue is particularly pertinent in the context of cognitive research, where the data collected may include highly personal and intimate details about an individual's thought processes, emotions, and behavior (Diaz-Asper et al., 2024; Fiske et al., 2019).

To mitigate these risks, it is crucial to have robust ethical frameworks and regulatory mechanisms in place (Ashok et al., 2022). Innovative algorithmic techniques, such as differential privacy, homomorphic encryption, and federated learning, can enhance the protection of personal data while still allowing for meaningful research to be conducted. Additionally, the development of comprehensive international regulations and ethical guidelines can help ensure that AI-driven cognitive research is carried out in a manner that respects individual rights and upholds ethical principles.

Furthermore, the deployment of AI in cognitive research must be accompanied by a strong emphasis on transparency and accountability. AI systems used in this domain should be designed to be transparent and explainable, allowing researchers and the public to understand the decision-making processes and the potential biases inherent in the algorithms (Brundage et al., 2020). Equally important is the need for ongoing human oversight and intervention in the application of AI to cognitive research. While AI can provide powerful analytical capabilities, the final decision-making and interpretation of findings should remain in the hands of human experts who can exercise ethical judgment and ensure that the research is conducted in a responsible manner (Peters et al., 2020).

Another key ethical consideration is the potential for AI-driven cognitive research to exacerbate existing societal biases and inequalities. If the data used to train AI systems is skewed or limited in its diversity, the resulting insights and findings may perpetuate or even amplify biases against marginalized groups. To address this challenge, researchers must actively work to diversify their data sources, collaborate with a wide range of stakeholders, and continuously monitor their AI systems for potential bias and discrimination.

Overall, the application of AI to cognitive research holds immense promise, but it must be accompanied by a robust ethical framework that prioritizes the protection of individual privacy, the transparency of AI systems, and the mitigation of societal biases.

2.3.9 The Future of Cognitive Psychology Research with AI and ML

The symbiotic relationship between artificial intelligence and machine learning technologies on the one hand and cognitive psychology on the other hand, holds immense potential, allowing researchers to gain unprecedented insights into the intricate cognitive processes that govern human behavior, decision-making, and learning (Luxton, 2014).

One key area where AI and ML are poised to revolutionize cognitive psychology is in the realm of data processing and analysis. The exponential growth in computational power and the availability

of vast datasets have enabled researchers to leverage advanced algorithms and models to uncover patterns and relationships that were previously beyond the scope of manual analysis. This ability to process and interpret large volumes of data can lead to a deeper understanding of cognitive phenomena, such as memory formation, language acquisition, and emotional processing, ultimately informing the development of more effective interventions and therapies.

Moreover, the emergence of sophisticated language models, such as those powered by transformer-based architectures, presents exciting opportunities for cognitive psychologists to simulate and test hypotheses about human behavior at a scale and speed that was un-thinkable in the past (Grossmann et al., 2023).

Another critical area of intersection between cognitive psychology and AI/ML is the field of human-centered AI. By leveraging insights from cognitive science and psychology, researchers can design AI systems that are better equipped to support and augment human cognition, learning, and decision-making. This includes developing intelligent tutoring systems that can provide personalized feedback and guidance, as well as AI-powered assistants that can enhance human perception, memory, and problem-solving abilities.

CHAPTER 3: Digital Tool for Measurement

3.1 Platform Architecture and Implementation Details

The virtual experimentation platform (Sakkas et al., 2024) is built using various web technologies, which are interconnected to achieve a complete and successful result. The online platform operates via the Internet, as shown in Figure 1. The main program runs on the server and there is direct connection to the database, which is also hosted on the server. Users access the platform through their preferred web browser over https protocol.

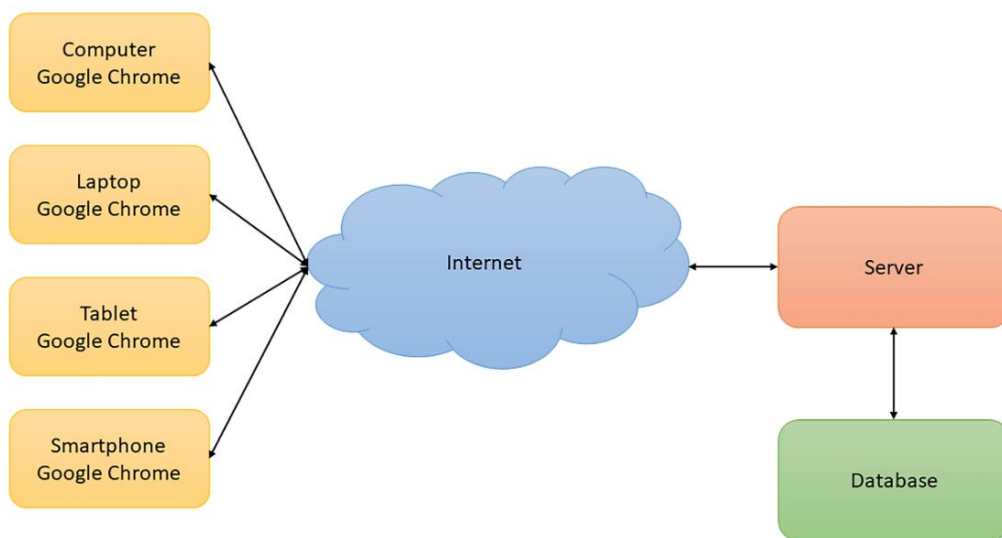


Figure 1. Virtual experimentation platform architecture

The Apache Web Server is used for serving the virtual experimentation platform, which allows multiple users to access the online platform at the same time. The technologies used to build the core of the virtual platform are HTML5, CSS3, JavaScript and PHP. For the connection with the robotic experimenter and the machine learning module, the programming language Python was also used. The program is divided into separate components that operate together and communicate with each other through the network. Recent advancements in networking technologies like the introduction of 5th Generation (5G) of mobile networks (Tsolkas & Koumaras, 2022) have enabled the digital platform components to communicate with each other without delay across all devices and technologies. These components are shown in Figure 2. and will be analyzed in detail below. This

initial prototype version of the virtual experimentation platform is localized only in the Greek language (as a consequent, examples in some figures below are in Greek language).

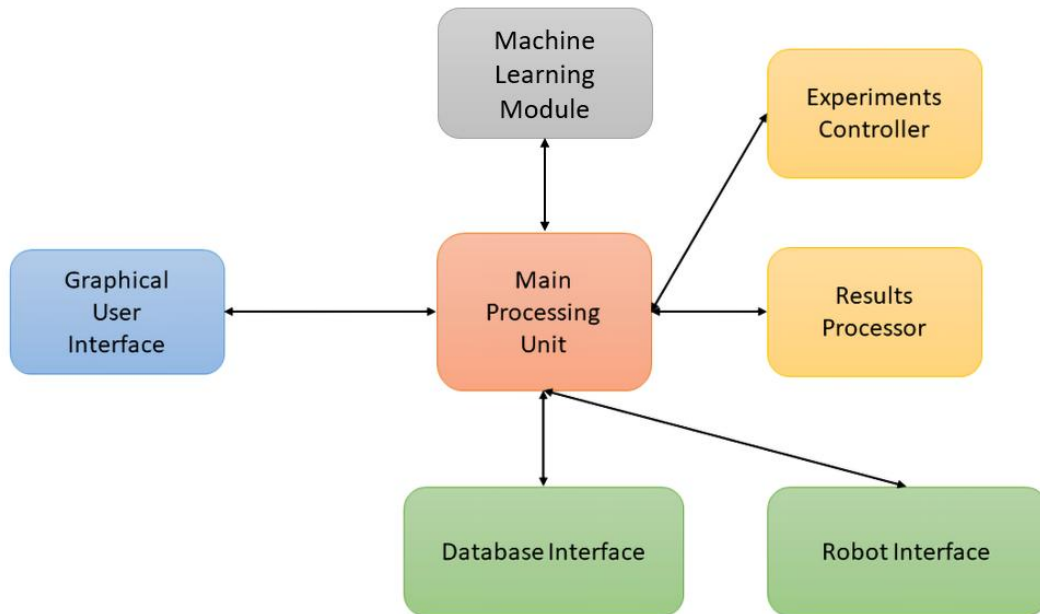


Figure 2. Core components of the program of the virtual experimentation platform

3.1.1 Main Processing Unit

The main processing unit of the virtual experimentation platform is the brain of the whole system which receives information from all the other components and determines which processes need to be executed. The most frequent interaction happens with the graphical user interface, as it receives all the necessary commands from there. Then according to these commands, it communicates with the rest of the components and sends back to the graphical user interface all the necessary information to be displayed on the users' screens.

3.1.2 Graphical User Interface

The graphical user interface is the environment that the user interacts with, in order to be able to use the virtual experimentation platform. Principles and techniques of modern software engineering and human computer interaction (HCI) were used to design and create the user experience (UX) (Alomari et al., 2020; Machado & Tao, 2007). The user interface is simple, but functional, without unnecessary buttons that could confuse the user. Also, the buttons and the information given to the user are placed in a manner that they are easily visible and clear.

The entire graphical interface follows the same design principles and it can be adjusted automatically depending on screen size and device type. All types of modern devices are supported, such as personal computers, laptops, tablets and smartphones. On large screens, the content is displayed as a whole throughout the screen, while on small screens the content components are automatically aligned one below the other and they are easily accessible by the user with the help of a scrollbar.

Finally, the online platform is compatible with all modern web browsers, namely: Google Chrome, Mozilla Firefox, Apple Safari and Microsoft Edge. This facilitates ease of access for users, without them having to download any additional software to their devices.

3.1.3 Experiments Controller

The experiments controller is activated and operates when there is at least one user executing an experiment. Its objective is to determine what is the next task in the current experiment, that the user should observe, and to keep track of time, results and responses in memory, so that all the data are collected properly and then they are transferred to the results processor.

3.1.4 Results Processor

The results processor is activated as soon as an experiment is completed and the corresponding command is given by the main processing unit. It will receive all the data and results, for the specific user and for the specific execution of the experiment, from the experiments controller and it will process them appropriately to prepare them for storage in the database. Once this process is complete the results will be sent to the database interface.

3.1.5 Database Interface

The database interface has only one task, to interact with the system database. This means both storing data and information and extracting them when they are needed by another component of the system. During these processes, data integrity checks are performed, as well as encryption and decryption when necessary.

3.1.6 Database

A database is used to store all the data and information of the platform. The database engine used is MySQL. Access to the database is password protected and the database contents are encrypted and secure. The database engine can easily be replaced if needed, since it communicates only with the Database Interface component, so changes would be required only to that component.

3.1.7 Machine Learning Module

The machine learning module is responsible for managing the neural networks, the models, and all the necessary processes required for training and generating predictive outputs using machine learning. This specific implementation is based on the Python programming language, the Keras high-level neural network API, and the TensorFlow low-level machine learning platform (Joseph et al., 2021). The module is designed to be highly adaptable and extensible, allowing for the customization of neural network models for each experiment within the virtual platform, optimizing predictive performance. Different sets of parameters and variables can be assigned dynamically to enhance model adaptability and improve prediction accuracy. Data are retrieved from the database, processed, and then stored back with additional predictive insights, including model-generated outputs and their associated confidence levels. A key feature of the machine learning module is its capability to be configured for automated daily model training. This continuous feedback loop enables the system to refine its predictions over time, leveraging newly acquired data to enhance predictive accuracy and responsiveness to evolving cognitive patterns.

It is important to highlight that the distinction between explanatory and predictive modeling is critical in understanding the role of machine learning in cognitive research. Explanatory models aim to identify causal mechanisms, while predictive models focus on generalizing to new data (Shmueli, 2010). In this research, the machine learning module is designed with a predictive objective, prioritizing accuracy in forecasting cognitive performance rather than isolating causal relationships.

3.1.8 Robot Interface

The robot interface is an optional feature-addon for the overall operation of the virtual experimentation platform. It is necessary only when the option of the robotic experimenter is enabled to perform experiments and it acts as a communication channel between the virtual experimentation platform and the program that controls the actions of the robot. Communication with the robotic experimenter is handled through this interface component, so that in the future, multiple different robots could be made easily compatible with the virtual experimentation platform.

3.1.9 Robotic Experimenter

The robot used as a prototype for the platform is EZ-Robot JD Humanoid and it is a humanoid robot built to be accessible to users and suitable for educational and other purposes (Feil-Seifer & Mataric,

2005; Nourbakhsh & Dautenhahn, 2003). It has many features such as motion, sound output, object recognition and voice recognition. Its movements range from simple hand movements to complex movements that use all the robot's joints. All this is possible due to the robot's brain, which has the ability to communicate directly with all the robot's sensors and motors, as well as with external programs on computers and tablets that perform several processes which are necessary for the robot (Fong et al., 2003). Using external programs and resources for some processes saves battery life, thus improving autonomy while providing at the same time the potential to utilize more computational power which is available in the cloud.

The robot's dimensions are 15 cm long, 13 cm wide, 33 cm high and it weighs 1.33 kg. More specifically, it consists of:

- EZ-B v4 / 2 Wi-Fi Robot hardware controller
- EZ-Builder robot control software
- An anthropomorphic robot head with built-in camera and 9 RGB LEDs for each eye
- An anthropomorphic body with battery holder, supporting 6 high performance engines for the body
 - 2 high performance hand motors
 - 2 high performance motors for legs and ankles
 - A 7.4v 1300mAh lithium battery

The robot can transmit live video and audio to its control device with the camera that is located in its head, thus enabling remote execution and supervision of robotic experiments without the subject being affected by human presence. It can also use the LEDs it has in its eyes to display different colors in different combinations. Robot speakers can produce audio, either pre-recorded (e.g. music, recorded messages), or created in real time by a microphone or text-to-audio converter.

The control software can easily and quickly record new movement actions and patterns for the robot, in turn making them available in the list of movements for immediate usage (Belpaeme et al., 2012).

Connection between the robot and the virtual experimentation platform is achieved with a custom software program that was specially developed and tailored to the needs of all experiments. This program is based on the Python programming language and the Web Sockets communication technology. It follows client-server architecture and it creates network connections to the virtual experimentation platform for synchronous data transfer between users. Also, at startup, it creates a

network connection to the robot management program to transmit the appropriate commands to the robot. The complete architecture for the robotic experimenter is depicted in Figure 3.

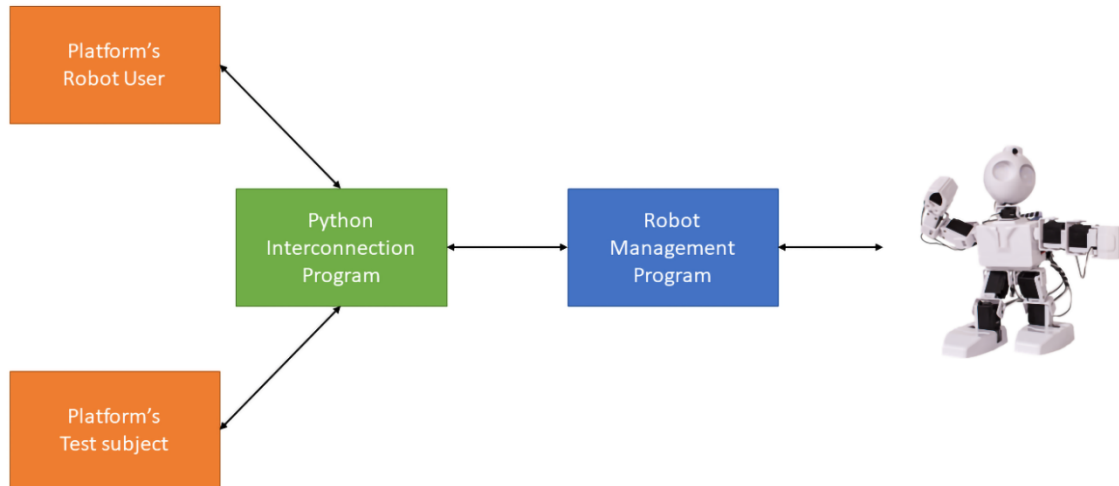


Figure 3. Robotic Experimenter Architecture

The robotic experimentation add-on of the virtual experimentation platform is designed to support multiple robotic experimenters and multiple users-subjects executing experiments concurrently on different remote locations, keeping everyone's data and information secure and isolated.

3.2 Digital Tool Usage Demonstration

The virtual experimentation platform has many functionalities and it focuses in providing, not only a testing environment for users, but also open and anonymized data for interested third party researchers to be used for further analysis and potential studies. Throughout this chapter, the functionalities of each user role that is available in the virtual experimentation platform will be presented. There is a single point of entry, in the form of a login page (requiring username and password) in the virtual experimentation platform, which handles all different user roles. Automatically, depending on the username and password, each user is redirected to the appropriate home page depending on his/her role.

3.2.1 Administrator Role

The administrator role has full control over the virtual experimentation platform and usually only few accounts are granted with this role. It can access overall statistics about the platform like how many

users are registered, how many experiments are available and how many times experiments or experiment-arrays have been executed. An example is depicted in Figure 4.

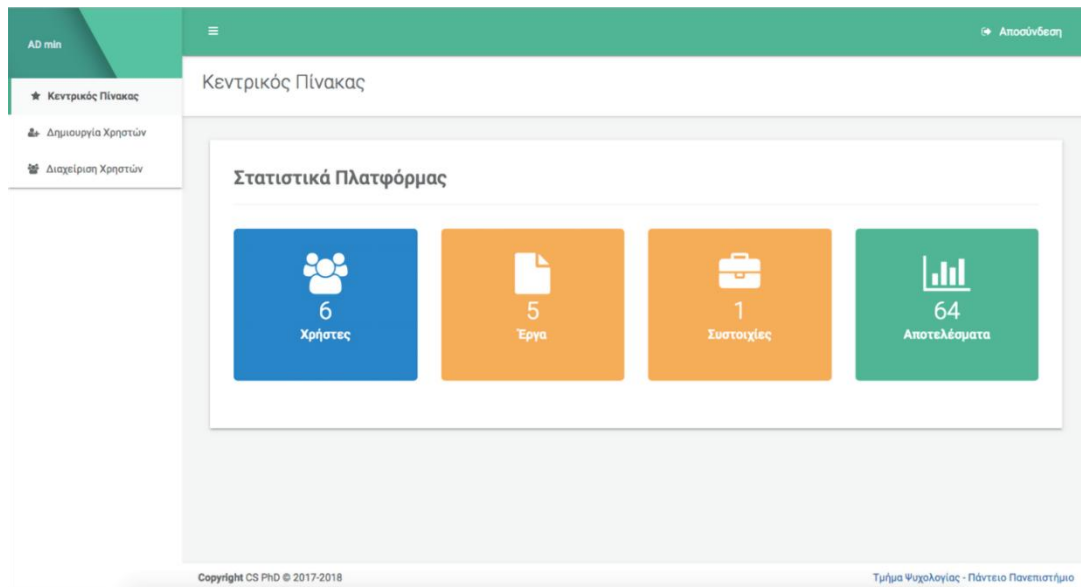


Figure 4. Administrator role statistics of the virtual platform

Another functionality that the administrator role has is that of user management. Administrators can create new users on the platform and assign specific roles to them. Also, administrators can enable and disable existing user accounts and view various information about them. A sample list of user accounts is presented in Figure 5.

ID χρήστη	Email	Όνομα	Επώνυμο	Γέννηση	Είδος	Ενεργός	Τελευταία Σύνδεση	Επιλογές
15	verifier3@test.test	doki	pisto	28/06/2013	verifier	1	2018-07-11 15:29:22	
13	admin@admin.admin	AD	min	01/01/1970	admin	1	2018-07-24 15:31:57	
12	verifier@test.test	veri	fier	01/01/1970	verifier	1	2018-07-10 14:17:13	
11	experimenter@test.test	exper	lmenter	01/01/1970	experimenter	1	2018-07-11 15:29:55	
8	kostas@test.test	Κώστας	Κωστάκης	13/06/2012	user	0	2018-07-10 14:17:22	
7	mikropaidi@test.test	Μικρό	Παίδι	16/06/2009	user	1	2018-07-24 14:43:20	
1	chsakkas@hotmail.com	Χρήστος	Σακκάς	18/10/1989	user	1	2018-07-11 04:27:31	

Figure 5. Administrator role list of user accounts

3.2.2 Data provider role

The data provider role provides access to anonymized data of experiments to external researchers, aiming to provide an open platform to share experimentation data. Those data are categorized by different experiments (Figure 6) and contain only information about the age of subjects at the time of experiment execution. No other personal information is provided, thus effectively anonymizing the subjects.

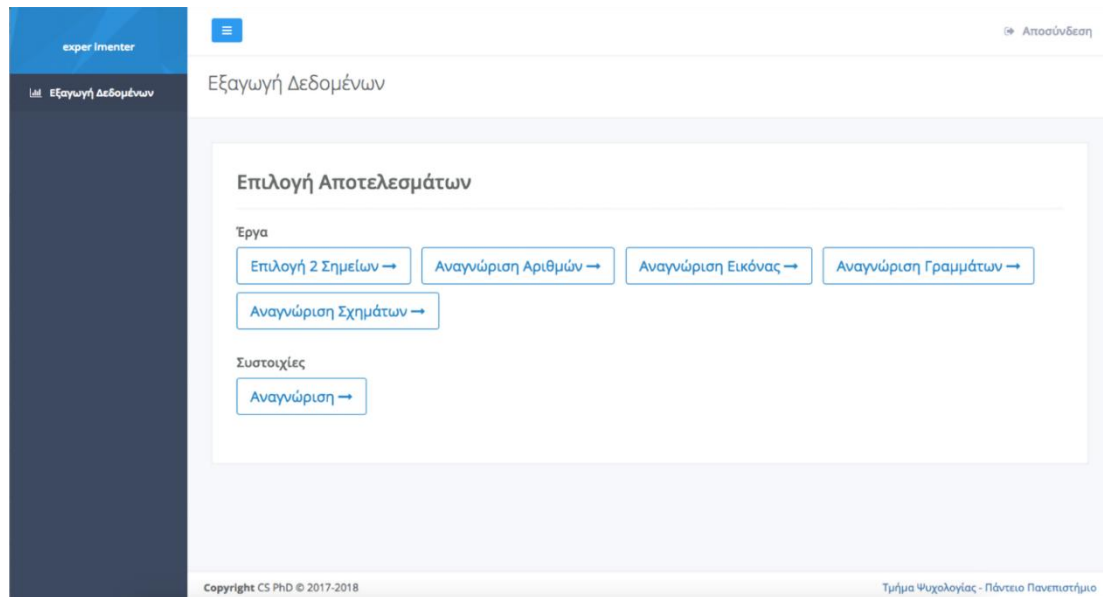


Figure 6. Data provider role experiment selection screen

A sample dataset of an experiment is depicted in Figure 7. Detailed data for each execution of the experiment are provided, like the encrypted user id, user age, datetime of execution, time of completion, tasks totals, execution times, results and averages. All those data are available for export and download in a csv file for further statistical analysis in specialized statistical programs, such as SPSS.

Επιλογή 2 Σημείων

Εξαγωγή →

ID χρήστη	Ηλικία	Εκτέλεση	Χρόνος	Σύνολο	M.O.	Ελάχιστο	Μέγιστο	Δ1	Δ2	Δ3	Δ4	Δ5	Δ6	Δ7	Δ8	Δ9	Δ10	Πιστοποίηση
902ba3cda1883801594b6e1b452790cc53948fda	13	2019-03-10 15:58:51	38	10	1857	605	4482	1587	605	4482	1278	1568	796	1234	838	2405	3775	0
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-07-11 15:27:48	30	10	615	509	981	582	570	636	511	520	580	509	722	981	534	1
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-07-11 03:22:56	32	10	695	519	1088	553	519	599	1088	588	565	939	949	618	531	0
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-07-10 18:14:45	30	10	710	517	1557	649	597	568	760	668	1557	587	517	546	651	1
356a192b7913b04c54574d18c28d46e6395428ab	32	2018-07-10 17:48:31	26	10	648	537	916	576	602	537	612	651	560	916	906	572	549	0
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-07-10 16:39:42	27	10	656	522	948	640	522	573	699	586	569	542	569	948	913	0
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-06-13 17:34:49	50	10	2781	765	11702	1260	975	2277	765	992	915	867	4636	11702	3421	0
902ba3cda1883801594b6e1b452790cc53948fda	13	2018-06-13 17:33:52	31	10	831	571	1132	767	767	788	956	617	571	1132	980	1108	628	0

Figure 7. Data provider role sample experiment data

3.2.3 Data verifier role

The data verifier role enables an optional but important functionality of the virtual experimentation platform. As this is an online accessible platform, some experiments can be designed to be publicly available without direct supervision from qualified experimenters. The results of these experiments cannot guarantee data integrity, thus there was a need to verify the data that were actually produced by experiments executed in a supervised environment. This is the functionality of the data verifier role. The verifier can choose which executions of the experiments are legit from a list of recent executions, depicted in Figure 8. Each verifier is assigned to multiple test subject accounts and they can verify only the experiment executions of those test subjects, in order to achieve isolation between users of the virtual platform and to avoid unauthorized changes.

ID χρήστη	Email	Όνομα	Επώνυμο	Συστοιχία	Εκτέλεση	Επιλογές
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Εικόνας	2018-07-11 15:29:00	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Αριθμών	2018-07-11 14:59:04	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Αριθμών	2018-07-11 14:58:00	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Σχημάτων	2018-07-11 04:34:35	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Γραμμάτων	2018-07-11 04:31:55	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Εικόνας	2018-07-11 04:30:32	✓ ✗
7	mikropaidi@test.test	Μικρό	Παιδί	Αναγνώριση Εικόνας	2018-07-11 04:29:35	✓ ✗

Figure 8. Data verifier role list of recent experiment executions

3.2.4 Robot user role

The robot user role enables the additional and optional functionality of having a remote-controlled robotic experimenter. It allows a humanoid robot, compatible with the virtual experimentation platform, to be controlled by simple buttons through a web browser. Simultaneously with sending commands for controlling the robot, additional commands are being sent to the test subject device that is executing the experiment, so that appropriate tasks and stages of the experiment are displayed on screen and they are synchronized with the movements and actions of the robot.

The home page of this user role is depicted in Figure 9 and it contains a button (“Connect with Experiment”) which, when pressed, redirects the robot user to the control screen of the active experiment.

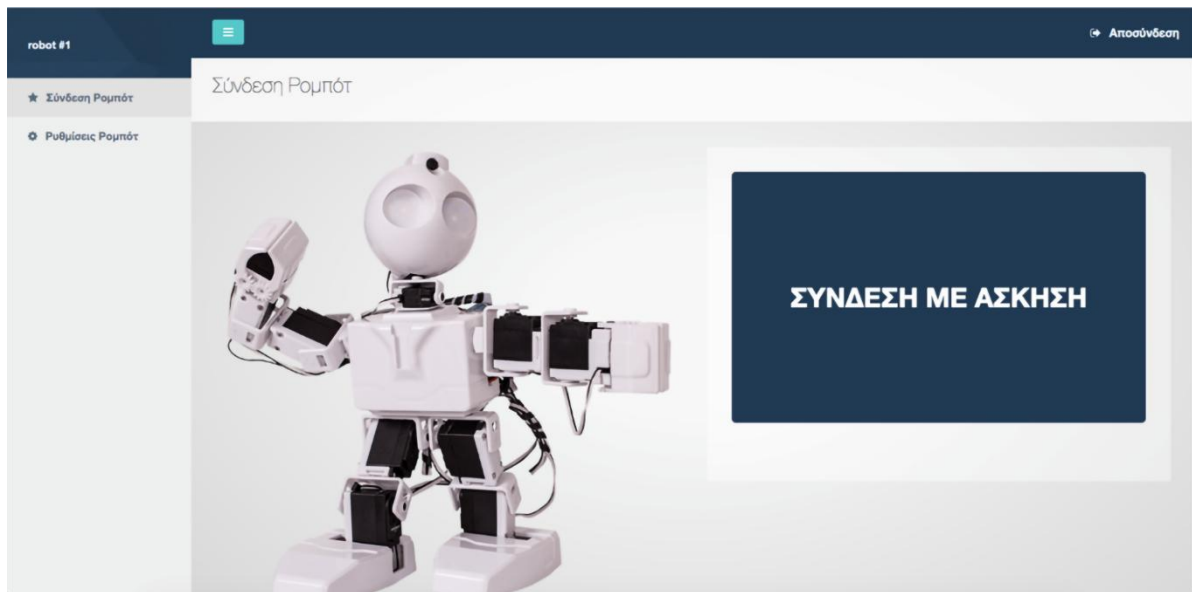


Figure 9. Robot user role home page

Just before the experiment control screen appears on screen, the program automatically detects if there is an active experiment ready for execution on a test subject user account, that requires robot experimenter. Association between robots and test subjects is configured by the settings screen, depicted in Figure 10. Then, the necessary commands and texts that are configured for the specific experiment are automatically loaded and displayed. Using the configuration screen, the robot user can configure the robot's name and IP address, so that every robot available in the virtual experimentation platform is uniquely identified and there is no conflict in the commands transmitted between the platform and the robots. This process is usually only needed once at the beginning, when installing a new robot on the virtual experimentation platform.

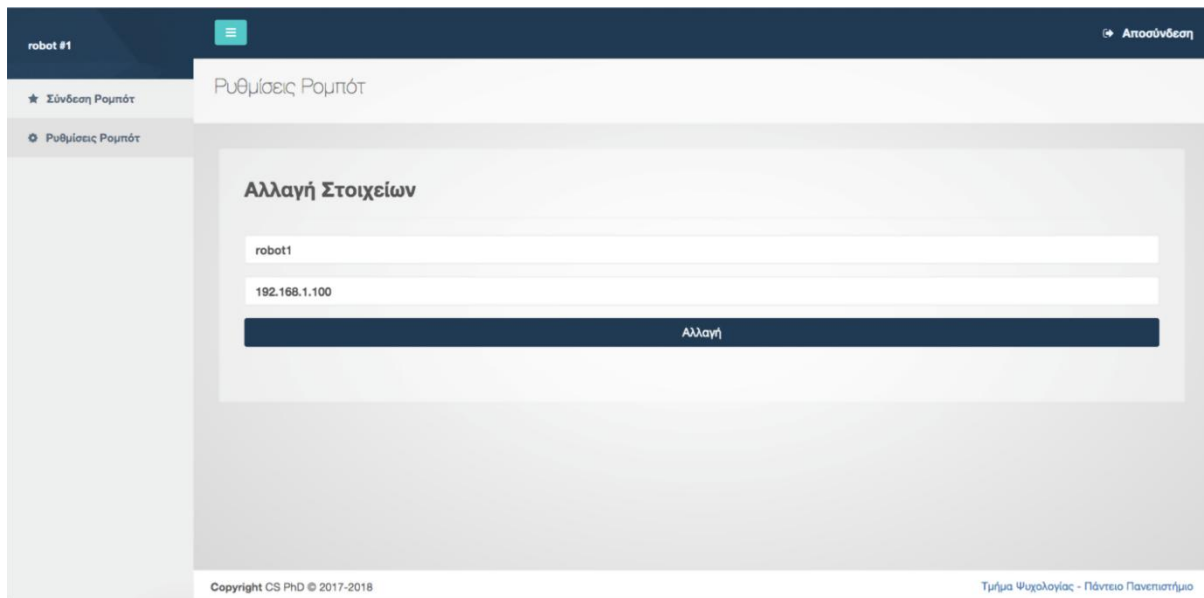


Figure 10. Robot user role configuration screen

The experiment control screen of the robot user role, depicted in Figure 11, contains all the necessary buttons required for each experiment. Each button corresponds to a command for a robot action coupled with commands for the content (visual and audio) that will be displayed on the device of the test subject which is executing the experiment.

The core commands of the active experiment are displayed on the left side of the screen. The commands are unique to each specific experiment, and they appear with the predetermined execution order, one by one. Also, there is information on the current, as well as the next step and text that the robot will produce from its speakers, in order to provide help and insight to the operator of the robot throughout the progression of the experiment.

On the right side of the screen there are generic actions that the robot can execute, which include different movement patterns or generic voice commands that can create general behaviors used to encourage, direct or motivate the test subjects. Although voice commands and movement commands can be executed concurrently, if the same type of command (e.g. 2 movement commands) is given at the same time, then the system will execute them sequentially.

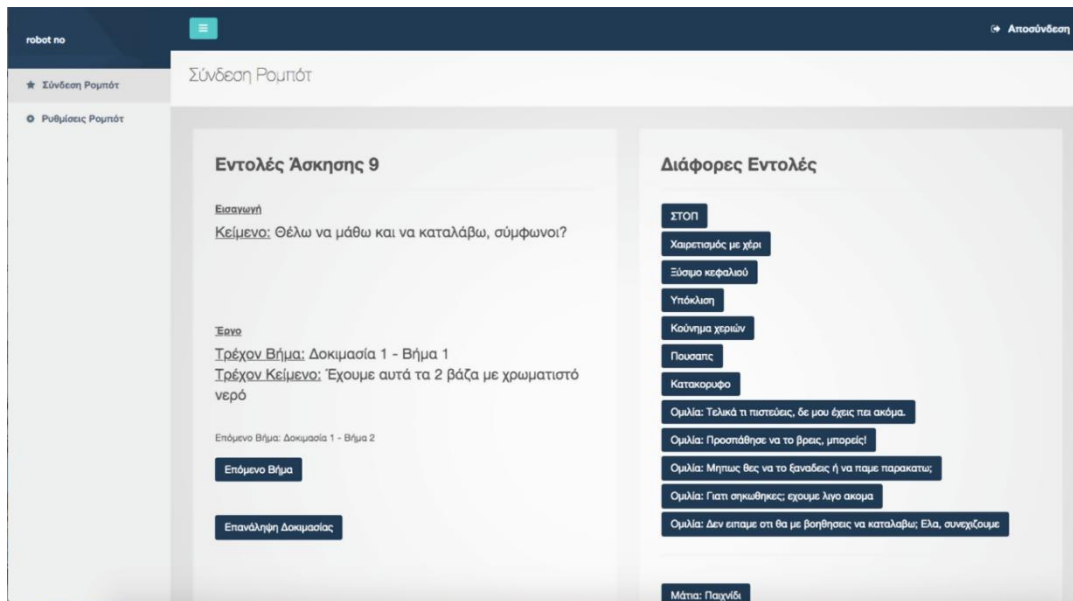


Figure 11. Robot user role experiment control screen

3.2.5 Test subject role

The test subject role has access to a list of available experiments (Figure 12), filtered by age, and they can execute them on demand. Each experiment information card consists of a title, a brief description and metadata describing the measurements that are acquired by executing the experiment.

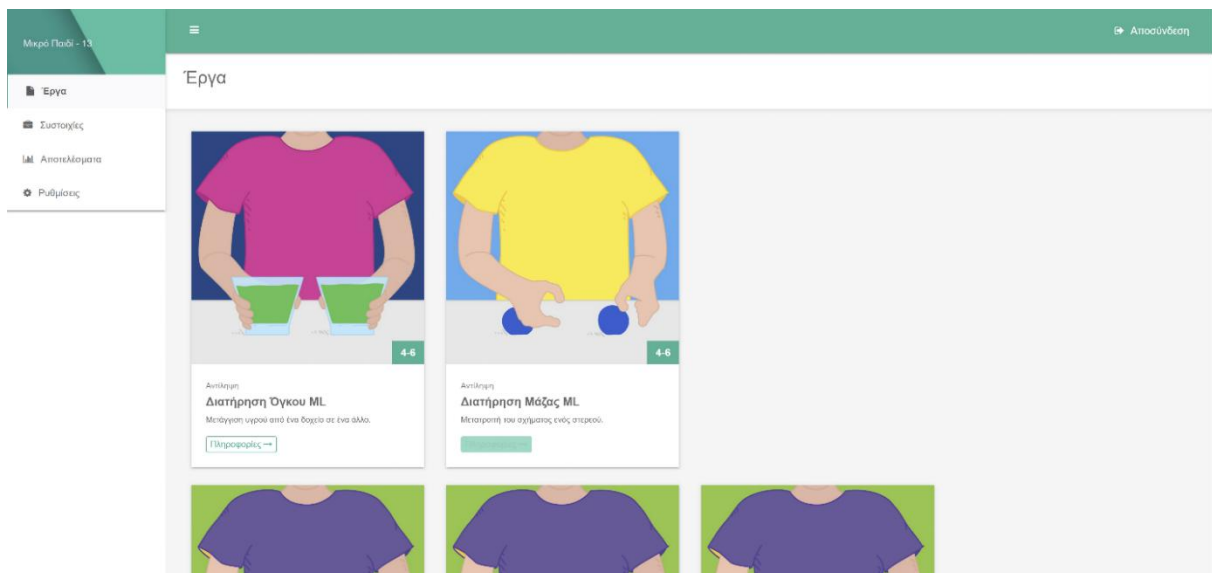


Figure 12. Test subject role list of available experiments

Additionally, the virtual experimentation platform has the option of enabling or not the access and visibility of experiment results to the test subject users that executed them. If this option is

enabled, those results are presented per execution of each experiment, and they are numerical and graphical. An example of such results is presented in Figure 13.

Επιλογή 2 Σημείων

2019-03-10 15:58:51

Χρόνος: 38 sec
Σύνολο: 10
Μέσος Όρος: 1857ms
Ελάχιστο: 605ms
Μέγιστο: 4482ms

x: αριθμός σημείου - y: χρόνος απόκρισης (ms)

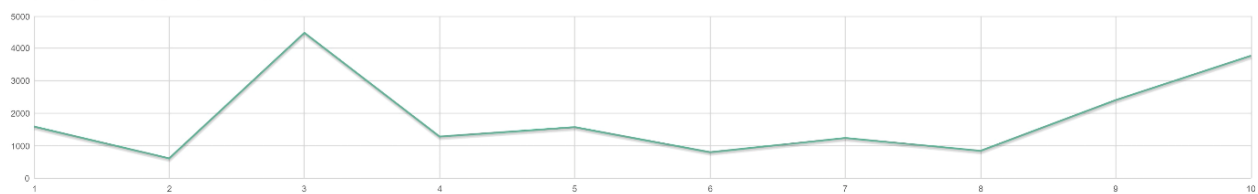


Figure 13. Test subject role sample experiment results

In order to examine thoroughly the questions that were arized and the theoretical approaches that were presented and analyzed in the theoretical chapters of this thesis, as well as to verify the functionality, and present the capabilities of the virtual experimentation platform, three separate studies were conducted. All experiments were implemented in accordance with The Declaration of Helsinki statement of ethical principles, World Medical Association (WMA), 1964 as well as The European Code of Conduct for Research Integrity, published by All European Academies (ALLEA) Berlin, 2017. Each experiment implemented as part of the virtual experimentation platform has different characteristics, description, execution and measurements. The specifics of each study will be presented and discussed in the following chapters.

CHAPTER 4: Study 1 - A Prototype Implementation of a Virtual Platform with Robotic Integration and Machine Learning Capabilities for the Execution of Cognitive Psychology Experiments in Children

4.1 Introduction

Virtualization has become more common in recent generations as open participation in the digital revolution has risen (Huamaní, 2014). Virtual applications for developmental study with children, on the other hand, have gotten very little consideration and the methods used to execute such cognitive developmental studies are still lacking the inclusion of technology, such as the use of virtual and automated platforms or even the inclusion of automated robots.

As the COVID-19 outbreak diminished social interaction, leading to the closure of many developing institution research facilities in 2020, scientists started to look for alternative ways of executing cognitive development experiments, among which the use of virtual research techniques is the most promising one (Gijbels et al., 2021), since it allows the execution of psychological experiments without requiring a direct social interaction and at the same time the participants are not influenced by the physical presence of the experimenter, which could affect negatively their behavior.

Considering this digital transition, the shift from in-person to virtual research is particularly challenging and recent research studying manipulation, proposed even tools of detecting manipulators among digital platforms users (Fedushko et al., 2019). This scientific challenge concerns also developmental psychologists due to lack of equipment used for recording critical aspects of experiments. Acknowledging this, researchers want to contribute to the field by providing tools that enable performing different and regulated virtual cognitive development experiments in children.

However, in order for these regulated virtual cognitive experiments to be executed and delivered to children, novel and sophisticated virtual platforms are required, which will be capable of parametrizing the experiment structure, e.g. its questions, answers and interface, while also providing innovative ways of interaction between the experimenter and the children, realizing the gamification of the whole process, attracting children's interest and therefore optimizing the process by obtaining the best possible results. Such virtual learning/experimentation platforms are extensively described and presented in the literature (e.g Bri et al., 2009; Georgouli, 2011; Kliziene

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et al., 2021), but they are not customizable enough and most of them are outdated and they do not integrate modern technologies, like automated humanoid robots and machine learning.

Towards this direction, the author was motivated to design and implement a novel virtual platform that can host different experiments, it is extensible and combines the use of an automated robot in the role of the experimenter (Dautenhahn, 1999; Feil-Seifer & Mataric, 2005; Nourbakhsh & Dautenhahn, 2003) in order to offer the children participants not only an easy way of interacting with the questions, but also an innovative gamified environment by using a robot (Wei et al., 2011), which transforms a currently traditional process to an interesting and unique experience. The aforementioned platform also has machine learning capabilities and it can automatically analyze the results of the experiments that are performed through it (Jacobucci & Grimm, 2020). The scope of this study is to describe in detail the design architecture and the implementation details of this virtual platform and perform a basic functionality test, by using three different modes of execution in a proof-of-concept experiment to showcase the possible use cases of the virtual platform. The experiment chosen is based on Piaget's conservation tasks, which is among the most popular experiments in cognitive development area. The scientific hypothesis concerning the high functionality of the virtual platform was formulated. The virtual platform is expected to reach 100% success rate in executing the experiments and storing results in the database and at the same time provide the users with a smooth and enjoyable experience. At the same time the results of the chosen experiment will be presented and analyzed in order to further reinforce and empower the significance and importance of the virtual platform in the area of modern psychology experimentation and measurement.

The rest of this study is organized as follows: The background section discusses the use of virtual platforms in psychology, briefly presents Piaget conversational tasks theory, analyzes why the inclusion of a robotic experimenter is in favor and provides a brief overview of machine learning in psychology. Then, the prototype implementation of the proposed virtual platform is presented in detail (Sakkas et al., 2024), showing its advantages in configurability and adaptability. Finally, the execution of experiments, based on the conservation tasks of Piaget, is used as an example of the virtual platform usage in cognitive developmental and the experimental methodology and results are presented and discussed.

4.2 Method

To showcase, validate and provide an initial proof of concept for the virtual experimentation platform an experiment was selected. This experiment is based on Piaget's conservation tasks, and more specifically, it is the volume conservation of liquids.

Liquid conservation experiment requires the test subject to answer if the volume of the liquid present in different containers remains the same or if it changes when the liquid is transferred from one container to another. The first container is short and wide while the second container is tall and narrow. The introductory screen of this experiment, containing various valuable information, is provided by the system to the test subject and it is depicted in Figure 14.

Figure 14. Volume conservation introductory page

The experiment is targeting children 5-6 years old, and it takes 3-5 minutes to complete. It can be completed either completely online and unsupervised, or with the help of an experimenter (human or robot). The research results that are produced by the system after the execution of the experiments are: i) total time needed for the completion of the whole experiment, ii) answer to each task provided by the test subject and iii) time needed for the test subject to provide the answer.

In order to assess all the available functionalities of the platform the experiment was executed in three different modes. The first 10 test subjects performed the experiment online in tablet devices. The second group of 10 test subjects again performed the experiment with the additional help of a robotic experimenter. The last group of subjects consisted of 120 participants, and it was used to

Study 1 - A Prototype Implementation of a Virtual Platform with Robotic Integration and Machine Learning Capabilities for the Execution of Cognitive Psychology Experiments in Children

gather data and perform the initial training of the machine learning module. Half of the test subjects in the first and second group were approximately 5 years old and the other half was approximately 6 years old. In the third group, 52 of the subjects were approximately 5 years old and the other 68 were approximately 6 years old.

The order of the tasks in the experiment is presented sequentially to the test subjects. These tasks fall into four different categories: the general concept of conservation, identity, compensation, and reversibility. A total of 4 tasks, one from each category, are used to complete the experiment. Random colors, containers and sizes are picked each time automatically and they are presented on screen.

Each individual task consists of 3 steps. Each step is described by voice, text and an image or a short video. The test subject at the end of the task, in step 3, is asked to select an answer by pressing the appropriate button (Figure 15). The available buttons for these two experiments are “SAME”, “MORE”, “LESS”, “DON’T KNOW” and they are displayed in random order for each task.

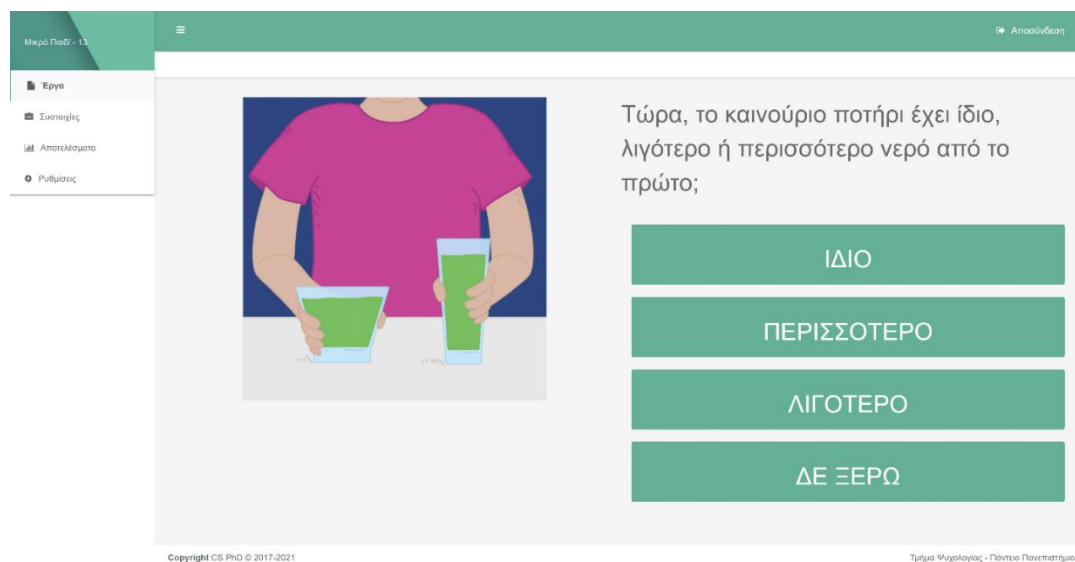


Figure 15. Test subject role experiment answer buttons screen.

In the end of the experiment execution, after all tasks are completed, there is the option to present the participant with the results of this execution. Such an example is depicted in Figure 16. Green color indicates correct answer and red color indicates wrong answer for the respective task.

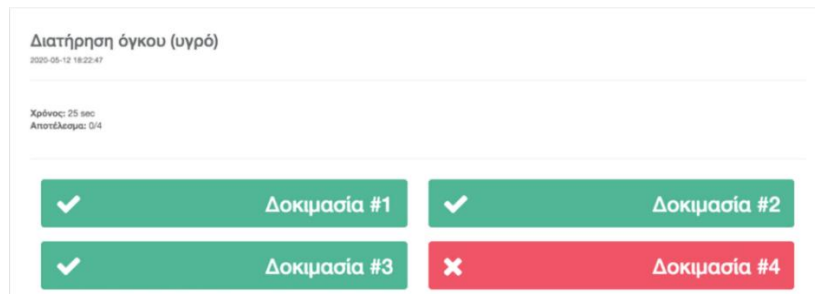


Figure 16. Test subject role experiment results

The neural network model used for this experiment consisted of four layers, one input, one output and two hidden layers (Figure 17). For the 3 first layers the rectified linear activation function (ReLU) was used. It is a linear function that will output the input directly if it is positive, otherwise, it will output zero. This has become the default activation function for many types of neural networks because a model that uses it is easier to train and often achieves better performance (Moolayil, 2019). The optimizer used was Adam, which features adaptive learning rates, bias correction and it has low memory requirements (Kingma & Ba, 2014). As this is a binary classification problem, since it has correct and wrong as possible answers the binary cross-entropy loss function was used. In combination with the sigmoid activation function from the output layer they create a synergistic effect for the following reasons:

- **Probabilistic Output:** The sigmoid function ensures the output is a probability, restricting the value between 0 and 1. This perfectly aligns with the binary cross-entropy function, which operates on predicted probabilities.
- **Effective Learning Gradient:** For efficient learning, the loss function should provide a good gradient. Owing to the mathematical properties of the sigmoid and binary cross-entropy functions, their gradient product is conducive to learning.
- **Penalty for Incorrect Predictions:** The combined use of these functions effectively penalizes wrong yet confident predictions. If the network makes a wrong prediction with high confidence, the sigmoid function will yield a value close to 0 or 1, leading to a large binary cross-entropy loss due to its logarithmic component.

The neural network created was trained for 400 epochs, in order to be accurate enough but also to avoid overfitting problems (Ying, 2019). Finally, after the machine learning module completed the training, the answers from the first two groups were fed into the system in order to evaluate the accuracy of the algorithm.

Study 1 - A Prototype Implementation of a Virtual Platform with Robotic Integration and Machine Learning Capabilities for the Execution of Cognitive Psychology Experiments in Children

```

Using TensorFlow backend.
conservation identity compensation reversibility age
0 0 0 0 0 5
1 1 0 1 1 5
2 0 0 0 1 5
3 0 0 0 0 5
4 0 0 0 0 5
['identity', 'compensation', 'reversibility', 'age']
-----
Layer (type)                Output Shape                Param #
-----
dense_1 (Dense)             (None, 4)                  20
-----
dense_2 (Dense)             (None, 16)                 80
-----
dense_3 (Dense)             (None, 16)                 272
-----
dense_4 (Dense)             (None, 1)                  17
-----
Total params: 389
Trainable params: 389
Non-trainable params: 0
-----
Epoch 1/400
120/120 [=====] - 1s 4ms/step - loss: 4.1260 - acc: 0.5917

```

Figure 17. Machine learning module model and training data screenshot

4.3 Results

The virtual experimentation platform functioned as intended in all experiment executions as presented in Table 1. Data from all the test subjects were stored in the database and they were available for further usage. Each test subject executed the experiment successfully in all modes. Thus, the virtual experimentation platform gathered a total of 600 answers, along with the accompanying research results for each one. The platform reached the desired 100% success rate in operational evaluation as it did not produce a single error during the execution of the tasks.

Table 1. Virtual experimentation platform liquid conservation execution results

Mode	Tasks	Conservation	Identity	Compensation	Reversibility	Total
Online	Success	10 (100.0%)	10 (100.0%)	10 (100.0%)	10 (100.0%)	40 (100.0%)
	Error	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	Total	10	10	10	10	40
Robot	Success	10 (100.0%)	10 (100.0%)	10 (100.0%)	10 (100.0%)	40 (100.0%)
	Error	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
	Total	10	10	10	10	40
ML	Success	120 (100.0%)	120 (100.0%)	120 (100.0%)	120 (100.0%)	480 (100.0%)

Error	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total	120	120	120	120	480

For the analysis of the results both incorrect answers (“MORE” and “LESS”) and the answer “DON’T KNOW” were considered as wrong. In Table 2 the frequencies of the answers of the participating children are presented.

Table 2. Virtual experimentation platform liquid conservation answers.

Mode	Tasks	Conservation	Identity	Compensation	Reversibility	Total
Online	Correct	4 (40.0%)	6 (60.0%)	6 (60.0%)	6 (60.0%)	22 (55.0%)
	Wrong	6 (60.0%)	4 (40.0%)	4 (40.0%)	4 (40.0%)	18 (45.0%)
	Total	10	10	10	10	40
Robot	Correct	4 (40.0%)	5 (50.0%)	3 (30.0%)	6 (60.0%)	18 (45.0%)
	Wrong	6 (60.0%)	5 (50.0%)	7 (70.0%)	4 (40.0%)	22 (55.0%)
	Total	10	10	10	10	40
ML	Correct	45 (37.5%)	49 (40.8%)	50 (41.7%)	66 (55.0%)	212 (44.2%)
	Wrong	75 (62.5%)	71 (59.2%)	70 (58.3%)	54 (45.0%)	268 (55.8%)
	Total	120	120	120	120	480

In Table 3, all possible outcomes of the experiment executed for each age are depicted. It is observed that some outcomes have probability close to 0.5, which means that the prediction for Correct or Wrong is done with very small confidence level and it is close to luck. However, other outcomes have probability very close to 1 or 0 which means that they are very accurate and they have important predictive value. By using more data to train the model, accuracy is expected to increase. Also, it is clear that on average, the predictions for 6-year-old children are a little more confident than for 5-year-old children.

Table 3. Machine learning neural network model outcomes matrix with probabilities.

Age	Identity	Compensation	Reversibility	Conservation Prediction	ML Probability
5	Correct	Correct	Correct	Correct	0.78
5	Wrong	Wrong	Wrong	Wrong	0.08
5	Correct	Wrong	Correct	Correct	0.81

Study 1 - A Prototype Implementation of a Virtual Platform with Robotic Integration and Machine Learning Capabilities for the Execution of Cognitive Psychology Experiments in Children

5	Correct	Correct	Wrong	Correct	0.67
5	Wrong	Correct	Correct	Wrong	0.25
5	Correct	Wrong	Wrong	Correct	0.65
5	Wrong	Correct	Wrong	Wrong	0.49
5	Wrong	Wrong	Correct	Wrong	0.12
6	Correct	Correct	Correct	Correct	0.78
6	Wrong	Wrong	Wrong	Wrong	0.06
6	Correct	Wrong	Correct	Correct	0.84
6	Correct	Correct	Wrong	Correct	0.67
6	Wrong	Correct	Correct	Wrong	0.18
6	Correct	Wrong	Wrong	Correct	0.68
6	Wrong	Correct	Wrong	Wrong	0.41
6	Wrong	Wrong	Correct	Wrong	0.08

To test the actual accuracy of the trained model, new data that were not in the training dataset needed to be fed in the system. In this case the answers from the first 20 participants (online and robot) were not in the training dataset for the machine learning module, so they were used as the validation dataset. Detailed results for each test subject are depicted in Table 4. After the subject id column, the following 4 columns contain the actual answers from the test subject. The final column contains the prediction for conservation from the machine learning module. Rows highlighted with gray background are the ones that presented difference between the prediction and the actual answer.

Table 4. Machine learning neural network model validation.

Test Subject	Age	Identity	Compensation	Reversibility	Conservation	ML Prediction
1	5	Wrong	Correct	Wrong	Wrong	Wrong
2	5	Correct	Correct	Correct	Wrong	Correct
3	5	Correct	Correct	Correct	Correct	Correct
4	5	Wrong	Wrong	Correct	Wrong	Wrong
5	5	Wrong	Wrong	Wrong	Wrong	Wrong

Development of Cognitive Abilities: Design and Implementation of a Digital Tool for Measurement

6	6	Correct	Wrong	Wrong	Wrong	Correct
7	6	Correct	Correct	Wrong	Correct	Correct
8	6	Wrong	Wrong	Correct	Wrong	Wrong
9	6	Correct	Correct	Correct	Correct	Correct
10	6	Correct	Correct	Correct	Correct	Correct
11	5	Correct	Wrong	Wrong	Wrong	Correct
12	5	Wrong	Wrong	Correct	Correct	Wrong
13	5	Wrong	Wrong	Wrong	Wrong	Wrong
14	5	Wrong	Wrong	Wrong	Wrong	Wrong
15	5	Correct	Correct	Correct	Correct	Correct
16	6	Correct	Correct	Correct	Correct	Correct
17	6	Wrong	Wrong	Correct	Wrong	Wrong
18	6	Correct	Correct	Correct	Wrong	Correct
19	6	Correct	Wrong	Correct	Correct	Correct
20	6	Wrong	Wrong	Wrong	Wrong	Wrong

The results indicate that the machine learning model evaluated by these data had 75% success rate (15/20 successful predictions) in predicting the conservation answer for new test subjects, if it already has their age and the answers for identity, compensation and reversibility. After the evaluation these data were used to additionally train the model in order to improve its accuracy for future predictions.

4.4 Discussion

In the literature numerous virtual learning/experimentation platforms are presented (e.g Bri et al., 2009; Georgouli, 2011; Kliziene et al., 2021), but most of them are outdated and they do not integrate modern technologies, like automated humanoid robots. Given that virtual applications for developmental study with children have gotten little consideration and that the methods used to execute such cognitive developmental studies are still lacking the inclusion of technology, the virtual platform described in this study constitutes a precious tool. It is friendly to any user and answers to the scientists' interest for alternative ways of executing cognitive development experiments using virtual research techniques (Gijbels et al., 2021). This platform permits also to overcome cognitive

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obstacles mentioned in literature concerning a direct social interaction, as children are not influenced by the physical presence of the experimenter, which could negatively affect their behavior (McGarrigle & Donaldson, 1974).

Modern web technologies and methodologies were used in the design and development of the virtual experimentation platform (Gabarró, 2006), as well as software tests were performed (Myers et al., 2011) in order to validate the proper and complete functionality. Additionally, data from the 140 test subjects validated the tool and verified the hypothesis concerning the high level of functionality of the platform. It seems that the use of an automated robot in the role of the experimenter (Dautenhahn, 1999) offer the children an easy way of interacting with the questions, and an innovative gamified environment (Wei et al., 2011), which transforms a currently traditional process to an interesting experience. The proposed condition ensures equal roles to both participants, child, and robot-experimenter, during their interaction. Furthermore, a very special advantage of this virtual platform is, that no manipulation of the user's feelings or decision making in on-line communication occurs, contrary to suggestions of some recent studies (Fedushko et al., 2019). Finally, the machine learning module presented in this study constitutes a significant tool for researchers, enabling the extraction of meaningful conclusions and the identification of complex patterns within cognitive development data. The experiment selected for the machine learning module utilized a limited number of variables to be analyzed by the neural network, as its primary objective was to demonstrate the virtual platform's capabilities rather than conduct an extensive predictive analysis. However, due to the platform's extensibility, researchers can leverage its computational power to develop more sophisticated neural network models, optimizing the predictive accuracy of cognitive assessments through artificial intelligence.

This study has introduced a prototype implementation of a virtual platform integrating robotics and machine learning for conducting cognitive developmental psychology experiments in children. The research highlights the advantages of employing a virtual platform for this purpose, particularly in terms of its configurability, adaptability to diverse experimental designs, and capacity to tailor the user interface to different research questions. Additionally, the study provides a comprehensive description of the platform's architecture and functionalities. A key contribution to the scientific community is the open access to experimental data, allowing further exploration and validation of findings in cognitive development research.

The platform's implementation and usage were validated through a cognitive developmental experiment based on Piaget's theory of conservation of liquid, tested on 140 participants. The predictive power of machine learning, when integrated into such a research framework, holds significant implications for advancing cognitive assessment methodologies. Beyond research, the platform's applications extend to health, education, and child development, offering an accessible and scalable tool for analyzing and understanding cognitive processes in a data-driven manner.

**CHAPTER 5: Study 2 - 5-Year-Old Children Performing Piaget's Liquid Conservation Tasks
Demonstrated in Physical and Digital Environment**

5.1 Introduction

The advent of digital technology has transformed our manner to perceive and interact with the world, a change that is profoundly evident in the field of child development. With the increasing ubiquity of digital devices in children's lives, it becomes imperative to understand how interactions with virtual environments influence cognitive development (Sung et al., 2016; Zhang & Nouri, 2018). This study delves into the cognitive processes of children aged approximately 5 years old and specifically in their understanding of liquid conservation, a concept pivotal in Piaget's theory of cognitive development (Babakr et al., 2019; Piaget 1951,1954; Piaget & Inhelder 1974). Conservation tasks, which assess a child's ability to recognize that certain properties of objects remain constant despite changes in their form or arrangement, have long been a cornerstone in evaluating cognitive growth.

In this study, a novel dimension of this theory is explored by juxtaposing children's interaction with a liquid conservation task in two distinct environments: the digital and the physical. Do children perceive and process information differently when presented in a digital format compared to a physical one? This question lies at the heart of this study. The comparison of digital and physical environments in understanding liquid conservation provides a unique lens through which the impact of digital environments on cognitive development is examined. This study, therefore, seeks to bridge the gap between traditional developmental theories and the contemporary digital context in which today's children are immersed. Recent studies have shed light on the evolving landscape of digital learning tools in early childhood education (Behnamnia et al., 2020). Researchers have studied the impact of these tools on learning outcomes, exploring how they contribute to cognitive development, literacy, and other essential skills (Palaiologou, 2016). Concurrently, concerns have arisen regarding the effects of prolonged screen time on children's attention span, social interaction, and overall well-being, prompting deeper investigations. Central to these inquiries is the quality of content and design, with a focus on assessing the effectiveness of interactive games, educational apps, and multimedia resources in engaging young learners (Murcia et al., 2018). Equally important is the role of educators in integrating digital tools into curricula, necessitating attention to teacher training and ongoing support mechanisms. So the comparison performed in this research is not only a matter of

academic interest but has practical implications in areas ranging from educational technology to parenting strategies in the digital era.

Piaget's conservation theory is a fundamental concept in developmental psychology, and it is also central to Piaget's stages of cognitive development. This theory suggests that children reach the ability to grasp conservation at the concrete operational stage (Elkind, 1967; Piaget, 1951, 1954). Key experiments involving the conservation of number, length, mass, and liquid volume were used to demonstrate this theory, revealing how younger children often struggle with understanding that the transformation of an object's shape or arrangement does not necessarily mean a change in its quantitative properties. This foundational theory has significantly influenced the understanding of children's cognitive development. Experiments were conducted where, for instance, liquid would be poured from a short, wide glass into a tall, thin glass, and children would be asked if the amount of liquid changed. Younger children typically responded that the quantity had changed, demonstrating a lack of conservation understanding. This concept is crucial in the study of cognitive development, indicating a shift from preoperational to concrete operational stages in a child's thinking, where they begin to understand the world more logically.

Whereas some studies often replicated Piaget's original experiments, others expanded on them, and they added additional features and parameters (e.g., Gelman, 1969; Kwong See et al., 2012; Light et al., 1979; McGarrigle & Donaldson, 1974). Other studies have explored factors influencing conservation understanding, including age, cultural background, and education (e.g., Goldschmid et al., 1973; Kim, 1987; Nambeye, 2020). Also, contemporary studies have started using conservation experiments with the embodied cognition approach that considers perception, action, and cognition as tightly linked (Lozada & Carro, 2016). Nevertheless, Piaget's work on child development, particularly concerning his methodology and assumptions about children's cognitive abilities did not evade criticism (Lourenço & Machado, 1996). Although Piaget's theory about stages of cognitive development have been foundational in psychology and education, it is not without its challenges. Researchers critiquing Piaget have pointed out several key issues such as underestimation of children's abilities (Gruen, 1965), methodological concerns (Light et al., 1979), and issues with repeating the question in conservation tasks (McGarrigle & Donaldson, 1974).

None of the aforementioned studies and existing research compares the execution of Piaget's conservation tasks in a physical environment with the execution in a digital environment. Thus, the rationale for comparing digital and physical environments in the context of conservation tasks lies in

Study 2 - 5-Year-Old Children Performing Piaget's Liquid Conservation Tasks Demonstrated in Physical and Digital Environment

understanding how different environments influence a child's cognitive development and learning processes. This comparison can reveal insights into how children perceive, interact with, and learn from digital versus physical stimuli, thereby informing educational strategies and developmental theories in the contemporary, technology-oriented world. Also, several key points justifying the need of such comparison can be identified:

1. **Perceptual Differences:** Digital and physical environments offer different sensory experiences. Understanding how these differences affect a child's perception, especially in tasks like conservation, which rely on visual and spatial judgments, is important.
2. **Developmental Stages:** They provide insight into whether developmental stages identified by Piaget, such as the concrete operational stage, manifest differently when children interact with digital versus physical environments.
3. **Cognitive Development Understanding:** It helps in understanding whether the abstract thinking and reasoning skills required in conservation tasks are developed differently in digital versus physical settings.
4. **Technological Integration:** With children increasingly exposed to digital environments, it is crucial to understand how these virtual experiences influence their capacity to incorporate technological knowledge into their existing representational system.
5. **Educational Practices Incorporating Digital Learning:** As education increasingly incorporates digital tools, understanding how children adapt to and learn from virtual environments is key to designing effective educational content.
6. **Future Research Direction:** Such comparisons could open avenues for further research in cognitive psychology and educational technology, considering the evolving nature of digital media.

Hence the main objective of this study (Sakkas & Samartzi, 2024), which is to explore whether a digital environment yields better results than a physical environment in conservation tasks, is pivotal because it examines how and if a child's cognitive understanding is enhanced by digital methods. The second objective of this study is to correlate the answers of the general concept of conservation with three more specific concepts, identity, compensation, and reversibility (Acredolo & Acredolo, 1979; Brainerd, 1972; Siegler, 1981). These concepts are considered by Piaget to be easier to understand by children in comparison to the concept of conservation that is based on

reasoning because they are based on perception. For this reason, they are normally acquired before the conservation concept (Hooper, 1969).

In the following sections, the methodology of the study and the results will be presented. Then the results and their implications in the broader context of child development and cognitive technology will be discussed.

5.2 Method

5.2.1 Participants

The participants were 86 children, with equal gender representation, from public and private institutions. Participants were approximately 5 years old, an age group that falls within Piaget's preoperational stage of cognitive development, where children begin to engage in symbolic play but still struggle with logic and conservation concepts. There were no apparent disparities in the children's developmental stage or socioeconomic status, and everyone was in good health. The execution of the study was conducted with full consent and awareness of both the guardians and the administrative bodies of the institutions. Additionally, the children themselves gave verbal assent to participate in this research. All 86 of the participants answered questions about the general concept of conservation. 20 of the participants answered questions about the concept of identity. Thirty-six of the participants answered questions about the concept of compensation, and 30 of the participants answered questions about the concept of reversibility. Additionally, half of the participants answered the questions first in the physical environment and then in the digital environment, while the other half followed the reverse order.

5.2.2 Research Design

The experimental design for this study was structured to compare children's understanding of conservation across physical (real glasses and water) and digital (tablet-based) environments using a series of water-pouring tasks. Each participant completed four distinct conservation tasks, each one repeated three times. Two of the tasks concerned the general concept of conservation, one in a physical environment and the other in a digital environment. The other two were either about identity or compensation or reversibility concepts, again one in each environment.

The first task in both environments involved simply transferring water from one glass to another, testing the basic concept of liquid conservation. The other task in both environments was one of the following three. For testing the identity concept, the idea that the new glass was taller and

Study 2 - 5-Year-Old Children Performing Piaget's Liquid Conservation Tasks Demonstrated in Physical and Digital Environment

thinner was introduced, prompting children to consider changes in shape and volume perception. For testing the compensation concept, explicit information that no additional liquid was added during the transfer was included, emphasizing the conservation of quantity despite visual differences. For testing the concept of reversibility, pouring the water back into the original glass was added to the demonstration process, allowing children to directly observe the reversibility of the action.

More specifically, two sets of experimental tools were utilized:

1. **Digital Environment Tool:** An Android tablet device was used for digital tasks. This device displayed images, static and animated, of water being poured between glasses (Figure 18). The tablet's interactive interface and vivid graphics provided a realistic virtual experience, enabling children to engage with the conservation tasks in a digital format (Sakkas & Samartzi, 2023).
2. **Physical Environment Tools:** For the physical tasks, real glasses were used. These included a set of two different glasses—one short and wide, and the other tall and thin—to demonstrate the conservation of liquid. The glasses were transparent, allowing children to clearly observe the water level during and after pouring. Real water was used to visually demonstrate the conservation principle in a tangible way.

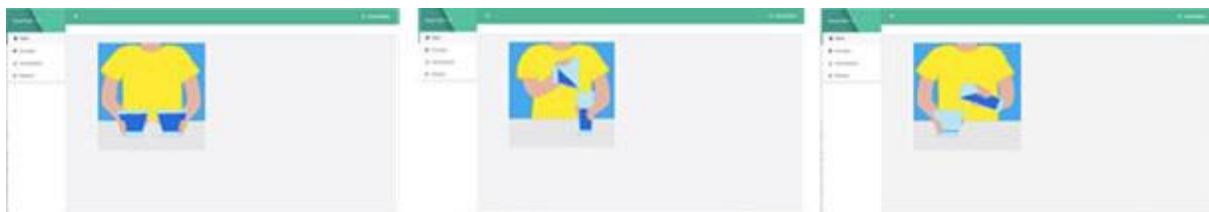


Figure 18. Example of the Android tablet screen display

In each task of the study, there were two distinct phases: the demonstration phase and the question phase. This design ensured that each child had the same experience and basis for understanding before answering the questions.

1. Demonstration Phase

- a. In both the digital and physical environments, the experimenter first demonstrated the action of pouring water from one glass to another. The vocal instructions from the experimenter were the same, regardless of the environment, and they described the actions that were demonstrated.
- b. For the digital tasks, this was done using images and animations on the tablet, simulating the pouring of water.

- c. For the physical tasks, the experimenter physically poured water from one real glass to another in front of the children.

2. Question Phase

- a. Following the demonstration, children were asked whether the amount of water in the glasses remained the same or changed after the transfer.
- b. Except from motivational phrases when the children became idle, such as “What do you think—you haven’t told me yet,” “Try to find the answer—you can do it,” “We agreed to help me understand—let’s continue,” no additional information or help was provided to the children.

5.2.3 Procedure

The child participant sat at a table across from the experimenter, and the two of them were the only people present in the room. For the physical environment tasks, the experimenter used real glasses filled with water, pouring it from one to the other. For the digital environment tasks, the experimenter used a tablet device to present on the screen the appropriate static and animated images. The experimenter followed exactly the research design and used the same language, instructions, and expressions in both physical and digital environment tasks. Each child completed all tasks in between 10 and 15 minutes in total. The children received no feedback on their answers during or after the experiment. Finally, each child was assigned a random ID number to conceal their identity; all children participated anonymously in the research.

5.3 Results

Researchers analyzed the data using IBM SPSS Statistics (Version 26). Table 1 demonstrates the results of the liquid conservation tasks that were performed in the experiment. In each cell appears the absolute number of answers followed by the percentage of total participants in each task. The data are split by environment: physical when the tasks were demonstrated by real glasses and digital when the tasks were demonstrated by images in the tablet screen. An answer was considered correct when the child told the experimenter that the amount of liquid after the demonstration was equal, whereas an answer was considered wrong when the child told the experimenter that the amount of liquid was different (either more or less). Also, to perform the statistical analysis, the answers of each participant for each task’s three repetitions were aggregated in a single answer following the rule that if at least two out of three answers were correct, the participant answered correctly.

Study 2 - 5-Year-Old Children Performing Piaget's Liquid Conservation Tasks Demonstrated in Physical and Digital Environment

Table 5. Liquid Conservation Tasks Results

Environment	Answers	General (n=86)	Identity (n=20)	Compensation (n=36)	Reversibility (n=30)
Physical	Correct	11 (12.8%)	1 (5.0%)	3 (8.3%)	20 (66.7%)
	Wrong	75 (87.2%)	19 (95.0%)	33 (91.7%)	10 (33.3%)
Digital	Correct	15 (17.4%)	1 (5.0%)	3 (8.3%)	21 (70.0%)
	Wrong	71 (82.6%)	19 (95.0%)	33 (91.7%)	9 (30.0%)

To better visualize these results, the number of correct and wrong answers were plotted for each concept of conservation in bar charts, one for physical tasks and one for digital tasks (Figure 19 and Figure 20, respectively). Blue indicates correct answers, and red indicates wrong answers. The majority of the answers in the general concept of conservation, the identity, and the compensation tasks is wrong, whereas in the reversibility tasks, the majority of the answers is correct. The answers for each concept are consistent and follow the same distribution regardless of the environment of execution of the tasks, physical or digital.

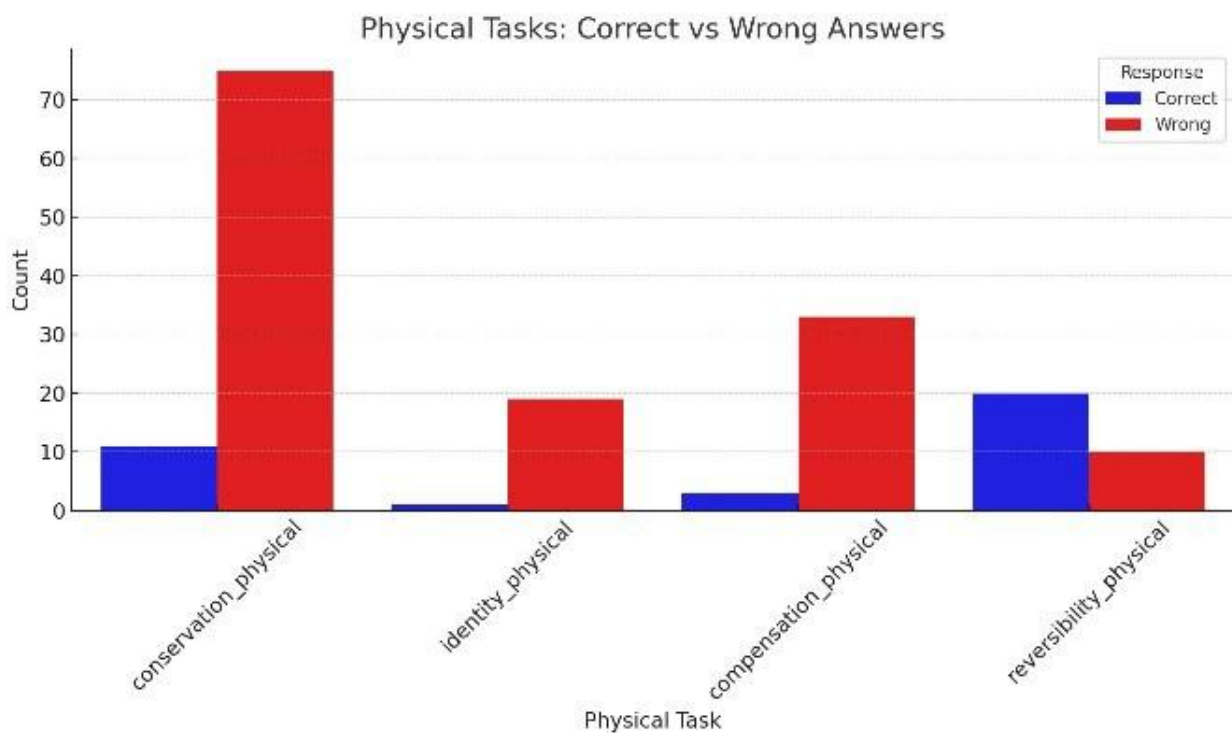


Figure 19. Answers for Physical Environment

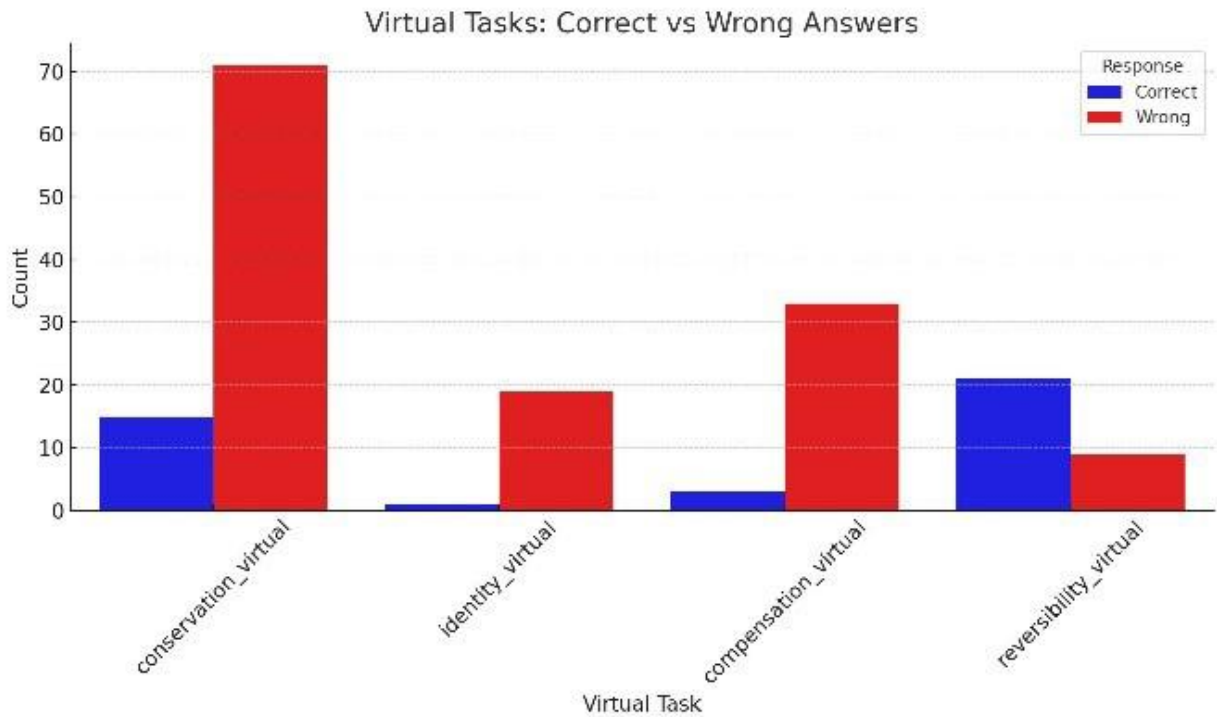


Figure 20. Answers for Digital Environment

To analyze the results, Fischer's Exact Test was performed to check for possible associations between physical and digital environment conditions in each concept of conservation separately.

1. For the general concept of conservation: Out of 11 children who answered correctly in the physical environment condition, six answered correctly in the digital environment condition, and five answered wrong. Out of 75 children who answered wrong in physical environment condition, 66 answered wrong in the digital environment condition, and nine answered correctly. Significant association was found between the physical and digital environment in the general concept of conservation. Fisher's Exact Test $p=0.003$.
2. For the concept of identity: Out of one child who answered correctly in the physical environment condition, one also answered correctly in the digital environment condition, and zero answered wrong. Out of 19 children who answered wrong in the physical environment condition, 19 answered wrong in the digital environment condition, and zero answered correctly. Marginal significant association was found between the physical and digital environment in the concept of identity: Fisher's Exact Test $p=0.05$.
3. For the concept of compensation: Out of three children who answered correctly in the physical environment condition, zero answered correctly in the digital environment condition, and all three answered wrong. Out of 33 children who answered wrong in the

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physical environment condition, 30 answered wrong in the digital environment condition, and three answered correctly. No significant association was found between the physical and digital environment in the concept of compensation: Fisher's Exact Test $p=1.000$.

4. For the concept of reversibility: Out of 20 children who answered correctly in the physical environment condition, 16 answered correctly in the digital environment condition, and four answered wrong. Out of 10 children who answered wrong in the physical environment condition, five answered wrong in the digital environment condition and five answered correctly. No significant association was found between the physical and digital environment in the concept of reversibility: Fisher's Exact Test $p=0.115$.

Further analysis targeted the relationship between the three specific concepts of conservation and the general concept of conservation in each environment condition. Again, Fischer's Exact Test was used with the continuity correction adjustment to determine statistical associations.

For tasks performed in the physical environment:

1. Out of one child who answered correctly about the general concept of conservation, one also answered correctly about the identity concept, and zero answered wrong. Out of 19 children who answered wrong about the general concept of conservation, 19 also answered wrong about the identity concept, and zero answered correctly. Marginal significant association was found between the two concepts: Fisher's Exact Test $p=0.05$.
2. Out of two children who answered correctly about the general concept of conservation, two also answered correctly about the compensation concept, and zero answered wrong. Out of 34 children who answered wrong about the general concept of conservation, 33 also answered wrong about the compensation concept, and one answered correctly. Significant association was found between the two concepts: Fisher's Exact Test $p=0.005$.
3. Out of eight children who answered correctly about the general concept of conservation, six also answered correctly about the reversibility concept, and two answered wrong. Out of 22 children who answered wrong about the general concept of conservation, eight also answered wrong about the reversibility concept, and 14 answered correctly. No significant association was found between the two concepts: Fisher's Exact Test $p=0.682$.

For tasks performed in the digital environment:

1. Out of one child who answered correctly about the general concept of conservation, one also answered correctly about the identity concept, and zero answered wrong. Out of 19 children who answered wrong about the general concept of conservation, 19 also answered wrong about the identity concept, and zero answered correctly. Marginal significant association was found between the two concepts: Fisher's Exact Test $p=0.05$.
2. Out of five children who answered correctly about the general concept of conservation, three also answered correctly about the compensation concept, and two answered wrong. Out of 31 children who answered wrong about the general concept of conservation, 31 also answered wrong about the compensation concept, and zero answered correctly. Significant association was found between the two concepts: Fisher's Exact Test $p=0.001$.
3. Out of nine children who answered correctly about the general concept of conservation, seven also answered correctly about the reversibility concept, and two answered wrong. Out of 21 children who answered wrong about the general concept of conservation, seven also answered wrong about the reversibility concept, and 14 answered correctly. No significant association was found between the two concepts: Fisher's Exact Test $p=0.681$.

5.4 Discussion

The results of this study point out that liquid conservation tasks of compensation and reversibility concepts on 5-year-old children yield different results depending on the environment of execution. In contrast, for liquid conservation tasks of conservation and identity concepts, the results are expected to be similar regardless of the environment of execution, whether it is physical or digital.

In addition, the number of correct and wrong answers were approximately the same within each concept of conservation, in both environments. For the general concept of conservation, the identity concept, and the compensation concept, the majority of the answers was wrong, averaging approximately 87% of the total, whereas for the reversibility concept, the majority of the answers was correct, at approximately 68%. Research on Piaget's conservation concepts suggests that although traditionally it has been believed that children under 6 years of age could not understand these concepts, more recent studies indicate that younger children may indeed be capable of grasping them (Rothenberg, 1969; Sakas & Samartzi, 2023). For instance, several studies (Watanabe, 2017a, 2017b, 2019, 2022) found that children as young as 3 years old might be able to acquire Piaget's conservation concepts when these tasks are integrated into play. These studies also

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observed that a 4-year-old was able to robustly acquire the conservation concept for numbers and length, indicating a potential acceleration in cognitive development compared to the age previously presumed by Piaget. This shift in understanding aligns with the broader observation that younger children today may have higher intelligence than those in previous generations (Flynn, 2012; Pietschnig & Voracek, 2015). As Piagetian tasks generally assess logical thinking, an increase in intelligence quotient (IQ) could positively affect the ability to correctly solve these tasks. It is interesting to notice that out of the three specific concepts of conservation investigated in the present study, only reversibility presented a positive percentage of correct questions, thus suggesting that it is more easily acquired by this marginal age group for Piaget's conservation understanding.

The similar performance of children in both digital (using a tablet) and physical (using real glasses) settings for liquid conservation tasks can be understood through several perspectives. Research on the use of tablets and their effects on learning and development in young children suggest that digital technology, when meaningfully integrated, can positively affect areas like math, science, problem-solving, and self-efficacy (Peirce, 2013). This indicates that tablet-based learning can effectively engage children in similar ways to physical tasks, aiding in their cognitive development (Sammelmann et al., 2016). Moreover, researchers can use tablets effectively in developmental cognitive research with children (Frank et al., 2016). Researchers compared the reliability, performance, and sensitivity of response times in tablet-based tasks to other methods and found tablets to be equally or more favorable. This supports the idea that tablet-based tasks can be as effective as physical ones in assessing cognitive abilities in children. Therefore, these studies collectively suggest that when tablet-based learning is designed appropriately, it can be as effective as traditional physical learning methods, including tasks that assess cognitive development like liquid conservation. The key factor appears are the quality of interaction and engagement that the learning tool (whether digital or physical) facilitates rather than the medium itself. Nonetheless, the design of digital learning tools plays a pivotal role in curriculum development, particularly in early childhood education. Effective integration of digital tools requires careful alignment with curriculum objectives, pedagogical principles, and developmental milestones (Laurillard, 2010). Design considerations encompass user interface, interactivity, content relevance, and accessibility, ensuring that tools are engaging, age-appropriate, and conducive to learning. Digital learning tools can serve as dynamic resources that enrich educational experiences and support holistic development in early childhood settings.

Adding to the existing literature, the results of this study were that physical and digital environments' associations were statistically significant in two out of the four concepts: in the general concept of conservation and the identity concept. In the compensation and reversibility concepts, no statistical significance was observed. Interesting results were also produced regarding the association of the general concept of conservation with the three specific concepts: identity, compensation and reversibility. Statistical significance was observed in identity and compensation concepts when they were associated with the general concept of conservation. The reversibility concept presented no statistical significance when associated with the general concept of conservation in both environments. The absence of statistical significance and the high number of correct answers in reversibility concept compared to the others further reinforces the results and views of previous studies, which suggests reversibility may be acquired developmentally prior to conservation and possibly is not closely related (Brainerd, 1972; Bruner et al., 1966; Murray & Johnson, 1969).

Finally, as noted, the age group of this study is on the margin of the preoperational stage of Piaget's theory because the main objective of the study was to find the limit of understanding of conservation concepts of children. Future research should focus on older aged children because they will provide more balanced answers in terms of correct and wrong, thus enabling the identification of stronger associations among all concepts of conservation. Another interesting research direction would be the investigation of embodied cognition, which can be implemented by having the children, instead of being only observers of the liquid conservation demonstration, to interact and participate in the experimental process in various ways (Lozada & Carro, 2016), like handling the glasses themselves and pouring the water from one to another in the physical environment and pressing buttons to manipulate the animation on the tablet device in the digital environment.

CHAPTER 6: Study 3 - Human–Human Versus Human–Robot Interaction in Piaget's Liquid and Mass Conservation Performed by 5–6-Year-Old Children

6.1 Introduction

Several researchers have investigated the applicability of Piaget's theory of cognitive development. Among his many achievements, Piaget discovered that children between the ages of 5 and 8 understand the logical idea of conservation. Conservation tasks have received the most extensive investigation of any Piagetian assignment. A given set of achievements coincide with a specific age

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following Piaget’s stages of cognitive development. According to Piaget, children do not develop meaningful operational skills until they are 7 years old (Babakr et al., 2019). As a result, children start to think rationally and conclusively around the age of 7. Children use tangible representations to address problems throughout this time. They continuously come into contact with new experiences, objects, and words owing to their rapid advances in motor ability and linguistic development. When they are faced with something new, they can either assimilate it into an existing schema by matching it with what they already know or expand their knowledge structure to fit the new scenario, covering the major developmental theories. Many of the children’s preexisting schemas will be tested, enlarged, and rearranged during this stage. Conservation presents the most difficulty during the concrete operating phase (Nambeye, 2020).

Despite making significant contributions to the corpus of knowledge concerning intelligence, Piaget has received criticism, which is crucial to highlight (Lourenço & Machado, 1996). Contemporary but also older researchers have indicated that children possess many abilities at an earlier age than was identified by Piaget. Young children may be more capable of thought than originally thought (Gruen, 1965). Most of the critics focus on the methodology of the “clinical method of Piaget.” This procedure can cover the real cognitive capacities of young children, putting them into an uncomfortable and even stressful condition facing the experimenter, who is usually an “expert” adult with concrete expectations of them. Children try to recognize the communicative intention of the experimenter from the global condition, that is, the verbal and the nonverbal information, as it is described in cognitive linguistics by relevance theory (Chapelle, 2019). Furthermore, according to critics concerned especially with Piaget’s conservation tasks, asking a child a similar question more than once is a blatant indication that the initial response was incorrect. As a result, researchers discovered that some 6-year-olds provided the right response whenever they replicated Piaget’s tasks and only posed the question after the transition was performed (Light et al., 1979). Other academics criticized Piaget’s assignment on quantity conservation, arguing that alterations made by adults led children to perceive that the modification was just as significant. Therefore, researchers developed an experiment on conservation of number that was comparable to Piaget’s (McGarrigle & Donaldson, 1974). The researchers confused the counts whenever they stretched out the column of counters using the “Naughty Teddy Bear,” making the shift appear unintentional. Over 62% of children responded affirmatively when asked if the candies in the first and second rows were comparable, higher than the response rate of less than 15% from Piaget’s research.

Although some academics have criticized Piaget's findings, experiments conducted by other academics such as Elkind (1967) have shown that this is not the case. Elkind highlighted Piaget's research on American children between the ages of 5 and 6 (Watanabe, 2022). These findings supported Piaget's theories on conservation tasks, showing that the capacity for conservation dramatically rises with age. Thus, various research has been conducted on conservation and the age that children become aware of it.

An analysis of the numbers, mass, weight, and volume developmental sequencing in children was the aim of a similar study. The researcher's primary goal was to determine the period at which children could perform the aforementioned conservation tasks. Over 159 primary school students between the ages of 4 and 11 participated in the research (Nambeye, 2020). To determine whether conservation starts as soon as 4 years old, researchers tried to include children as young as that age who were in the preoperational stage. The findings were consistent with Piaget's claims that the children showed a similar sequential accomplishment of conservation of numbers, mass, weight, and volume. Children from the conventional and solid operational levels were examined in the research. In another study (Kim, 1987), the factors that could impact conservation were examined. Two hundred kindergarten students were included in the study, whose ages varied from 4 to 8 years, with an average of 5 years. Among the overall population, 55% were boys and 45% girls. The findings indicated age as a principal factor of conservation capacity and that children aged 6 or older performed noticeably better than those aged under 6. Another important study (Goldschmid et al., 1973) was performed to evaluate the order and speed of conservation knowledge acquisition in a variety of children between the ages of 4 and 8 across different countries. The Concept Assessment Kit-Conservation (De Vries et al., 1969) was used, and 250 children from six countries—Australia, Holland, England, New Zealand, Poland, and Uganda—made up the sample. According to the research, there were only a few differences in the rate of accumulation, which were presumably caused by different environmental factors. Age and the capacity to conserve were also relatively constant in males and females. Recent research (Watanabe, 2019) has also shown the influence of affective factors on the acquisition of the conservation concepts.

In the research presented in this study, the conservation concept is studied using the well-known Piagetian conservation tasks of liquid and mass, but with a substantial shift: the introduction of a robot experimenter instead of a human. Robots nowadays are becoming sharper and more advanced nearly every day. Robotic systems may soon be moving from the production line into our

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residences and even taking care of the children, thanks to recent developments in artificial intelligence and software algorithms. Nonhumanoid and mainly humanoid Socially Assistive Robots are used to improve children’s creativity, motivation, and social skills (Ali et al., 2019; Masson et al., 2017). Harvard University researchers have also entered the field of child-friendly robotics (Rubenstein et al., 2015). They started developing a cheap robot in 2014 that could be readily controlled utilizing an application and a basic programming system. Any institution might utilize such robotics to inspire students to learn to program. Future generations will see more and more robots in daily life. It has been demonstrated that engaging students with robots in the classroom increases understanding. According to Solace Shen, a Cornell University psychologist specializing in developing young children and experiments on robot–human interrelations, contemporary research indicates that children could benefit from communicating with robotics (Bennington-Castro, 2017), and they can learn by teaching robots, improving linguistic, reading, writing, reasoning, and other cognitive capacities (Jamet et al., 2018). It is possible that among the first jobs that child-friendly robots will do is helping preschool instructors. Researchers are investigating the potential use of robotics in classrooms with children as part of studies (Leite et al., 2012). According to extensive literature available, children with special needs are drawn to robotics because they are less complicated and unpredictable than individuals, less frightening, endlessly patient and constant in their voice quality and attitude, and extremely configurable and adaptive to the requirements of individual children. Most of these values can be transferred to typically developed children and ease the adjustment period for experiments and provide more accurate results.

Therefore, in this study the hypothesis is that using a robot experimenter would aid in knowledge and understanding of the conservation concept, eliminating the human experimenter bias as previous academics have noted. Another objective of this study was to identify possible associations between the acquisition of the general concept of conservation and three more specific concepts, identity, compensation, and reversibility. These concepts are considered by Piaget to be easier to understand by children because they are based on perception, in comparison to the concept of conservation that is based on reasoning. Therefore, they are normally acquired before the conservation concept (Hooper, 1969; Piaget & Inhelder, 1974). Considering all the circumstances mentioned herein and empirical findings supporting that the vast majority of children develop into Partial Conservers for liquid and mass throughout this period (Church & Goldin-Meadow, 1986), three developmental phases are anticipated to occur between those ages: children who continuously

identify the conservation concept (Total Conservers, TC), those doing so to a limited extent (Partial Conservers, PC), and children who do not (Non-Conservers, NC).

6.2 Method

6.2.1 Participants

The participants were 160 first graders from public and private institutions. Participants ranged in age from 5 to 6 years old, an age group whose developmental growth is thought to be incomplete. There were no apparent disparities in the children's developmental stage or socioeconomic status, and everyone was in good health. All operations were carried out with the guardians' and the institutions' administrations' full knowledge and approval. Moreover, the children verbally agreed to participate in the research. Every participant was required to answer five introductory questions before being accepted in the study to ensure that an understanding of basic concepts existed. Results from children who did not answer at least four out of five introductory questions correctly were not considered. The introductory questions were:

- Which glass holds more, a large or a small one?
- Which is bigger, the truck or the taxi?
- Which glass has less in it, one full or one empty?
- Which is higher, the roof of the apartment building or the sidewalk?
- Which is wider, a plate or a glass?

6.2.2 Research Design

The experiment consisted of two consecutive conservation tests based on the Piagetian conservation tasks and developed on tablet devices. Each test consisted of four separate tasks, the first one concerned with the general concept of conservation and the three others with the more specific concepts of identity, compensation, and reversibility. One of the tests was based on liquid conservation, and the other one was based on mass conservation. Visual instructions were presented to the participants via the tablet device. Each task was structured in three different stages presenting to the participant one unique image, either static or animated. The last stage also contained three buttons on screen that were used to provide the answer by pressing them. The buttons were MORE, LESS, and EQUAL, and their order of appearance was randomized each time a task was presented. Audio instructions accompanied each task stage, either from the human or the robot experimenter. Half of the study participants received guidance from humans (human–human interaction), and the

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other half received guidance from a robot (human–robot interaction) without any human presence or human interaction. The audio instructions were predefined and the same for the two groups. Except from the instructions for each task stage, some encouraging phrases were prepared in case some children needed motivation to continue with the experiment. Such phrases were: “What do you think, you haven’t told me yet,” “Try to find the answer, you can do it!”, “We agreed to help me understand, let’s continue,” “Do you want to see it again, or should we proceed?”. The robot used for the experiments was EZ-Robot JD Humanoid, a humanoid robot built to be accessible to users and suitable for educational and other purposes (Mubin et al., 2013). It has many features such as motion and sound output. Its movements range from simple hand movements to complex movements that use all the robot’s joints. The robot dimensions are 15 cm long, 13 cm wide, and 33 cm high, and it weighs 1.33 kg (Figure 21). To maintain the attention and interest of the children, the robot could perform some simple movement actions such as wave of hand, bow, head scratch, and hand movement.



Figure 21. Robot Experimenter Used in the Tests

To achieve complete understanding of the experiment, a detailed description of each test, task, and stage follows:

- Liquid conservation – Task 1

The first task of the liquid conservation test concerned the general concept of conservation. The visual guidance is depicted in Figure 22. Stage 1 presented a static image with two identical glasses, stage 2 presented an animated image showing the person picking up one glass and pouring water from one glass to a different one, and stage 3 presented a static image again with the two glasses. The audio guidance was provided by the phrases “We have those two glasses of water” for

stage 1, “We pour water from one glass to the other” for stage 2, and finally “Now, does the new glass have the same amount as, less than, or more than the amount of water from the first one?”.

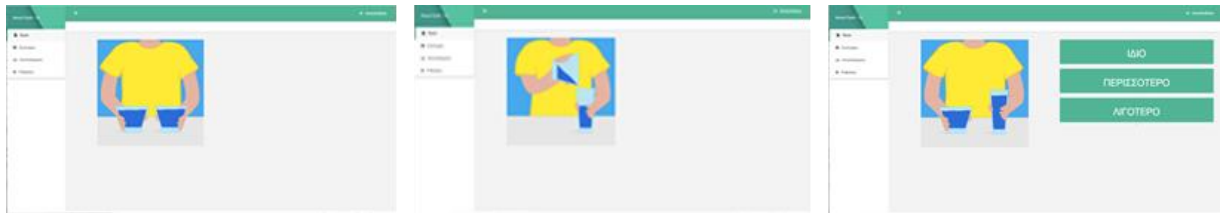


Figure 22. General Concept of Liquid Conservation

- Liquid conservation – Task 2

The second task of the liquid conservation test concerned the concept of identity. The visual guidance was the same as Task 1, depicted in Figure 22. Stage 1 presents a static image with two identical glasses, stage 2 presents an animated image showing the person picking up one glass and pouring water from one glass to a different one, and stage 3 presents a static image again with the two glasses. The audio guidance was provided by the phrases “We have those two glasses of water” for stage 1, “We pour water from one glass to the other. We didn’t add additional water, only the one that existed” for stage 2, and finally “Now, does the new glass have the same amount as, less than, or more than the amount of water from the first one?”.

- Liquid conservation – Task 3

The third task of the liquid conservation test concerned the concept of compensation. The visual guidance was the same as Task 1, depicted in Figure 22. Stage 1 presents a static image with two identical glasses, stage 2 presents an animated image showing the person picking up one glass and pouring water from one glass to a different one, and stage 3 presents a static image again with the two glasses. The audio guidance was provided by the phrases “We have those two glasses of water” for stage 1, “We pour water from one glass to the other. Be careful, the new glass is taller and narrower” for stage 2, and finally “Now, does the new glass have the same amount as, less than, or more than the amount of water from the first one?”.

- Liquid conservation – Task 4

The fourth task of the liquid conservation test concerned the concept of reversibility. The visual guidance is depicted in Figure 23. Stage 1 presents a static image with two identical glasses, stage 2 presents an animated image showing the person picking up one glass and pouring water from one glass to a different one, and stage 3 presents an animated image showing the person picking up the new glass and pouring the water in the old glass again. The audio guidance was provided by the

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phrases “We have those two glasses of water” for stage 1, “We pour water from one glass to the other” for stage 2, and finally “Now, we pour the water back again. Is the amount of water the same, less, or more than it was at first?”.

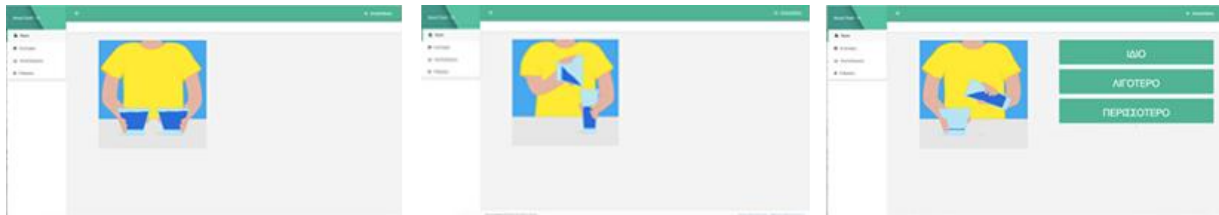


Figure 23. Reversibility Concept of Liquid Conservation

- Mass conservation – Task 1

The first task of the mass conservation test concerned the general concept of conservation. The visual guidance is depicted in Figure 24. Stage 1 presents a static image with two identical spheres, stage 2 presents an animated image showing the person picking up one sphere and transforming it into a lengthy structure, and stage 3 presents a static image again with the sphere and the lengthy structure. The audio guidance was provided by the phrases “We have two identical clay balls” for stage 1, “With one clay ball we create a cylinder” for stage 2, and finally “Now, does the cylinder have the same amount of clay, more, or less?”.

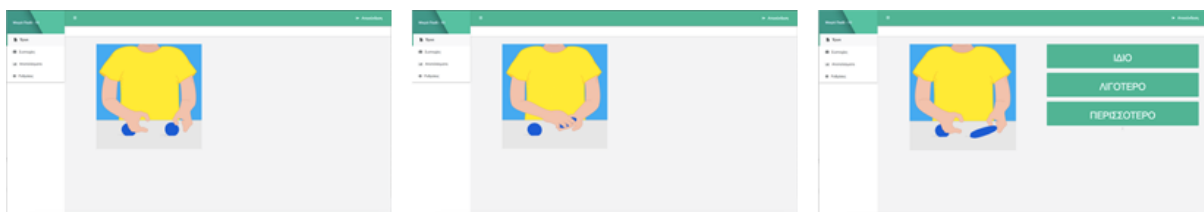


Figure 24. General Concept of Mass Conservation

- Mass conservation – Task 2

The second task of the mass conservation test concerned the concept of identity. The visual guidance is the same as Task 1, depicted in Figure 24. Stage 1 presents a static image with two identical spheres, stage 2 presents an animated image showing the person picking up one sphere and transforming it into a lengthy structure, and stage 3 presents a static image again with the sphere and the lengthy structure. The audio guidance was provided by the phrases “We have two identical clay balls” for stage 1, “With one clay ball we create a cylinder. We didn’t add additional clay, only what already existed” for stage 2, and finally “Now, does the cylinder have the same amount of clay, more, or less?”.

- Mass conservation – Task 3

The third task of the mass conservation test concerned the concept of compensation. The visual guidance is the same as Task 1, depicted in Figure 24. Stage 1 presents a static image with two identical spheres, stage 2 presents an animated image showing the person picking up one sphere and transforming it into a lengthy structure, and stage 3 presents a static image again with the sphere and the lengthy structure. The audio guidance was provided by the phrases “We have two identical clay balls” for stage 1, “With one clay ball we create a cylinder. Be careful, the cylinder is longer but narrower” for stage 2, and finally “Now, does the cylinder have the same amount of clay, more, or less?”.

- Mass conservation – Task 4

The fourth task of the mass conservation test concerned the concept of reversibility. The visual guidance is depicted in Figure 25. Stage 1 presents a static image with two identical spheres, stage 2 presents an animated image showing the person picking up one sphere and transforming it into a lengthy structure, and stage 3 presents an animated image showing the person transforming the lengthy structure into a sphere again. The audio guidance was provided by the phrases “We have two identical clay balls” for stage 1, “With one clay ball we create a cylinder” for stage 2, and finally “With the cylinder we create a ball again. Does the ball have the same amount of clay, more, or less than the one we had at first?”.

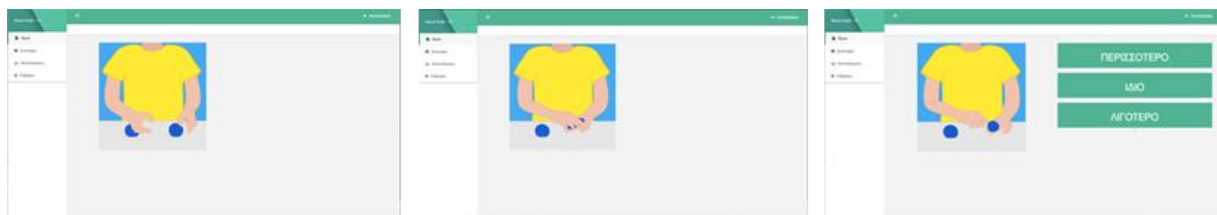


Figure 25. Reversibility Concept of Mass Conservation

6.2.3 Procedure

One child at a time took part in an experimental process that lasted around 20–30 minutes during a typical afternoon. The research was conducted in education centers located in Athens, Greece in appropriately designed rooms to meet the necessary conditions. Every child participating sat at a table, addressing either the human experimenter or the robot experimenter, and had a tablet right in front of them. Both the human and the robot experimenters were at a distance on the opposite side of the table. More specifically, when the experimenter was the robot there was no visible contact between the child and the human operating the robot. The child was monitored via a specially placed camera, which showed in real time what was happening in the room on a screen accessible by the

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robot’s human operator. The children received no feedback on their answers during or after the experiment. Finally, the children participated anonymously in the research, so each subject was assigned a random ID number, and every answer that was given in the tablet device was stored in the database for further analysis, associated only with this ID number.

6.3 Results

The data were analyzed using IBM SPSS Statistics (Version 26). Table 1 demonstrates the results of liquid conservation tests, and Table 2 demonstrates the results of mass conservation tests. Both tables are split by experimenter, robot, and human. A correct answer was considered when the child pressed the button “EQUAL” on the tablet device, while a wrong answer was considered when the child pressed either the button “MORE” or the button “LESS.” In each cell there is the absolute number of answers followed by the percentage of total participants in each task.

Table 6. Liquid Conservation Test Results

Experimenter	Answers	General	Identity	Compensation	Reversibility
		(n=80)	(n=80)	(n=80)	(n=80)
Robot	Correct	50 (62.5%)	57 (71.3%)	53 (66.3%)	52 (65.0%)
	Wrong	30 (37.5%)	23 (28.8%)	27 (33.8%)	28 (35.0%)
Human	Correct	38 (47.5%)	48 (60.0%)	47 (58.8%)	47 (58.8%)
	Wrong	42 (52.5%)	32 (40.0%)	33 (41.3%)	33 (41.3%)

Table 7. Mass Conservation Test Results

Experimenter	Answers	General	Identity	Compensation	Reversibility
		(n=80)	(n=80)	(n=80)	(n=80)
Robot	Correct	45 (56.3%)	50 (62.5%)	54 (67.5%)	55 (68.8%)
	Wrong	35 (43.8%)	30 (37.5%)	26 (32.5%)	25 (31.3%)
Human	Correct	41 (51.3%)	50 (62.5%)	50 (62.5%)	46 (57.5%)
	Wrong	39 (48.8%)	30 (37.5%)	30 (37.5%)	34 (42.5%)

To better analyze these results, the number of correct answers for each concept of conservation was plotted in a bar chart. By looking at the chart (Figure 26), it is easy to notice that

the general concept of conservation in both tests (liquid in blue color, mass in yellow color), for both experimenters, has a lower number of correct answers compared to the identity, compensation, and reversibility tasks.

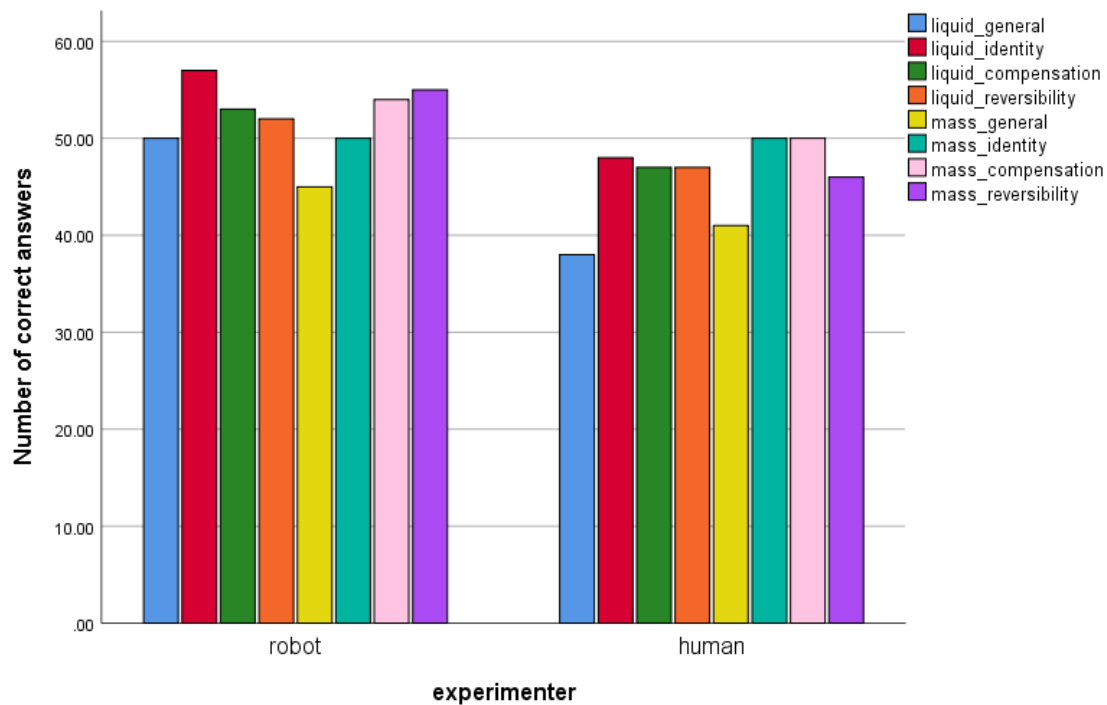


Figure 26. Correct Answers for Each Conservation Task's Results.

Following that observation, chi square test of independence was performed to check for possible associations between the general concept of conservation and each of the three specific concepts. Bonferroni correction was used to determine the acceptable p value, which was calculated to be 0.004 (0.05/12). In general, no cases had significant statistical association ($p < 0.004$), thus with those sample sizes and age group of children we cannot confirm any overall association among the tasks.

For liquid conservation tests performed by the robot experimenter:

- Out of 50 children who answered correctly to the general concept of conservation, 37 answered also correctly to the identity concept and 13 answered wrong. Out of 30 children who answered wrong to the general concept of conservation, 10 answered also wrong to the identity concept and 20 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 0.492, p = 0.483$.

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- Out of 50 children who answered correctly to the general concept of conservation, 36 answered also correctly to the compensation concept and 14 answered wrong. Out of 30 children who answered wrong to the general concept of conservation, 13 answered also wrong to the compensation concept and 17 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 1.972, p = 0.160$.
- Out of 50 children who answered correctly to the general concept of conservation, 36 answered also correctly to the reversibility concept and 14 answered wrong. Out of 30 children who answered wrong to the general concept of conservation, 14 answered also wrong to the reversibility concept and 16 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 2.872, p = 0.090$.

For liquid conservation tests performed by the human experimenter:

- Out of 38 children who answered correctly to the general concept of conservation, 20 answered also correctly to the identity concept and 18 answered wrong. Out of 42 children who answered wrong to the general concept of conservation, 14 answered also wrong to the identity concept and 28 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 1.637, p = 0.201$.
- Out of 38 children who answered correctly to the general concept of conservation, 23 answered also correctly to the compensation concept and 15 answered wrong. Out of 42 children who answered wrong to the general concept of conservation, 18 answered also wrong to the compensation concept and 24 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 0.942, p = 0.759$.
- Out of 38 children who answered correctly to the general concept of conservation, 24 answered also correctly to the reversibility concept and 14 answered wrong. Out of 42 children who answered wrong to the general concept of conservation, 19 answered also wrong to the reversibility concept and 23 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 0.580, p = 0.446$.

For mass conservation tests performed by the robot experimenter:

- Out of 45 children who answered correctly to the general concept of conservation, 29 answered also correctly to the identity concept and 16 answered wrong. Out of 35 children who answered wrong to the general concept of conservation, 14 answered also wrong to the identity concept

and 21 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 0.166, p = 0.684$.

- Out of 45 children who answered correctly to the general concept of conservation, 34 answered also correctly to the compensation concept and 11 answered wrong. Out of 35 children who answered wrong to the general concept of conservation, 15 answered also wrong to the compensation concept and 20 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 3.043, p = 0.081$.
- Out of 45 children who answered correctly to the general concept of conservation, 36 answered also correctly to the reversibility concept and 9 answered wrong. Out of 35 children who answered wrong to the general concept of conservation, 16 answered also wrong to the reversibility concept and 19 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 6.059, p = 0.014$.

For mass conservation tests performed by the human experimenter:

- Out of 41 children who answered correctly to the general concept of conservation, 30 answered also correctly to the identity concept and 11 answered wrong. Out of 39 children who answered wrong to the general concept of conservation, 19 answered also wrong to the identity concept and 20 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 4.086, p = 0.043$.
- Out of 41 children who answered correctly to the general concept of conservation, 29 answered also correctly to the compensation concept and 12 answered wrong. Out of 39 children who answered wrong to the general concept of conservation, 18 answered also wrong to the compensation concept and 21 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 2.432, p = 0.119$.
- Out of 41 children who answered correctly to the general concept of conservation, 27 answered also correctly to the reversibility concept and 14 answered wrong. Out of 39 children who answered wrong to the general concept of conservation, 20 answered also wrong to the reversibility concept and 19 answered correctly. No significant association between the two concepts was found, $\chi^2(df=1, N=80) = 2.402, p = 0.121$.

The next step was to perform the analysis to determine whether the robot experimenter yielded better results than the human experimenter. Chi square test of independence was performed

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in each concept of conservation to check the association between the robot and human experimenters. Although the tests performed by the robot experimenter presented a slightly larger number of correct answers, there was no significant association between the experimenters in every case. The exact number of correct and wrong values can be found in Table 1 for liquid conservation and Table 2 for mass conservation. The chi square analysis results are:

- For the general concept of liquid conservation: $\chi^2(df=1, N=80) = 3.636, p = 0.057$
- For the identity concept of liquid conservation: $\chi^2(df=1, N=80) = 2.244, p = 0.134$
- For the compensation concept of liquid conservation: $\chi^2(df=1, N=80) = 0.960, p = 0.327$
- For the reversibility concept of liquid conservation: $\chi^2(df=1, N=80) = 0.662, p = 0.416$
- For the general concept of mass conservation: $\chi^2(df=1, N=80) = 0.402, p = 0.526$
- For the identity concept of mass conservation: $\chi^2(df=1, N=80) = 0.000, p = 1.000$
- For the compensation concept of mass conservation: $\chi^2(df=1, N=80) = 0.440, p = 0.507$
- For the reversibility concept of mass conservation: $\chi^2(df=1, N=80) = 2.175, p = 0.140$

Then the aggregated results of each child were analyzed. Each child was labeled as TC if the child answered correctly on all four tasks of each test, PC if the child answered correctly on at least one of the tasks of each test, and NC if the child provided no correct answers (Church & Goldin-Meadow, 1986). TC was assigned the value 2, PC was assigned the value 1, and NC was assigned the value 0. Table 3 demonstrates the assignment of labels and the values of each test case. In each cell there is the absolute number of labeled participants followed by the corresponding percentage of the total participants in each test.

Table 8. Conservation Tasks Aggregated Scores

Experimenter	Subject Status	Liquid Conservation	Mass Conservation
		(n=80)	(n=80)
Robot	NC	5 (6.3%)	4 (5.0%)
	PC	52 (65.0%)	55 (68.8%)
	TC	23 (28.8%)	21 (26.3%)
Human	NC	8 (10.0%)	7 (8.8%)

PC	58 (72.5%)	58 (72.5%)
TC	14 (17.5%)	15 (18.8%)

A different representation of Table 3 is presented using bar charts for each test (liquid conservation, mass conservation) and experimenter (robot, human), in the following figures. Figure 27 depicts the robot experimenter's liquid conservation number of children in each group. Figure 28 depicts the robot experimenter's mass number of children in each group. Figure 29 depicts the human experimenter's liquid conservation number of children in each group. Figure 30 depicts the human experimenter's mass conservation number of children in each group. All four test cases follow the same trend in the distribution of results.

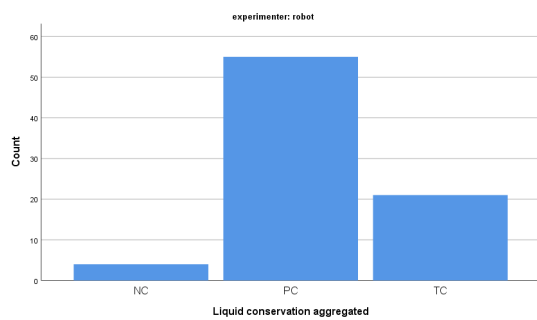


Figure 27. Robot Experimenter Liquid Conservation

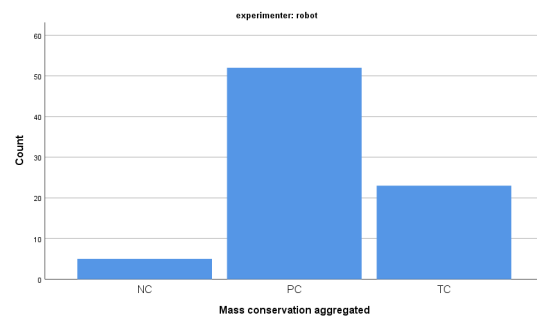


Figure 28. Robot Experimenter Mass Conservation

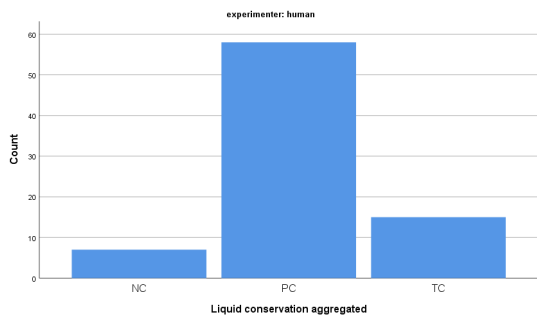


Figure 29. Human Experimenter Liquid Conservation

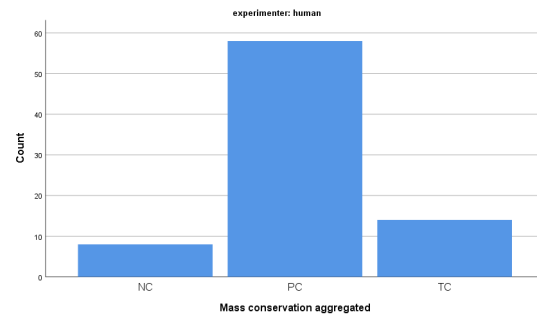


Figure 30. Human Experimenter Mass Conservation

The tests performed by the robot experimenter, either liquid or mass conservation, show better performance compared to the tests performed by the human experimenter. More specifically, liquid conservation tests PCs and TCs combined in the case of the robot experimenter were 75, whereas in the case of the human experimenter they were 72 (4.08% difference). Mass conservation tests PCs and TCs combined in the case of the robot experimenter were 76, whereas in the case of the human experimenter they were 73 (4.02% difference). An interesting observation is that the

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number of TCs in liquid conservation for the robot experimenter was 23 and for the human experimenter was 14 (48.64% difference), whereas in mass conservation for the robot experimenter it was 21 and for the human experimenter was 15 (33.33% difference). Unfortunately, the chi square tests of independence that were performed to check associations between the experimenters indicated no significant statistical differences. For the liquid conservation case the result was $\chi^2(df=1, N=80) = 1.898$, $p = 0.387$, and for the mass conservation case the result was $\chi^2(df=1, N=80) = 3.209$, $p = 0.201$.

Finally, Gamma coefficient was used to assess the association of the status (TC, PC, NC) of conservation awareness between liquid conservation and mass conservation labeled participants. Significant statistical association was found between them by having γ value of 0.693 and p value of 0.001 for the robot experimenter and γ value of 0.691 and p value of 0.002 for the human experimenter.

For tests performed by the robot experimenter:

- Out of 4 NCs in liquid conservation 2 were NCs and 2 were PCs in mass conservation.
- Out of 55 PCs in liquid conservation 3 were NCs, 40 were PCs, 12 were TCs in mass conservation.
- Out of 21 TCs in liquid conservation 10 were PCs, 11 were TCs in mass conservation.

For tests performed by the human experimenter:

- Out of 7 NCs in liquid conservation 2 were NCs, 4 were PCs, 1 was TC in mass conservation.
- Out of 58 PCs in liquid conservation 6 were NCs, 47 were PCs, 5 were TCs in mass conservation.
- Out of 15 TCs in liquid conservation 7 were PCs, 8 were TCs in mass conservation.

Thus, not only it is verified that the majority of children were PCs for that age group, but also that there was an association between the conservation tasks and knowledge transfer between them.

6.4 Discussion

The present study shows that the performance of children 5–6 years old, in Piaget’s conservation tests of liquid and mass, is enhanced for liquid conservation (4% more achieving at least partial conservation, while 48% more achieving total conservation) and for mass conservation (4% more achieving at least partial conservation, while 33% more achieving total conservation) when they are guided by a robot experimenter instead of a human one. Removing the human factor from the experimental process seems to improve the children’s awareness of the fact the liquid and mass

quantities remained the same throughout all the tasks in general, despite the changes in appearance that occurred. Nowadays children are highly familiarized with technology, hence robots and tablets feel natural to them, and they need very little time to adjust. Humanoid-social robots offer multiple advantages to children and have been the subject of extensive research (e.g., Jamet et al., 2018). Children are motivated and they have a positive attitude and better concentration when they interface with a robot to perform tasks. Human experimenters can influence the answers of children (McGarrigle & Donaldson, 1974) because they act as authority figures and frequently, they put children in a stressful position of feeling that they are being judged. In contrast, robot experimenters are perceived as an equal interlocuter by children, making them feel calm and relaxed, thus performing at their best. We believe that the performance enhancement that occurred in the case of the robot experimenter in both tests was mostly owing to the aforementioned advantages.

Furthermore, it is important to note that comparing the percentage of complete conservers, partial conservers, and non-conservers, we discovered that the vast majority of children understood the conservation concepts. Most of them were classified as partial conservers, which validates our original hypothesis. Also, it is expected for that age group because it is near the end of the preoperational stage of Piaget's phases of cognitive development. A crucial role, for having such positive results in the test, was played by the fact that children were required to answer correctly in four out of five introductory questions to ensure their understanding of basic concepts before they were eligible for participation in the study. This prerequisite definitely improved the percentage of correct results because children who were a little late in cognitive development and failed to answer the introductory questions were filtered out completely. This filtering was necessary because one of our main objectives was to examine the associations between the concepts of conservation for that developmentally marginal age group, and having subjects who could not answer any answers correctly would not provide any added value. To determine the exact age that conservation awareness occurs was out of scope of the current research.

Finally, the correct answers' percentages, in all cases (robot-liquid, robot-mass, human-liquid, human-mass), in the general concept of conservation were lower compared to the correct answers' percentages in all three specific concepts, identity, compensation, and reversibility. This is in line with the Piagetian theory that the specific concepts are prerequisites for children to achieve the general concept of conservation (Hooper, 1969). Unfortunately, except for the general trend of better performance in the specific concepts, significant associations between them and the general concept

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of conservation could not be established in this study because the statistical analysis of the results of the pairs (general-identity, general-compensation, general-reversibility) did not verify them. Previous research has indicated that conservation awareness can occur at earlier ages (e.g., McGarrigle & Donaldson, 1974) than initially thought by Piaget, and our results verified those claims. Though, it is possible that by experimenting on an older age group (e.g., 6–7+ years old), that is supposed to have acquired understanding of the conservation concepts more than younger ages, might provide more clear and significant associations between the general concept on the one hand and identity, compensation, and reversibility concepts on the other. Implications of the importance of the role of technology represented in this research by the robot-experimenter are evident in the fields of psychology and education and would be an interesting topic for further continuation of our research because, by keeping the experimental design and procedure the same, we can gain more insight on what is happening as a transitive state between the two age groups and Piaget’s cognitive stages, preoperational and concrete operational.

CHAPTER 7: General Discussion

This dissertation investigates the role of digital platforms and socially assistive robotics in cognitive development, focusing on children's understanding of Piagetian based conservation tasks. By examining cognitive performance across physical, digital, and robotic-mediated environments, it contributes to the understanding of how technological environments affect children's cognitive engagement and developmental processes. This chapter synthesizes the findings from each study, discusses their theoretical implications, and explores their broader contributions to the field of cognitive and developmental psychology. Although the studies were not specifically designed to test other theories of cognitive development, elements of these theories are present and identifiable in the findings, offering insights into how different theoretical perspectives may intersect with the role of technology in cognitive processes. Together, these studies provide a holistic view of the potential benefits and limitations of technology-enhanced environments for children's cognitive development, engagement, and learning processes. Across the three studies, the digital platform demonstrated both adaptability and efficacy in assessing children's cognitive abilities within a virtual environment.

One of the core theoretical contributions of this dissertation is the application of Piagetian theories to digital and robotic contexts. Piaget's model of cognitive development, particularly his theory of conservation, posits that children's understanding of quantitative concepts progresses in structured stages, largely influenced by direct interactions with physical objects (Piaget, 1954). The digital environment, however, provides an alternate medium through which children can explore these concepts, potentially accelerating or altering the traditional developmental trajectory. This phenomenon supports some contemporary critiques of Piagetian stage theory, which argue that cognitive development may not follow rigid, universally sequential stages, particularly in digitally enriched contexts (Lourengo & Machado, 1996).

The transition from physical to digital and robotic-mediated environments invites further discussion on the role of context in cognitive engagement. Research suggests that digital environments can offer unique advantages in structuring children's focus and engagement due to the customizable, interactive elements available in digital interfaces (Kim et al., 2020). The findings from this dissertation align with this view, demonstrating that children's attention to cognitive tasks may be more sustained in digital settings, likely due to the gamification of tasks and immediate feedback. This is consistent with research on the role of digital technology in enhancing higher-order thinking skills by fostering interactive, exploratory environments that support sustained focus

(Ahmad et al., 2020). In the first study the introduction of the virtual experimentation platform with machine learning capabilities showcase innovative and contemporary technologies used to support cognitive development experiments. In the second study, the digital environment may have provided an external structure that limited distractions typically present in physical environments, creating a focused space for cognitive tasks. The robotic experimenter in the third study introduced another dimension, potentially enhancing attention and autonomy through consistent, unbiased interactions. These findings underscore the need for additional studies exploring the contextual factors that influence engagement and task performance in cognitive development research.

The digital platform and robotic elements developed in this dissertation have practical implications for educational technology, particularly in areas such as early childhood education and personalized learning. Research suggests that digital tools can effectively support individualized learning by providing immediate feedback, tracking progress, and adapting to students' cognitive levels (Barclay et al., 2018). The platform developed here exemplifies this potential, allowing educators to assess children's cognitive skills and provide customized support tailored to their developmental stage. Another important application of this dissertation is the platform's capacity to enhance children's self-efficacy and independence in learning. In particular, the robotic experimenter's neutral and consistent feedback potentially reduced performance anxiety and encouraged self-driven exploration and problem-solving. This finding aligns with studies demonstrating that unbiased, automated interactions can foster autonomy and build self-confidence in children, especially in high-pressure tasks or subjects where social judgment may otherwise impact performance (Gijbels et al., 2021). The platform's adaptability also opens avenues for cross-cultural research in cognitive development. As developmental psychology increasingly emphasizes the importance of cultural factors (Gauvain et al., 2011), tools like the one introduced here could be used to study how children from different cultural and socioeconomic backgrounds approach cognitive tasks. Such an approach would provide a broader understanding of the universality and variability in cognitive development across diverse contexts, addressing critiques of Piaget's theory that call for a more nuanced view of developmental stages influenced by cultural and social factors (Thomas & Fam, 1984).

Cooperative and social learning technologies are designed to facilitate collaborative learning experiences where children interact, share ideas, and build knowledge together. These technologies often include features such as shared virtual spaces, real-time communication tools, and interactive

platforms that allow students to work on tasks collectively, mimicking face-to-face interactions in a digital environment. Examples include online learning games, collaborative whiteboards, and social media platforms specifically designed for educational use (e.g., Google Classroom, Kahoot, and Minecraft Education). In cooperative learning, children often gain deeper insights by explaining concepts to each other, observing alternative strategies, and engaging in joint problem-solving, which can enhance both cognitive and social skills. The platform developed in this thesis, including its virtual environment, machine learning elements, and robotic experimenter, introduces a different yet complementary approach to learning and cognitive assessment. Instead of direct peer interaction, the platform provides a structured, interactive environment where children engage with cognitive tasks individually. The platform's gamified elements and immediate feedback offer guidance tailored to each child's needs, with machine learning models enabling adaptive responses based on individual performance. The robotic experimenter adds a unique dimension by serving as a neutral guide, facilitating structured learning without the social biases that may emerge in peer-to-peer settings and it allows children to engage with the tasks without judgment, which can be beneficial for children who may feel self-conscious in group settings. This design aligns with principles from both social learning theory and cooperative learning but achieves learning outcomes through a different, technology-mediated approach. Instead of relying on peer interaction, the platform simulates structured support, scaffolding, and neutral feedback to help children explore cognitive tasks within their Zone of Proximal Development (Vygotsky, 1987). This approach mirrors some aspects of cooperative learning by creating a supportive learning environment, yet it focuses on individual engagement and tailored feedback rather than peer collaboration.

In order to discuss more specifically the theoretical and applied issues of the present thesis, a brief overview of the three empirical studies effectuated is presented below.

The first study validated the platform's capabilities, establishing its usability for cognitive research, especially in conducting conservation tasks in controlled digital settings. This study aligns with the growing body of literature supporting the role of digital technology in modern psychological assessments (e.g., Zhang & Nouri, 2018). By providing a customizable and engaging interface, the platform addresses limitations in traditional assessments, where environmental variables and experimenter bias may influence results (Fedushko et al., 2019). Additionally, it was enhanced with machine learning capabilities in order to provide predictions about children's performance on cognitive tasks, particularly focusing on Piagetian conservation tasks. Machine learning within this

context allowed the platform to monitor children's interactions and identify patterns in their responses. The first study's findings highlight the digital platform's adaptability and effectiveness as a cognitive assessment tool. The platform showed a high task completion rate and effective user engagement. These results are consistent with research indicating that digital environments can sustain children's focus more effectively than traditional environments (Kim et al., 2020). This aligns with Piaget's theory of cognitive development, particularly his emphasis on the importance of environmental interactions in promoting cognitive growth (Piaget, 1954). Validation of the effectiveness of a digital platform as a tool designed to facilitate cognitive assessments in children was performed. Analysis demonstrated operational task completion rate reaching the desired 100%, indicating that the virtual experimentation platform functions as intended. The platform's design—gamified and interactive—seems particularly effective in engaging children, supporting previous findings that digital environments can motivate and sustain focus through structured, visually stimulating tasks (Ahmad et al., 2020; Alsalhi et al., 2020). The study also revealed some variability in task result prediction with machine learning based on age group, with younger children (aged 5) showing lower confidence in the prediction compared to older children (aged 6). This age-based variability highlights the potential influence of developmental stages on engagement with digital tasks, a finding consistent with Piaget's stage theory, which suggests that older children in the concrete operational stage exhibit more structured cognitive processing, allowing them to engage more effectively in systematic tasks.

The second study highlighted the unique cognitive responses elicited in digital versus physical settings. It examined how children approach conservation tasks in physical versus digital environments. Specifically, children's understanding of conservation appeared to not be modulated by the medium in which they were assessed, suggesting that digital environments influence those specific cognitive processes the same way as traditional physical contexts (Sung et al., 2016). These findings resonate with Piagetian theories on the influence of environmental interaction on cognitive development (Piaget, 1951) and extend them to contemporary digital contexts, emphasizing the role of interface, interaction style, and user engagement in shaping cognitive performance. The findings suggest that digital platforms might offer cognitive benefits by creating a focused environment that reduces extraneous stimuli, a feature difficult to replicate in physical spaces. Theoretically, these results expand on Piaget's theories of conservation by demonstrating that cognitive milestones like conservation may not be uniformly bound to specific age ranges. The observed performance in the

reversibility concept of conservation suggests that Piagetian stages might be more adaptable than originally conceived. This aligns with critiques that propose flexibility within Piaget's stages, particularly in environments enriched with interactive digital support (Lourenço & Machado, 1996). Furthermore, the positive association between digital environments and task performance resonates with Vygotsky's sociocultural theory, suggesting that digital tools act as cultural mediators that can shape cognitive development. In digital settings, children may benefit from immediate feedback, autonomy over task pacing, and visual reinforcement, all of which encourage deeper cognitive engagement. These elements not only align with Vygotsky's emphasis on mediated learning but also suggest that digital platforms like the one developed in this thesis can act as "scaffolds," enhancing cognitive engagement and accelerating understanding.

In the third study, the use of a robotic experimenter further enhanced the platform's potential for reducing experimenter bias and provided insights into the role of socially assistive robotics in cognitive assessments. Children's increased engagement and potentially higher levels of autonomy in robotic interactions highlighted the effectiveness of robotic agents in facilitating unbiased, adaptable assessments. These results support emerging literature on socially assistive robotics, which suggests that robotic interaction can enhance engagement and facilitate learning through consistent, nonjudgmental interactions (Ali et al., 2019; Jamet et al., 2018). The introduction of a robotic experimenter was found to positively influence children's engagement, task completion, and overall performance. Notably, children showed a 4% increase in achieving partial conservation, both in mass and liquid conservation, a 33% increase in mass conservation and a 48% increase in liquid conservation, in achieving total conservation when interacting with a robotic experimenter compared to a human experimenter. This effect may be due to the robot's neutrality, which likely reduced social pressure and provided children with a consistent, nonjudgmental interaction partner (Jamet et al., 2018). This aligns with research in human-robot interaction, suggesting that children tend to perceive robots as unbiased and approachable, which enhances their willingness to engage actively and autonomously in tasks (Cameron et al., 2016). The robotic experimenter's effectiveness can be explained by theories of social learning and interaction. Studies in socially assistive robotics suggest that children perceive robots as neutral, nonjudgmental entities, which reduces anxiety and increases willingness to engage (Bennington-Castro, 2017). This outcome is also in line with Vygotsky's emphasis on social scaffolding, where a robotic agent can act as a supportive, nonjudgmental presence that fosters a child's confidence in exploring and mastering complex tasks.

By eliminating experimenter bias, the robotic agent provides a consistent interaction that enables children to focus on task-related cognition, potentially supporting Piagetian learning stages through unbiased, structured interactions. Furthermore, the robotic condition's success in reducing experimenter influence offers insights into the "Naughty Teddy Bear" experiment, where children's task responses were influenced by perceived experimenter expectations (McGarrigle & Donaldson, 1974).

7.1 Discussion regarding Information Processing Theory, Awareness and Attention

According to Information Processing Theory, cognitive processes such as awareness, attention, encoding, and retrieval are crucial for effective learning and problem-solving. This theory provides a framework to interpret the results of each study, particularly in terms of how the digital platform and gamified environment impacted children's cognitive engagement with conservation tasks (Kihlstrom, 1987; Lachman et al., 2015).

In Study 1, the platform's validation phase indicated high levels of task engagement. The Information Processing framework helped explaining these results by suggesting that the interactive and visual elements of the digital platform acted as cognitive cues, capturing and sustaining children's attention. By integrating game-like elements such as scores and immediate feedback, the platform likely helped children maintain focus on the task, enhancing their awareness of the task goals and reinforcing attention. This aligns with studies indicating that interactive digital interfaces can facilitate deeper information processing by reducing distractions and directing focus toward task-relevant elements (Zhang & Nouri, 2018).

In Study 2, a comparison of physical and digital environments revealed approximately the same accuracy rates in conservation tasks within the digital and physical environments. Information Processing Theory suggests that the digital platform's structure facilitated cognitive engagement and focus, possibly reducing cognitive load. The streamlined, interactive design of the digital setting allows children to concentrate more fully on task elements without peripheral distractions present in physical environments. This structured environment may have promoted deeper encoding and comprehension of conservation concepts, as the digital cues consistently directed children's attention to relevant details (Kim et al., 2020).

Study 3 introduced a robotic experimenter, with results showing increases in the performance of the children. Information Processing Theory offers insights here as well: the robot's consistent and

neutral presence likely reduced social distractions and experimenter bias, allowing children to allocate their cognitive resources more fully to task-related processing. The robot's non-judgmental, supportive feedback may have reinforced attention and facilitated encoding by providing immediate responses without the social pressure often present with human experimenters. Thus, the robotic setting optimized the cognitive environment for information processing, enhancing children's awareness of task objectives and focus on problem-solving.

7.2 Discussion regarding Papert's Constructionism and Gamified Environments

Papert's constructionism theory emphasizes active, playful learning and the value of exploration in cognitive development. Papert suggests that learning environments that encourage experimentation and personal engagement can enhance children's understanding of abstract concepts. Also, this theory complements this by highlighting how the platform's gamified, exploratory structure promotes active engagement and intrinsic motivation. The digital elements embedded in the tasks turn cognitive assessments into playful challenges, encouraging children to engage deeply without fear of judgment or failure (Khalil et al., 2022; Nicolopoulou et al., 2009). Because of that, growth is enhanced in environments where children can experiment, receive immediate feedback, and learn autonomously. The robotic experimenter further supports this theory, as its neutral feedback helped children focus on task objectives without the potential social distractions of a human presence. Papert's theory aligns closely with the gamified elements of the digital platform used across all studies and provides a framework for interpreting how these elements impacted children's performance and engagement.

In Study 1, the virtual platform's digital features, such as animation and immediate feedback, appeared to foster intrinsic motivation and engagement. The platform's design transformed traditional conservation tasks into interactive, child-centered challenges. According to Papert, this playful, autonomous interaction is critical for cognitive engagement and supports deeper learning. Children's high completion rates in this study underscored how the virtual platform promoted learning by creating a low-pressure, exploratory environment in line with Papert's principles (Papert, 1984).

In Study 2, the digital environment's structure provided a unique setting for conservation tasks, where children could experiment without the constraints often associated with traditional

physical environments. Papert's theory suggests that the platform's digital features can test childrens' understanding with the same efficiency as physical environments.

In Study 3, the robotic experimenter introduced a new dimension of playful interaction, aligning with Papert's emphasis on learning through discovery and experimentation. The robot's neutrality and non-judgmental feedback allowed children to focus on task exploration rather than worry about social evaluation, a factor that may have contributed to the observed increase in successful answering. Papert's theory would suggest that the robot's presence fostered an environment where children felt free to make mistakes and learn through trial and error, further reinforcing their understanding of conservation concepts.

7.3 Discussion regarding Bruner's Theory and Cognitive Representations

Bruner's theory on the development of cognitive representations emphasizes three modes of knowledge representation: enactive, iconic, and symbolic (Bruner, 2021; Conway, 2007; Rowland, 1968). Bruner proposed that children first understand the world through direct manipulation and action (enactive representation), then through images and visual organization (iconic representation), and finally through abstract symbols, such as language and numbers (symbolic representation). This framework is particularly relevant to this research, as each study involved a different interaction with cognitive tasks, ranging from physical manipulation to digital and robotic engagement. The results across all three studies suggest that digital and robotic tools can be highly effective in supporting the development of cognitive representations. The digital environment, by providing clear visual representations and structured feedback, helps children transition from enactive to iconic and then to symbolic representation. By allowing children to engage with conservation tasks in an exploratory, visually organized way, the digital platform may facilitate the formation of mental models that align with Bruner's iconic and symbolic stages (Harmes et al., 2016; Onyango & Gitonga, 2017). The robotic experimenter adds an additional layer, acting as a scaffold that supports symbolic representation by encouraging children to focus on task principles without social pressures. This setup enables children to internalize cognitive concepts more effectively, aligning with Bruner's view that structured guidance fosters the development of abstract representations.

In Study 1, the digital platform served as an intermediary step between enactive and iconic representations. Children interacted with conservation tasks in a digital environment where they

could observe virtual objects and receive immediate visual feedback. The digital platform's design likely enhanced children's understanding by reinforcing their actions with visual cues, which aligns with Bruner's enactive and iconic stages. From Bruner's perspective, the digital platform's interactive features helped children progress from enactive to iconic representation by allowing them to engage with conservation tasks in a way that mimicked physical manipulation but provided clearer, structured visual representations of their actions and consequences. The platform's ability to respond immediately to children's inputs may have encouraged them to form mental images or "iconic" representations of the tasks, which are essential for developing abstract, transferable cognitive skills.

Study 2 compared children's understanding of conservation in physical versus digital environments. Digital tasks may enhance the shift from iconic to symbolic representation, particularly in structured, gamified settings. Bruner posited that as children develop iconic representations, they become better equipped to internalize symbolic representations, allowing them to think abstractly and understand complex principles like conservation. In the digital setting, conservation tasks were presented visually, allowing children to engage with and analyze visual symbols (e.g., liquid levels in containers). For children who may already be progressing from iconic to symbolic thinking, this structured visual environment likely reinforced abstract conservation concepts through repeated, visually organized interactions. Bruner's theory suggests that structured visual guidance—such as that provided by digital interfaces—can bridge the gap between concrete actions and abstract concepts.

In Study 3, the use of a robotic experimenter introduced a structured yet neutral presence, supporting children's engagement with conservation tasks. Bruner's theory highlights the importance of "scaffolding," or structured support, in helping children internalize abstract concepts. In this study, the robotic experimenter acted as a scaffolding tool, guiding children through the task without introducing potential social biases or pressures associated with human interaction. The statistical results showing increased performance with the robotic experimenter, suggest that the robotic interface provided a conducive setting for children to form symbolic representations. The robot's unbiased, structured feedback helped children concentrate on task elements, likely reinforcing their ability to internalize conservation concepts at a symbolic level. Bruner's theory suggests that such structured guidance is critical for helping children move from concrete (iconic) to abstract (symbolic) understanding. The robotic experimenter's role as a consistent guide may have

enabled children to apply symbolic thinking more effectively, reducing cognitive load and allowing them to focus on the task's symbolic aspects, such as volume and mass conservation. Furthermore, the robotic experimenter's non-judgmental feedback aligns with Bruner's theory of discovery learning, where children learn best when they are guided to discover principles on their own rather than being told directly. The robotic setup encouraged children to explore conservation concepts independently, promoting the internalization of these concepts at a symbolic level. This is especially valuable in cognitive development, as it reinforces the ability to transfer abstract knowledge to different contexts—a skill central to symbolic representation.

7.4 Discussion regarding Zone of Proximal Development and Educational Tools

Vygotsky's concept of the Zone of Proximal Development (ZPD) describes the range between what a learner can achieve independently and what they can achieve with guided support (Vygotsky, 1987). In educational psychology, ZPD is a foundational principle, suggesting that learners perform best when tasks are slightly beyond their current abilities but within reach through supportive guidance, or "scaffolding" (Wells, 1999). Scaffolding in this context refers to tools, instructions, or interactions that help learners achieve tasks they would struggle to complete on their own. The digital platform and robotic experimenter in this research provide forms of scaffolding, facilitating children's cognitive development by guiding them through Piagetian conservation tasks with structured, interactive support. The studies in this thesis offer insights into how digital and robotic tools can operate within children's ZPD, making conservation concepts more accessible and potentially accelerating cognitive development. Each study showcases a different aspect of scaffolding, whether through visual feedback, gamified structures, or the neutral, consistent support of a robotic experimenter, all of which play significant roles in enhancing children's engagement and comprehension within their ZPD (Beliavsky, 2006; Bruner, 1984; Doolittle, 1995).

In Study 1, the digital platform presented its potential to sustain engagement and facilitate task comprehension. By digitalizing conservation tasks, the platform provided motivational scaffolding, which aligns well with Vygotsky's ZPD framework. The interactive nature of the platform, which provided immediate feedback and prompted children to think critically about each task, allowed children to attempt conservation tasks slightly above their independent skill level. This structured, supportive environment made it easier for children to bridge the gap between their current understanding and the required level of cognitive complexity. The statistical success in task

completion rates and sustained engagement further suggests that the platform effectively operated within each child's ZPD. Vygotsky's theory implies that children learn best when supported by structured guidance, and the digital platform's interactive elements acted as virtual scaffolding, helping children engage more deeply and stay focused on task objectives. These findings underscore the potential of digital tools to serve as effective scaffolds in cognitive development, where the platform's feedback mechanisms can guide children in progressively understanding conservation concepts. Also, the machine learning model acted as an invisible scaffold, continuously assessing each child's performance and predicting conservation results. This predictive adaptability is crucial in developmental psychology, where learning tasks need to be both accessible and challenging to promote growth. By predicting performance trends, the platform facilitated a learning environment that helped children make cognitive progress within their ZPD. This approach enhances the effectiveness of the ZPD by providing dynamic, individualized support that evolves with each child's learning progress.

Study 2 compared children's performance in physical and digital settings, highlighting how a structured digital environment can act as a scaffold that supports learning within the ZPD. The digital environment provided children with consistent cues, visual organization, and immediate feedback, which likely helped them reach an understanding of conservation concepts with the same effect than in a traditional physical environment. Vygotsky emphasized that the ZPD is an ideal range where learning is maximized through guidance, and the digital environment exemplifies this principle by acting as a "digital scaffold." The digital setting provided visual cues that kept children focused on relevant elements, thereby helping them bridge the gap between initial and full understanding. This suggests that well-designed digital tools can offer cognitive support that maximizes children's learning potential, especially when tasks are structured to guide them toward progressively challenging goals within their ZPD.

Study 3 introduced a robotic experimenter, adding another layer of scaffolding by serving as a consistent, neutral guide that kept children engaged and focused on the task. Vygotsky posited that social interaction is key to scaffolding within the ZPD, and although the robotic experimenter is non-human, its neutral presence served a similar role by providing consistent feedback without the biases or expectations associated with human experimenters. The statistical improvement in task performance in the robotic setting suggests that the robot's presence created an optimal environment for children to engage with tasks within their ZPD, without the pressures of social

evaluation. By providing non-judgmental, neutral support, the robotic experimenter allowed children to explore conservation tasks at their own pace, helping them build confidence and work through challenging aspects of the task. This structured interaction is akin to a “scaffolded learning partnership,” as proposed by Vygotsky, where children feel supported in their exploration and encouraged to achieve new cognitive milestones. The robotic experimenter’s consistent and unbiased feedback allowed children to work within their ZPD with a reduced cognitive load, enhancing their ability to internalize conservation concepts over repeated interactions.

7.5 Discussion regarding Embodied Cognition and Cognitive Development

Embodied cognition is a theory in cognitive science suggesting that cognitive processes are deeply rooted in the body’s interactions with the physical world. Rather than viewing cognition as purely abstract or brain-bound, embodied cognition argues that cognitive development is influenced by sensory and motor experiences, where the mind, body, and environment interact dynamically (Foglia & Wilson, 2013). This theory suggests that understanding and knowledge are shaped by one’s physical actions, interactions, and experiences in the environment. In cognitive development, embodied cognition emphasizes that children learn through action and physical interaction, which contribute to forming mental models and internalizing concepts (Mills et al., 2022). The studies in this thesis, which involve both physical and digital tasks and the use of a robotic experimenter, offer a unique perspective on embodied cognition by examining how different environments—physical, virtual, and robotic—impact children’s learning and understanding of cognitive tasks like conservation. Each study demonstrates varying degrees of physical and sensory interaction, from tangible manipulation in physical settings to digital engagement on a screen and interaction with a robotic entity. Analyzing the results of these studies through the lens of embodied cognition sheds light on the role of physicality, interaction, and sensory feedback in fostering children’s understanding of cognitive concepts (Lozada & Carro, 2016).

In Study 1, children engaged with a digital platform designed to facilitate conservation tasks. This platform minimized physical manipulation, focusing instead on interactive, visual engagement with virtual objects. Although physical embodiment is limited in a digital environment, the platform’s design compensates by using gamified elements and interactive feedback to maintain children’s engagement and reinforce cognitive processing. From an embodied cognition perspective, the limited physical interaction in the digital platform might constrain children’s ability to fully internalize

concepts like conservation, as they are not directly manipulating physical objects. However, embodied cognition research also suggests that virtual environments can simulate aspects of physicality by encouraging users to mentally simulate actions they would perform in a physical context (Johnson-Glenberg et al., 2014). In this study, children's improved performance in the digital environment could indicate that the platform's interactivity allowed them to mentally simulate physical manipulation, which aligns with embodied cognition's emphasis on interaction as a bridge to understanding. Furthermore, the platform's use of immediate feedback and visual cues allowed children to engage cognitively with conservation concepts without direct physical manipulation. This outcome supports the view that, while physical interaction is ideal, well-designed digital environments can still engage embodied cognition by encouraging children to visualize and mentally rehearse conservation tasks.

Study 2 directly compared children's performance in physical and digital settings, allowing for an examination of how physical interaction impacts cognitive development compared to virtual engagement. In physical settings, children engaged directly with objects to explore conservation concepts, providing an embodied experience that aligns with the principles of embodied cognition. Physical manipulation of objects enables children to experience conservation through actions, such as pouring of liquid, which reinforces their understanding by engaging sensory and motor systems. Embodied cognition theory posits that this physical interaction should ideally enhance cognitive development, as children's understanding of conservation concepts is strengthened by tactile and kinesthetic feedback. Interestingly, children in the digital setting showed approximately equal accuracy. This result challenges the notion that direct physical interaction is always superior for learning, suggesting that structured digital environments can offer comparable cognitive benefits. The study suggests a complex interaction between embodied cognition and digital environments. The digital setting may have provided sufficient interactive features to facilitate an "embodied" understanding of conservation by engaging children's attention and encouraging mental simulation of physical actions. These findings align with research suggesting that virtual environments can promote embodied learning by requiring users to engage in mental simulations of physical experiences. This study indicates that digital platforms can partially substitute for physical embodiment, offering structured, interactive cues that help children mentally simulate physical tasks, thereby supporting cognitive growth.

Study 3 introduced a robotic experimenter, adding a unique form of embodied interaction to the task. The robotic agent provided a physical presence, which, while not an object for manipulation, created an environment where children could engage with a consistent, neutral figure. This interaction aligns with embodied cognition's view that cognitive processes are influenced by social as well as physical interactions. In this case, the robot's presence may have enhanced engagement by providing a non-judgmental, interactive guide, allowing children to focus on cognitive aspects of conservation without social pressure. The embodied cognition framework suggests that the robot's physical presence could help ground children's attention in the task, serving as a consistent "anchor" that supports task focus and cognitive processing. The robot's neutral guidance might have encouraged children to engage with the conservation tasks more confidently, as they received structured feedback without social distractions. Additionally, the robot's physicality provided an interactive element that encouraged children to engage more deeply, potentially reinforcing understanding through embodied interaction. From an embodied cognition perspective, the robot's role in the learning environment might support cognitive engagement through a process called "social embodiment," where interaction with another physical presence (even a robot) influences cognitive processes. This interaction supports the development of cognitive skills by providing embodied cues that encourage children to focus and sustain attention on task elements, facilitating mental processing of the conservation concepts.

7.6 Discussion regarding Integrating Findings with Cognitive Developmental Theory

The combined results of these studies suggest that digital platforms and robotic experimenters may offer significant benefits in structuring children's focus, providing unbiased feedback, and adapting to individual developmental needs. These findings support theoretical critiques that suggest Piaget's stages may not be as rigid as previously thought. The enhanced task performance and engagement observed in digital and robotic settings indicate that cognitive development can be supported through technology-mediated environments, potentially accelerating cognitive milestones traditionally associated with specific ages. This perspective aligns with dynamic systems theories in cognitive psychology, which propose that cognitive development is not a strictly linear progression but can vary with environmental support and intervention (Spencer & Darvizeh, 1981). The platform's success in fostering engagement and comprehension also reinforces Vygotsky's idea that cultural tools, including digital platforms, actively shape cognitive processes. Thus, digital and robotic

environments may serve as developmental catalysts that accelerate understanding by providing structured, scaffolded interactions that may be otherwise unavailable in traditional settings.

Taken together, the three studies underscore the potential of digital and robotic environments to enrich cognitive development research and suggest practical implications for educational settings. Across studies, the structured, interactive nature of the digital platform and the impartial presence of a robotic experimenter collectively enhance children's cognitive engagement, task focus, and problem-solving abilities. These findings indicate that digital and robotic tools can play a substantial role in early cognitive education, potentially fostering greater autonomy, self-efficacy, and resilience in young learners. The dissertation's findings highlight a growing divergence from traditional cognitive developmental theories, suggesting that technological environments can reshape the cognitive milestones once thought to be strictly age-bound. Specifically, the enhanced cognitive performance observed in digital and robotic settings indicates that cognitive abilities may emerge earlier or more robustly when children engage with adaptive, supportive digital tools. This is consistent with dynamic systems theories, which propose that cognitive development is not linear but contextually adaptable, influenced by the interactions between the individual and the environment.

The findings also have significant implications for educational technology, particularly in early childhood education. The digital platform's high performance rates suggest that similar tools could be used in educational settings to foster attention, focus, and autonomy among young learners. Additionally, the robotic experimenter's positive impact on engagement and performance highlights the potential for robotic agents to serve as unbiased facilitators in educational and clinical settings. This supports research advocating for the integration of socially assistive robotics in education to enhance motivation and cognitive engagement (Bennington-Castro, 2017). By creating adaptive, non-judgmental learning environments, digital and robotic tools mitigate social biases and pressures in educational assessments. This aligns with findings from studies on behaviorism and constructivism, which indicate that interactive, gamified learning environments can positively impact children's focus and retention of information (Efgivia et al., 2021a). The virtual platform and robotic experimenter developed in this dissertation present practical applications for education. By fostering self-directed exploration and structured feedback, these tools can support individualized learning, enabling educators to provide customized, adaptive learning experiences that align with each child's developmental needs (Barclay et al., 2018). This aligns with growing support for personalized learning

environments that leverage technology to cater to diverse cognitive and developmental profiles. Furthermore, the predictive power of the virtual platform suggests that machine learning has substantial potential for creating adaptive, supportive educational tools (Mills et al., 2022). By continuously learning from each child's interactions, the machine learning model can provide precisely targeted guidance, which enhances engagement and promotes a deeper understanding of complex cognitive tasks. For future educational tools, this predictive model could be expanded to include additional cognitive indicators, offering an even more nuanced understanding of individual learning trajectories. Educational tools can leverage machine learning to create environments that not only adapt to learners but also anticipate their needs, providing optimal scaffolding that supports cognitive development.

In conclusion, this dissertation advances the field of cognitive development by demonstrating the potential of digital platforms and socially assistive robotics in research and educational contexts. The findings from the three studies support the integration of technology in cognitive assessments, offering unique insights into the ways digital and robotic environments impact children's cognitive processes, engagement, and self-perception. The virtual platform and its applications mark a step forward in developmental psychology, suggesting that digital and robotic tools, when thoughtfully implemented, can enhance cognitive development research and support children's growth in focused, autonomous, and culturally responsive ways. These contributions open new paths for research at the intersection of technology, education, and psychology, with far-reaching implications for modern learning and cognitive development.

Limitations and Future Research

While this dissertation presents a novel approach to cognitive development research by integrating digital and robotic tools, it is important to acknowledge several limitations that can be addressed in future studies. One of the primary limitations is the sample size used across the experiments. Although the platform demonstrated its utility and adaptability, the findings would benefit from a larger, more diverse participant pool to improve the robustness and generalizability of the results. Particularly in the application of machine learning models for cognitive assessments, a larger subject count is essential to train models effectively, ensure stability in predictions, and account for variability in children's responses. Future studies could thus aim to include a broader and more heterogeneous participant base to strengthen the machine learning component and enhance the precision of the platform's adaptive feedback mechanisms. Also, the current implementation focuses on predictive modeling for cognitive assessments, future extensions could explore the integration of explanatory modeling techniques. Shmueli (2010) underscores that explanatory and predictive models serve distinct but complementary purposes, suggesting that a hybrid approach could enhance both theoretical understanding and practical application in developmental psychology research.

Another limitation is the relatively narrow scope of demographic factors and contextual influences considered in the current study. While the research primarily focused on cognitive assessment and learning within a controlled digital environment, cognitive development is inherently shaped by various socio-cultural and environmental factors. Future research could expand on this work by incorporating parameters such as cultural background, socioeconomic status, and educational setting, which may significantly impact children's cognitive engagement, learning processes, and interpretation of digital tasks. Studies exploring cultural influences, for example, could examine how children from different cultural backgrounds approach conservation tasks and interact with digital or robotic experimenters, potentially revealing insights into the cross-cultural applicability of digital cognitive assessment tools.

Additionally, this work primarily concentrated on cognitive assessments related to Piagetian conservation tasks. However, cognitive development encompasses a broad range of domains, such as executive function, memory, social cognition, and language processing. Future research could explore the application of this digital platform across these domains, potentially expanding its utility to offer a more comprehensive view of cognitive development in children. Furthermore, integrating longitudinal studies into future research designs could offer valuable insights into how repeated

exposure to digital and robotic learning environments impacts cognitive skills over time, enabling researchers to assess the long-term benefits and any potential drawbacks of these technological interventions.

The potential for robotics in this research is an area ripe for further exploration. While this dissertation investigated the impact of a robotic experimenter in a limited capacity, future studies could delve deeper into the various roles robotic agents might play in cognitive assessments and learning environments. Different robot types, behaviors, and interaction styles could be tested to determine how children's engagement, focus, and cognitive outcomes vary with different forms of robotic assistance. Additionally, as robotic technologies continue to evolve, future studies could investigate how more advanced, AI-driven robotic agents might provide even more personalized and responsive interactions, thereby enhancing the potential for individualized learning experiences. Future networks and technologies like the 6G system's user-centric paradigm and network service customization capabilities (Gkatzios et al., 2024) can also improve the use of robotics and the user experience in the digital platform developed as part of this thesis. 6G networks can dynamically adapt to individual requirements, fostering personalization and efficiency, enriching theoretical insights and also providing practical methodologies for integrating adaptive, user-driven principles into digital platforms, robotics, and educational technologies explored in this thesis.

Finally, in addition to the features presented in this study, numerous enhancements can be incorporated in future iterations of the platform. For instance, instead of displaying only the torso and hands in the tablet's screen, a full-body human avatar could be introduced to enrich the realism and social presence of the digital environment. Another new feature could be the incorporation of a mechanism that allows children to provide feedback after responding to questions. This could offer valuable insights into their reasoning processes, engagement levels, and potential difficulties they encounter, further refining the system's adaptability and effectiveness.

In conclusion, this work provides a foundation for future research at the intersection of cognitive development, digital platforms, and robotics. Addressing the identified limitations and expanding the scope of inquiry will not only enrich our understanding of how technology can support cognitive development but also enable the development of more versatile, culturally responsive, and effective tools for educational and psychological assessment.

Conclusion

Conclusion

This dissertation presents a comprehensive exploration of cognitive development in children through the lens of technology-enhanced environments, particularly focusing on digital platforms and socially assistive robotics. By designing and implementing an innovative digital platform that facilitates cognitive assessments, specifically Piagetian based conservation tasks, this research investigates how digital and robotic tools can support, enhance, and possibly transform developmental psychology research. The work builds on classic theories of cognitive development, incorporating modern technology to provide new insights into children's learning processes and cognitive abilities in the context of the digital age.

The research framework consisted of three primary studies, each contributing uniquely to the validation and examination of the digital platform's utility in cognitive development research. The first study focused on validating the platform, ensuring that its design, functionality, and user interface met the specific needs of developmental psychology assessments. This validation included evaluating its adaptability, ease of use, and suitability for various cognitive tasks, setting the foundation for more complex experiments. The second study explored children's performance on liquid conservation tasks within physical and digital environments, yielding valuable insights into how digital settings might impact cognitive engagement, focus, and comprehension of conservation concepts. The findings highlighted key differences in cognitive engagement between environments, suggesting that digital platforms may offer unique advantages in sustaining children's attention and providing a more structured, distraction-free setting for learning and assessment. The third study introduced a robotic experimenter into the digital platform to assess the effects of robotic facilitation on children's understanding of conservation tasks. This approach tested the hypothesis that robotic agents could reduce experimenter bias, providing a neutral, consistent, and interactive interface for children. Findings from this study pointed to the potential benefits of robotic interaction, such as increased engagement, curiosity, and independence in problem-solving, adding a layer of novelty and engagement to the cognitive tasks.

A major contribution of this research lies in its pioneering combination of digital environments and socially assistive robotics for cognitive assessment. Unlike previous studies that relied solely on in-person or purely digital methodologies, this dissertation takes a multidimensional approach that leverages both digital platforms and robotic agents, demonstrating their complementary strengths. The digital platform's interactive interface, combined with the neutrality and novelty of robotic

experimenters, enables a more engaging and bias-reduced assessment environment, thus advancing the field of developmental psychology by providing a model for future research in digital and robotic-mediated cognitive assessment. This innovative approach offers a new perspective on Piagetian conservation tasks and reveals how digital tools can be optimized to study children's cognitive development with greater flexibility and adaptability. The research further highlights the scalability and accessibility of digital platforms, suggesting that they may bridge gaps in developmental psychology research by providing remote, easily accessible tools for cognitive assessment.

The practical applications of this work are profound, especially for educational settings. By incorporating game-like elements into the cognitive tasks, the platform provides a more engaging and motivational environment for children, which could significantly impact their learning experiences. The digital environment's structured design enhances children's focus and minimizes distractions, which are common in traditional assessment settings. Furthermore, the robotic experimenter adds a dimension of social learning and engagement that is not only novel but also beneficial in fostering persistence, curiosity, and resilience in children as they work through cognitive tasks. This could be particularly useful in educational technology, where engagement is crucial to maintaining students' interest and fostering a positive attitude towards learning. By enhancing children's attention to tasks and promoting deeper focus, the digital and robotic aspects of this platform provide valuable insights into how technology can be leveraged to address the challenges of cognitive engagement and motivation in educational environments.

The implications of this work extend beyond cognitive tasks to encompass broader aspects of children's self-image, autonomy, and sense of competence. As children engage with the digital platform, they have the option to receive immediate feedback tailored to their responses, which allows them to progress at their own pace and experience a sense of accomplishment. This personalized learning approach helps to build confidence in their problem-solving abilities, reinforcing a positive self-image and encouraging a growth mindset. The neutral nature of robotic interaction removes the typical social pressures that may arise in the presence of an adult experimenter, allowing children to engage more freely and independently with the tasks. The platform's emphasis on adaptive, responsive feedback supports a learning environment where children feel safe to explore, make mistakes, and ultimately succeed, reinforcing their cognitive development and self-perception in constructive ways.

Conclusion

Furthermore, this work has additional significant implications for the field of cognitive development research and educational practice. While research and education are closely related, they are not necessarily the same, as research aims to generate new knowledge and theoretical insights, whereas education focuses on the practical application of knowledge to foster learning and development. This distinction is explicitly addressed, as this work approaches research by analyzing how cognitive processes can be objectively assessed through digital and robotic tools, emphasizing methodological advancements, data-driven insights, and the predictive capabilities of machine learning. The educational perspective, however, focuses on the practical implications of these findings, particularly how digital platforms and AI-driven predictions can be integrated into learning environments to support individualized instruction, enhance engagement, and improve learning outcomes. By differentiating these perspectives, this work ensures that while technological innovations are rigorously tested and validated within a research framework, their applicability in real-world educational settings is also considered, ensuring meaningful translation from experimental findings to pedagogical practice.

With the integration of digital and robotic tools into developmental psychology assessments, this research provides a model for a more accessible, flexible, and child-centered approach to cognitive assessment. The platform's adaptability suggests that it could be customized for a wide range of cognitive tasks, expanding its application beyond Piagetian conservation tasks to other areas of cognitive psychology, such as executive function, memory, and language development. Furthermore, the scalability of digital and robotic platforms allows for broader research participation, enabling developmental psychology to reach more diverse and geographically dispersed populations. This could be particularly impactful in educational settings, where individualized digital assessments may provide educators with a better understanding of each child's unique cognitive profile, thus facilitating more tailored and effective teaching strategies.

In conclusion, this dissertation underscores the transformative potential of technology in developmental psychology, demonstrating how digital and robotic tools can enhance cognitive assessment and offer unique benefits in understanding children's cognitive development, attention, focus, and self-image. By bridging traditional theories with modern technology, this research opens up new directions for the field, suggesting that digital platforms and robotic agents could become integral components of cognitive assessment and educational practices in the future. The findings advocate for an expanded view of cognitive development research, where technology is used not

only to simplify assessment but also to actively engage and support children's cognitive growth. This work provides a foundation for further innovation at the intersection of developmental psychology, educational technology, and socially assistive robotics, promoting a more adaptable, engaging, and child-centered approach to studying and supporting cognitive development.

References

References

- Abdelaziz, H. A., & Al Zehmi, O. (2021). E-cognitive scaffolding: does it have an impact on the English grammar competencies of middle school underachieving students?. *Open Learning: The Journal of Open, Distance and e-Learning*, 36(1), 5-28.
<https://doi.org/10.1080/02680513.2020.1774356>
- Abdellaoui, M., Daghouj, D., Fattah, M., Balboul, Y., Mazer, S., & Bekkali, M E. (2020). Artificial Intelligence Approach for Target Classification: A State of The Art. *Advances in Science, Technology and Engineering Systems Journal (ASTESJ)*, 5(4), 445-456.
<https://doi.org/10.25046/aj050453>
- Acredolo, C., & Acredolo, L. P. (1979). Identity, Compensation, and Conservation. *Child Development*, 50(2), 524-35. <https://doi.org/10.2307/1129432>
- Adams, H., Narasimham, G., Rieser, J., Creem-Regehr, S., Stefanucci, J., & Bodenheimer, B. (2018). Locomotive recalibration and prism adaptation of children and teens in immersive virtual environments. *IEEE transactions on visualization and computer graphics*, 24(4), 1408-1417.
<https://doi.org/10.1109/TVCG.2018.2794072>
- Adams, R. B., Albohn, D. N., & Kveraga, K. (2017). A Social Vision Account of Facial Expression Perception. *The Science of Facial Expression*, 315.
doi:10.1093/acprof:oso/9780190613501.003.0017
- Afari, E., & Khine, M. S. (2017). Robotics as an educational tool: Impact of lego mindstorms. *International Journal of Information and Education Technology*, 7(6), 437-442.
- Agrawal, P., Tan, C., & Rathore, H. (2023). Advancing Perception in Artificial Intelligence through Principles of Cognitive Science. *arXiv preprint arXiv:2310.08803*.
<https://doi.org/10.48550/arxiv.2310.08803>
- Ahmad, M., Mansor, N. R., Sung, C. M., Rashid, R. A., Abdullah, N. A. C., Zakaria, R., & Azmy, S. N. M. S. (2020). Mobile Technology in Enhancing Students' Higher Order Thinking Skill. In *Journal of Physics: Conference Series* (Vol. 1529, No. 4, p. 042057). IOP Publishing.
<https://doi.org/10.1088/1742-6596/1529/4/042057>
- Alaa'Shdefat, N. B., & Abdullah, A. H. B. (2020). A Proposed List of Secondary School Teachers' Competencies to Discover and Develop the Multiple Intelligences of their Class Students. *International Journal of Academic Research in Business and Social Sciences*, 10(2), 323-345. <https://doi.org/10.6007/ijarbss/v10-i2/6933>

- Alanazi, A. (2016). A critical review of constructivist theory and the emergence of constructionism. *American Research Journal of Humanities and Social Sciences*, 2(1), 1-8.
<https://doi.org/10.21694/2378-7031.16018>
- AlDahdouh, A. A. (2021). Information search behavior in fragile and conflict-affected learning contexts. *The Internet and Higher Education*, 50, 100808.
<https://doi.org/10.1016/j.iheduc.2021.100808>
- Alharbi, J. M. (2023). Insight into the role of interaction in language acquisition: Vygotsky's interactionist theory of language. *Arab World English Journal*, 14(2), 281-294.
<https://doi.org/10.24093/awej/vol14no2.20>
- Ali, S., Moroso, T., & Breazeal, C. (2019). Can children learn creativity from a social robot?. In *Proceedings of the 2019 Conference on Creativity and Cognition* (pp. 359-368).
<https://doi.org/10.1145/3325480.3325499>
- Allen, K. A., & Bowles, T. (2012). Belonging as a Guiding Principle in the Education of Adolescents. *Australian Journal of Educational & Developmental Psychology*, 12, 108-119.
<http://files.eric.ed.gov/fulltext/EJ1002251.pdf>
- Allen, L., Kelly, B. B., & National Research Council. (2015). Child development and early learning. In *Transforming the workforce for children birth through age 8: A unifying foundation*. National Academies Press (US). <https://www.ncbi.nlm.nih.gov/books/NBK310550/>
- Alomari, H. W., Ramasamy, V., Kiper, J. D., & Potvin, G. (2020). A User Interface (UI) and User eXperience (UX) evaluation framework for cyberlearning environments in computer science and software engineering education. *Heliyon*, 6(5), e03917.
<https://doi.org/10.1016/j.heliyon.2020.e03917>
- Alonso, O. (2019). The Practice of Labeling: Everything You Always Wanted to Know About Labeling (But Were Afraid to Ask). In *Companion Proceedings of The 2019 World Wide Web Conference* (pp. 1293-1293). <https://doi.org/10.1145/3308560.3320083>
- Alsaadat, K. (2018). The Impact of Social Media Technologies on Adult Learning. *International Journal of Electrical & Computer Engineering* (2088-8708), 8(5).
<https://doi.org/10.11591/ijece.v8i5.pp3747-3755>
- Alsahhi, N. R., Al-Qatawneh, S., Eltahir, M., Althunibat, F., & Aljarrah, K. (2020). The role of academic electronic books in undergraduate students' achievement in higher education. *Heliyon*, 6(11).
<https://doi.org/10.1016/j.heliyon.2020.e05550>

References

- Alsobhi, A. Y., & Alyoubi, K. H. (2019). Adaptation algorithms for selecting personalised learning experience based on learning style and dyslexia type. *Data Technologies and Applications*, 53(2), 189-200. <https://doi.org/10.1108/dta-10-2018-0092>
- Altschul, D., Iveson, M., & Deary, I. J. (2021). Generational differences in loneliness and its psychological and sociodemographic predictors: An exploratory and confirmatory machine learning study. *Psychological medicine*, 51(6), 991-1000. <https://doi.org/10.1017/S0033291719003933>
- Amalia, E. R., & Khoiriyati, S. (2018). Effective learning activities to improve early childhood cognitive development. *Al-Athfal: Jurnal Pendidikan Anak*, 4(1), 103-111. <https://doi.org/10.14421/al-athfal.2018.41-07>
- An, Y. (2021). A History of Instructional Media, Instructional Design, and Theories. *International Journal of Technology in Education*, 4(1), 1-21. <https://doi.org/10.46328/ijte.35>
- Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. *Journal of Pre-College Engineering Education Research (J-PEER)*, 9(2), 2. <https://doi.org/10.7771/2157-9288.1223>
- Araújo, U. F. (2019). 3D Immersive Platforms and Problem-Based Learning Projects: A Search for Quality in Education. *The Wiley Handbook of Problem-Based Learning*, 575-591. <https://doi.org/10.1002/9781119173243.ch25>
- Arsalidou, M., & Pascual-Leone, J. (2016). Constructivist developmental theory is needed in developmental neuroscience. *npj Science of Learning*, 1(1), 1-9. <https://doi.org/10.1038/npjscilearn.2016.16>
- Arun Kumar, U., Mahendran, G., & Gobhinath, S. (2022). A review on artificial intelligence based E-learning system. *Pervasive Computing and Social Networking: Proceedings of ICPCSN 2022*, 659-671.
- Ashok, M., Madan, R., Joha, A., & Sivarajah, U. (2022). Ethical framework for Artificial Intelligence and Digital technologies. *International Journal of Information Management*, 62, 102433.
- Asmussen, K., Law, J., Charlton, J., Acquah, D., Brims, L., Pote, I., & McBride, T. (2018). Key competencies in early cognitive development Things, people, numbers and words. *London: Early Intervention Foundation*.

- Azizah, H., & Irsyadi, F. Y. (2020). Educational Game in Learning Arabic Language for Modern Islamic Boarding School. *Jurnal RESTI (Rekayasa Sistem Dan Teknologi Informasi)*, 4(3), 489-496.
<https://doi.org/10.29207/resti.v4i3.1894>
- Babakr, Z. H., Mohamedamin, P., & Kakamad, K. (2019). Piaget's Cognitive Developmental Theory: Critical Review. *Education Quarterly Reviews*, 2(3), 517-524.
<https://doi.org/10.31014/aior.1993.02.03.84>
- De Back, T. T., Tinga, A. M., Nguyen, P., & Louwerse, M. M. (2020). Benefits of immersive collaborative learning in CAVE-based virtual reality. *International Journal of Educational Technology in Higher Education*, 17, 1-18. <https://doi.org/10.1186/s41239-020-00228-9>
- Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *The journal of the learning sciences*, 17(1), 102-141.
<https://doi.org/10.1080/10508400701793141>
- Baillifard, A., Gabella, M., Lavenex, P. B., & Martarelli, C. S. (2023). Implementing Learning Principles with a Personal AI Tutor: A Case Study. *arXiv preprint arXiv:2309.13060*.
<https://doi.org/10.48550/arxiv.2309.13060>
- Bandura, A. (1977). Social learning theory. *Englewood Cliffs*.
- Bandura, A. (1989). Human agency in social cognitive theory. *American psychologist*, 44(9), 1175.
<https://doi.org/10.1037/0003-066x.44.9.1175>
- BAOa, Y., Wang, G., & Zhengtang, S. U. N. (2022). Exploration and Research on Integrating Programming Education into Junior Middle School Mathematics Classroom. In *Proceedings of CECNet 2021: The 11th International Conference on Electronics, Communications and Networks (CECNet), November 18-21, 2021* (Vol. 345, p. 356). IOS Press.
<https://doi.org/10.3233/faia210422>
- Barclay, C., Donalds, C., & Osei-Bryson, K. M. (2018). Investigating critical success factors in online learning environments in higher education systems in the Caribbean. *Information Technology for Development*, 24(3), 582-611. <https://doi.org/10.1080/02681102.2018.1476831>
- Barrouillet, P. (2015). Theories of cognitive development: From Piaget to today. *Developmental Review*, 38, 1-12. <https://doi.org/10.1016/j.dr.2015.07.004>

References

- Bartlett, L. K., Pirrone, A., Javed, N., & Gobet, F. (2023). Computational Scientific Discovery in Psychology. *Perspectives on Psychological Science*, 18(1), 178-189.
<https://doi.org/10.1177/17456916221091833>
- Bavelier, D., Green, C. S., & Dye, M. W. (2010). Children, wired: For better and for worse. *Neuron*, 67(5), 692-701. <https://doi.org/10.1016/j.neuron.2010.08.035>
- Behnamnia, N., Kamsin, A., Ismail, M. A. B., & Hayati, A. (2020). The effective components of creativity in digital game-based learning among young children: A case study. *Children and Youth Services Review*, 116, 105227. <https://doi.org/10.1016/j.childyouth.2020.105227>
- Beland, L. P., & Murphy, R. (2016). Ill communication: technology, distraction & student performance. *Labour Economics*, 41, 61-76.
- Belfer, R., Kochmar, E., & Serban, I. V. (2022). Raising student completion rates with adaptive curriculum and contextual bandits. In *International Conference on Artificial Intelligence in Education* (pp. 724-730). Cham: Springer International Publishing.
<https://doi.org/10.48550/arxiv.2207.14003>
- Beliavsky, N. (2006). Revisiting Vygotsky and Gardner: realizing human potential. *Journal of Aesthetic Education*, 1-11. <https://doi.org/10.1353/jae.2006.0013>
- Belpaeme, T., Baxter, P., Read, R., Wood, R., Cuayáhuítl, H., Kiefer, B., ... & Humbert, R. (2012). Multimodal Child-Robot Interaction: Building Social Bonds. *Journal of Human-Robot Interaction*, 1(2), 33-53. <https://doi.org/10.5898/JHRI.1.2.Belpaeme>
- Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education*, 58(3), 978-988.
<https://doi.org/10.1016/j.compedu.2011.10.006>
- Bennington-Castro, J. (2017). *Let robots teach our kids? Here's why that isn't such a bad idea*. NBC News. <http://www.nbcnews.com/mach/technology/robots-will-soon-become-our-children-s-tutors-here-s-n748196>
- Berberyan, A. (2019). Readiness of teachers for designing a humanistically oriented educational environment of a university. In *SHS Web of Conferences* (Vol. 70, p. 01019). EDP Sciences.
<https://doi.org/10.1051/shsconf/20197001019>
- Berens, P., Cranmer, K., Lawrence, N. D., von Luxburg, U., & Montgomery, J. (2023). AI for Science: an emerging agenda. *arXiv preprint arXiv:2303.04217*.
<https://doi.org/10.48550/arxiv.2303.04217>

- Bhat, R. (2023). The impact of technology integration on student learning outcomes: A comparative study. *International Journal of Social Science, Educational, Economics, Agriculture Research and Technology (IJSET)*, 2, 592-596. <https://doi.org/10.54443/ijset.v2i9.218>
- Bhatt, P., Sethi, A., Tasgaonkar, V., Shroff, J., Pendharkar, I., Desai, A., ... & Jain, N. K. (2023). Machine learning for cognitive behavioral analysis: datasets, methods, paradigms, and research directions. *Brain informatics*, 10(1), 18.
- Bittman, M., Rutherford, L., Brown, J., & Unsworth, L. (2011). Digital natives? New and old media and children's outcomes. *Australian journal of education*, 55(2), 161-175.
- Bocanegra, J. O., & Gallup, J. (2018). Virtual training platforms and school psychology. In *Technology applications in school psychology consultation, supervision, and training* (pp. 162-178). Routledge.
- Bogue, R. (2014). The role of artificial intelligence in robotics. *Industrial Robot: An International Journal*, 41(2), 119-123. <https://doi.org/10.1108/ir-01-2014-0300>
- Boletsis, C., & Mccallum, S. (2014). Augmented reality cube game for cognitive training: an interaction study. In *pHealth 2014* (pp. 81-87). IOS Press.
- Boyatzis, R. E. (2011). Learning life skills of emotional and social intelligence competencies. *The Oxford handbook of lifelong learning*, 11-21. <https://doi.org/10.1093/oxfordhb/9780195390483.013.0038>
- Bracegirdle, H. (1990). Developmental social skills training programmes: Are they effective?. *British Journal of Occupational Therapy*, 53(5), 195-196. <https://doi.org/10.1177/030802269005300511>
- Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual review of psychology*, 53(1), 371-399. <https://doi.org/10.1146/annurev.psych.53.100901.135233>
- Brainerd, C. J. (1972). Reinforcement and reversibility in quantity conservation acquisition. *Psychonomic Science*, 27(2), 114-116. <https://doi.org/10.3758/BF03328907>
- Brayadi, B., Supriadi, S., & Manora, H. (2022). Information Processing And Cognitive Theories Of Learning. *Edification Journal: Pendidikan Agama Islam*, 4(2), 347-355. <https://doi.org/10.37092/ej.v4i2.363>
- Brekke, B., & Williams, J. D. (1975). Reversibility preceding conservation and reading readiness. *The Journal of Psychology*, 90(2), 191-196.

References

- Bri, D., García, M., Coll, H., & Lloret, J. (2009). A study of virtual learning environments. *Wseas transactions on advances in engineering education*, 6(1), 33-43.
- Bronfenbrenner, U. (2000). *Ecological systems theory*. American Psychological Association.
<https://doi.org/10.1037/10518-046>
- Ten Brummelhuis, L. L., & Bakker, A. B. (2012). A resource perspective on the work–home interface: The work–home resources model. *American psychologist*, 67(7), 545.
<https://doi.org/10.1037/a0027974>
- Brundage, M., Avin, S., Wang, J., Belfield, H., Krueger, G., Hadfield, G., ... & Anderljung, M. (2020). Toward trustworthy AI development: mechanisms for supporting verifiable claims. *arXiv preprint arXiv:2004.07213*. <https://doi.org/10.48550/arxiv.2004.07213>
- Bruner, J. S., Olver, R. R., & Greenfield, P. M. (1966). Studies in cognitive growth.
- Bruner, J. (1984). Vygotsky's zone of proximal development: The hidden agenda. *New directions for child development*.
- Bruner, J. (2021). Jerome Bruner and Constructivism. *Learning theories for early years practice*, 87.
- Bulut, O., Beiting-Parrish, M., Casabianca, J. M., Slater, S. C., Jiao, H., Song, D., ... & Morilova, P. (2024). The rise of artificial intelligence in educational measurement: Opportunities and ethical challenges. *arXiv preprint arXiv:2406.18900*. <https://doi.org/10.48550/arxiv.2406.18900>
- Busarello, R. I., Ulbricht, V. R., Fadel, L. M., & de Freitas e Lopes, A. V. (2016). Gamification Approaches to Learning and Knowledge Development: a theoretical review. In *New Advances in Information Systems and Technologies* (pp. 1107-1116). Springer International Publishing.
- Callanan, M A., Cervantes, C., Frye, D., & Moore, C. (1993). *Children's Theories of Mind: Mental States and Social Understanding*. University of Illinois Press, 106(4), 588-588.
<https://doi.org/10.2307/1422971>
- Cameron, D., Fernando, S., Collins, E., Millings, A., Moore, R., Sharkey, A., & Prescott, T. (2016). Impact of robot responsiveness and adult involvement on children's social behaviours in human-robot interaction. *arXiv preprint arXiv:1606.06104*.
<https://doi.org/10.48550/arxiv.1606.06104>
- Camilleri, M. A., & Camilleri, A. C. (2022). Remote learning via video conferencing technologies: Implications for research and practice. *Technology in society*, 68, 101881.
<https://doi.org/10.1016/j.techsoc.2022.101881>

- Caprara, G V., & Cervone, D. (2000). Unconscious Processes and Conscious Experience. *Cambridge University Press*, 311-337. <https://doi.org/10.1017/cbo9780511812767.016>
- Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *Multimedia tools and applications*, 51, 341-377.
- Carroll, R. G. (1998). Current and future impact of technology on physiology education. *Advances in Physiology Education*, 275(6), S8. <https://doi.org/10.1152/advances.1998.275.6.s8>
- Castellan, N. J. (1987). Computers and the shape of the future: Implications for teaching and learning. *Education and Computing*, 3(1-2), 39-48. [https://doi.org/10.1016/s0167-9287\(87\)80483-1](https://doi.org/10.1016/s0167-9287(87)80483-1)
- Chapelle, C. A. (2019). *The Concise Encyclopedia of Applied Linguistics*. John Wiley & Sons.
- Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications*, 79(9), 5501-5527. <https://doi.org/10.1007/s11042-019-08348-9>
- Chekroud, A. M., Bondar, J., Delgadillo, J., Doherty, G., Wasil, A., Fokkema, M., ... & Choi, K. (2021). The promise of machine learning in predicting treatment outcomes in psychiatry. *World Psychiatry*, 20(2), 154-170.
- Chen, Z., & Xu, Y. (2005). User-oriented relevance judgment: A conceptual model. In *Proceedings of the 38th Annual Hawaii International Conference on System Sciences* (pp. 101b-101b). IEEE. <https://doi.org/10.1109/hicss.2005.654>
- Cheng, Y., & Milikich, N. (2023). An Analysis of How COVID-19 Shaped the Realm of Online Gaming and Lesson Delivery. *arXiv preprint arXiv:2304.06102*. <https://doi.org/10.48550/arxiv.2304.06102>
- Chernova, N., & Mustafina, J. (2017). Electronic Educational Resource" Post-Graduate Foreign Language" and the Obtained Learning Curve. In *2017 10th International Conference on Developments in eSystems Engineering (DeSE)* (pp. 145-148). IEEE. <https://doi.org/10.1109/dese.2017.56>
- Ching, Y. H., & Hsu, Y. C. (2024). Educational robotics for developing computational thinking in young learners: A systematic review. *TechTrends*, 68(3), 423-434. <https://doi.org/10.1007/s11528-023-00841-1>

References

- Cho, B. H., Ku, J., Jang, D. P., Kim, S., Lee, Y. H., Kim, I. Y., ... & Kim, S. I. (2002). The effect of virtual reality cognitive training for attention enhancement. *CyberPsychology & Behavior*, 5(2), 129-137.
- Choi, S. E., & Lee, S. (2021). Applying Constructivism in Neurodiverse Classrooms. *Review of Educational Theory*, 4(4), 6-11. <https://doi.org/10.30564/ret.v4i4.3876>
- Chua, B. L., Tan, O. S., & Chng, P. S. W. (2017). Mediated learning experience: Questions to enhance cognitive development of young children. *Journal of Cognitive Education and Psychology*, 16(2), 178-192.
- Chua, H. W., & Yu, Z. (2024). A systematic literature review of the acceptability of the use of Metaverse in education over 16 years. *Journal of Computers in Education*, 11(2), 615-665. <https://doi.org/10.1007/s40692-023-00273-z>
- Church, R. B., & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition*, 23(1), 43-71. [https://doi.org/10.1016/0010-0277\(86\)90053-3](https://doi.org/10.1016/0010-0277(86)90053-3)
- Coghlan, S., Miller, T., & Paterson, J. (2021). Good proctor or “big brother”? Ethics of online exam supervision technologies. *Philosophy & Technology*, 34(4), 1581-1606. <https://doi.org/10.1007/s13347-021-00476-1>
- Cole, H. P. (1969). Process curricula and creativity development. *The Journal of Creative Behavior*, 3(4), 243-259. <https://doi.org/10.1002/j.2162-6057.1969.tb00058.x>
- Collins, W. A., & National Research Council. (1984). Cognitive development in school-age children: Conclusions and new directions. In *Development during middle childhood: The years from six to twelve*. National Academies Press (US). <https://www.ncbi.nlm.nih.gov/books/NBK216774/>
- Commins, V. M. (1991). Teaching mathematics for understanding: what is a number?. *Early Child Development and Care*, 73(1), 53-62. <https://doi.org/10.1080/0300443910730106>
- Conte, E., Ornaghi, V., Grazzani, I., Pepe, A., & Cavioni, V. (2019). Emotion knowledge, theory of mind, and language in young children: Testing a comprehensive conceptual model. *Frontiers in Psychology*, 10, 2144. <https://doi.org/10.3389/fpsyg.2019.02144>
- Conway, T. R. (2007). Jerome Bruner. *The Praeger Handbook of Education and Psychology*. Westport, CT: Praeger Publishers, 57-62.
- Craik, F. I., & Bialystok, E. (2011). Lifespan cognitive development: The roles of representation and control. In *The handbook of aging and cognition* (pp. 557-601). Psychology Press.

- Crawford, M. (2020). Ecological Systems theory: Exploring the development of the theoretical framework as conceived by Bronfenbrenner. *J Pub Health Issue Pract*, 4(2), 170.
<https://doi.org/10.33790/jphip1100170>
- Crépault, J. & Samartzi, S. (1989). Qualitative and Quantitative time reasoning in children. *In Proceedings of the 13th Annual Conference of the International Group for the Psychology of Mathematics Education*, vol.1, (p.p.196-203).
- Croft, W., & Cruse, D. A. (2004). *Cognitive Linguistics*. Cambridge University Press.
<https://doi.org/10.1017/cbo9780511803864>
- D'Mello, S. K., Southwell, R., & Gregg, J. (2020). Machine-learned computational models can enhance the study of text and discourse: A case study using eye tracking to model reading comprehension. *Discourse processes*, 57(5-6), 420-440.
<https://doi.org/10.1080/0163853X.2020.1739600>
- Daing, C., & Sinocruz, F. S. (2022). Study habits and scholastic performance of junior student-athletes in educational district IV. *International Journal of Educational Studies in Social Sciences*, 2 (3), 125-137.
- Dana, K. J., Andrews, C., Bekris, K., Feldman, J., Stone, M., Hemmer, P., ... & Yi, J. (2023). Socially Cognizant Robotics for a Technology Enhanced Society. *arXiv preprint arXiv:2310.18303*.
<https://doi.org/10.48550/arxiv.2310.18303>
- Daniela, L., & Lytras, M. D. (2019). Educational robotics for inclusive education. *Technology, Knowledge and Learning*, 24, 219-225.
- Darmawansah, D., Hwang, G. J., Chen, M. R. A., & Liang, J. C. (2023). Trends and research foci of robotics-based STEM education: a systematic review from diverse angles based on the technology-based learning model. *International Journal of STEM Education*, 10(1), 12.
- Dautenhahn, K. (1999). Robots as social actors: Aurora and the case of autism. In *Proc. CT99, The Third International Cognitive Technology Conference, August, San Francisco* (Vol. 359, p. 374).
- Davidson, P. M. (1987). Early function concepts: Their development and relation to certain mathematical and logical abilities. *Child development*, 1542-1555.
<https://doi.org/10.1111/j.1467-8624.1987.tb03865.x>
- Davydov, V. V. (1995). The influence of LS Vygotsky on education theory, research, and practice. *Educational researcher*, 24(3), 12-21.

References

- De León, L. (2012, April). Model of models: Preservice teachers in a Vygotskian scaffold. In *The Educational Forum* (Vol. 76, No. 2, pp. 144-157). Taylor & Francis Group.
<https://doi.org/10.1080/00131725.2011.653093>
- De Simone, M. (2019). Intertwinement of Rationality and Emotions in Mathematics Teaching: A Case Study. *Affect and mathematics education: Fresh perspectives on motivation, engagement, and identity*, 233-253. https://doi.org/10.1007/978-3-030-13761-8_11
- De Vries, R., Kohlberg, L., Hall, V. C., & Mery, M. (1969). Review of *The Concept Assessment Kit--Conservation* by M. L. Goldschmid & P. M. Bentler. *Journal of Educational Measurement*, 6(4), 263–269. <http://www.jstor.org/stable/1434029>
- Del Giudice, M. (2014). Middle Childhood: An Evolutionary-Developmental Synthesis. *Child Development Perspectives*, 8(4), 193-200. <https://doi.org/10.1111/cdep.12084>
- Del Río, P., & Álvarez, A. (2007). Inside and outside the zone of proximal development: An ecofunctional reading of Vygotsky. In H. Daniels, M. Cole, & J. V. Wertsch (Eds.), *The Cambridge companion to Vygotsky* (pp. 276–303). Cambridge University Press. <https://doi.org/10.1017/CCOL0521831040.012>
- Delgrande, J. P., Glimm, B., Meyer, T., Truszczyński, M., & Wolter, F. (2023). Current and future challenges in knowledge representation and reasoning. *arXiv preprint arXiv:2308.04161*. <https://doi.org/10.48550/arxiv.2308.04161>
- Derry, S. J., Sherin, M. G., & Sherin, B. L. (2014). Multimedia learning with video. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 785–812). Cambridge University Press. <https://doi.org/10.1017/CBO9781139547369.038>
- Di Giacomo, D., Ranieri, J., & Lacasa, P. (2017). Digital learning as enhanced learning processing? Cognitive evidence for new insight of smart learning. *Frontiers in psychology*, 8, 1329. <https://doi.org/10.3389/fpsyg.2017.01329>
- Diaferia, C., Artoni, V., & Rollo, D. (2018). Scaffolding in teacher-student interaction: an operationalization for evaluation in educational and clinical settings. In *2018 IEEE International Symposium on Medical Measurements and Applications (MeMeA)* (pp. 1-5). IEEE. <https://doi.org/10.1109/memea.2018.8438694>
- Diaz-Asper, C., Hauglid, M. K., Chandler, C., Cohen, A. S., Foltz, P. W., & Elvevåg, B. (2024). A framework for language technologies in behavioral research and clinical applications: Ethical challenges, implications, and solutions. *American Psychologist*, 79(1), 79.

- Dodig-Crnkovic, G. (2021). Natural Computational Architectures for Cognitive Information Communication. *arXiv preprint arXiv:2110.06339*. <https://doi.org/10.48550/arxiv.2110.06339>
- Doolittle, P. E. (1995). *Understanding Cooperative Learning through Vygotsky's Zone of Proximal Development*.
- Dror, I. E. (2008). Technology enhanced learning: The good, the bad, and the ugly. *Pragmatics & Cognition*, 16(2), 215-223. <https://doi.org/10.1075/pc.16.2.02dro>
- Dunn, J. (2000). Mind-reading, emotion understanding, and relationships. *International Journal of Behavioral Development*, 24(2), 142-144. <https://doi.org/10.1080/016502500383241>
- Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: the new normal and emerging technologies. *International journal of educational technology in Higher education*, 15, 1-16. <https://doi.org/10.1186/s41239-017-0087-5>
- Efgivia, M. G., Arista, A., & Kurniawati, R. (2021a). Analysis of Behaviorism Learning Theory, STEM Learning Model and Gamification. In *1st UMGESHIC International Seminar on Health, Social Science and Humanities (UMGESHIC-ISHSSH 2020)* (pp. 194-197). Atlantis Press. <https://doi.org/10.2991/assehr.k.211020.029>
- Efgivia, M. G., Rinanda, R. A., Hidayat, A., Maulana, I., & Budiarto, A. (2021b). Analysis of constructivism learning theory. In *1st UMGESHIC International Seminar on Health, Social Science and Humanities (UMGESHIC-ISHSSH 2020)* (pp. 208-212). Atlantis Press. <https://doi.org/10.2991/assehr.k.211020.032>
- El Msayer, M., Aoula, E. S., & Bouihi, B. (2024, May). Artificial intelligence in computerized adaptive testing to assess the cognitive performance of students: A Systematic Review. In *2024 International Conference on Intelligent Systems and Computer Vision (ISCV)* (pp. 1-8). IEEE.
- Elhai, J. D., & Montag, C. (2020). The compatibility of theoretical frameworks with machine learning analyses in psychological research. *Current Opinion in Psychology*, 36, 83-88. <https://doi.org/10.1016/j.copsyc.2020.05.002>
- Elkind, D. (1961). Children's discovery of the conservation of mass, weight, and volume: Piaget replication study II. *The journal of genetic psychology*, 98(2), 219-227.
- Elkind, D. (1967). Piaget's conservation problems. *Child Development*, 38(1), 15-27. <https://doi.org/10.2307/1127125>

References

- Evripidou, S., Georgiou, K., Doitsidis, L., Amanatiadis, A. A., Zinonos, Z., & Chatzichristofis, S. A. (2020). Educational robotics: Platforms, competitions and expected learning outcomes. *IEEE access*, 8, 219534-219562. <https://doi.org/10.1109/access.2020.3042555>
- Fedushko S., Kolos S., & Malynovska Yu. (2019). MBTI Principles in Detecting Emotional Manipulators among Digital Platforms Users. *Proceedings of the International Workshop on Conflict Management in Global Information Networks (CMiGIN 2019)*, Lviv, Ukraine
- Feil-Seifer, D., & Mataric, M. J. (2005, June). Defining socially assistive robotics. In *9th International Conference on Rehabilitation Robotics, 2005. ICORR 2005* (pp. 465-468). IEEE.
- Feldman, D. H. (2004). Piaget's stages: the unfinished symphony of cognitive development. *New Ideas in Psychology*, 22(3), 175-231. <https://doi.org/10.1016/j.newideapsych.2004.11.005>
- Ferrada, C., Carrillo-Rosúa, F.J., Díaz-Levicoy, D., & Silva-Díaz, F. (2020). Robotics from STEM areas in Primary Education: a systematic review. *Education in the Knowledge Society (EKS)* , 21 , 18. <https://doi.org/10.14201/eks.22036>
- Ferriz-Valero, A., Østerlie, O., García Martínez, S., & García-Jaén, M. (2020). Gamification in physical education: Evaluation of impact on motivation and academic performance within higher education. *International Journal of Environmental Research and Public Health*, 17(12), 4465. <https://doi.org/10.3390/ijerph17124465>
- Fierro, M. (2012). Conceptual Development in Cognitive Science. Part II. *Revista colombiana de psiquiatria*, 41(1), 185-196. <http://europepmc.org/abstract/MED/26573477>
- Fischer, K. W., & Hencke, R. W. (1996). Infants' construction of actions in context: Piaget's contribution to research on early development. *Psychological Science*, 7(4), 204-210. <https://doi.org/10.1111/j.1467-9280.1996.tb00360.x>
- Fischer, K. W., & Bullock, D. (1984). Cognitive development in school-age children: Conclusions and new directions. In *Development during middle childhood: The years from six to twelve*. Washington, DC: National Academy Press.
- Fiske, A., Henningsen, P., & Buyx, A. (2019). Your robot therapist will see you now: ethical implications of embodied artificial intelligence in psychiatry, psychology, and psychotherapy. *Journal of medical Internet research*, 21(5), e13216.
- Fjællingsdal, K. S., & Klöckner, C. A. (2017). ENED-GEM: A conceptual framework model for psychological enjoyment factors and learning mechanisms in educational games about the environment. *Frontiers in psychology*, 8, 1085. <https://doi.org/10.3389/fpsyg.2017.01085>

- Fleer, M. (1990). Scaffolding conceptual change in early childhood. *Research in science education*, 20, 114-123.
- Flynn, J. R. (2012). *Are we getting smarter? Rising IQ in the twenty-first century*. Cambridge University Press. <https://doi.org/10.1017/CBO9781139235679>
- Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(3), 319-325.
- Fong, T., Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and autonomous systems*, 42(3-4), 143-166. [https://doi.org/10.1016/S0921-8890\(02\)00372-X](https://doi.org/10.1016/S0921-8890(02)00372-X)
- Forstmann, B. U., & Wagenmakers, E. J. (Eds.). (2015). *An introduction to model-based cognitive neuroscience* (Vol. 614). Berlin, Germany: Springer. <https://doi.org/10.1007/978-1-4939-2236-9>
- Frank, M. C., Sugarman, E., Horowitz, A. C., Lewis, M. L., & Yurovsky, D. (2016). Using tablets to collect data from young children. *Journal of Cognition and Development*, 17(1), 1-17. <https://doi.org/10.1080/15248372.2015.1061528>
- Frankland, P. W., & Bontempi, B. (2005). The organization of recent and remote memories. *Nature reviews neuroscience*, 6(2), 119-130. <https://doi.org/10.1038/nrn1607>
- Freeman, M. (2003). Poetry and the scope of metaphor: Toward a cognitive theory of literature. In A. Barcelona (Ed.), *Metaphor and Metonymy at the Crossroads: A Cognitive Perspective* (pp. 253-282). Berlin, Boston: De Gruyter Mouton. <https://doi.org/10.1515/9783110894677.253>
- Frew, T. W., & Klein, N. K. (1982). Instructional models for children with special needs. *Theory into practice*, 21(2), 97-105. <https://doi.org/10.1080/00405848209542990>
- Furth, H. G. (1967). Concerning Piaget's view on thinking and symbol formation. *Child Development*, 819-826. <https://doi.org/10.2307/1127258>
- Gabarró, S. A. (2006). *Web Application Design and Implementation: Apache 2, PHP5, MySQL, JavaScript, and Linux/UNIX*. Wiley-IEEE Computer Society Pr.
- Gagne, R. M. (1980). Learnable aspects of problem solving. *Educational Psychologist*, 15(2), 84-92. <https://doi.org/10.1080/00461528009529218>
- Gaol, F. L., & Prasolova-Førland, E. (2022). Special section editorial: The frontiers of augmented and mixed reality in all levels of education. *Education and Information Technologies*, 1-13. <https://doi.org/10.1007/s10639-021-10746-2>

References

- Gardner, H. (1987) The theory of multiple intelligences. *Annals of Dyslexia* 37, 19–35.
<https://doi.org/10.1007/BF02648057>
- Gardner, H., & Hatch, T. (1989). Educational implications of the theory of multiple intelligences. *Educational researcher*, 18(8), 4-10.
- Merchán, E. C. G., & Molina, M. (2020). A machine consciousness architecture based on deep learning and gaussian processes. In *Hybrid Artificial Intelligent Systems: 15th International Conference, HAIS 2020, Gijón, Spain, November 11-13, 2020, Proceedings 15* (pp. 350-361). Springer International Publishing. <https://doi.org/10.48550/arxiv.2002.00509>
- Garton, A. (1995). *Social interaction and the development of language and cognition*. Psychology Press.
- Gauvain, M., Beebe, H., & Zhao, S. (2011). Applying the cultural approach to cognitive development. *Journal of Cognition and Development*, 12(2), 121-133.
<https://doi.org/10.1080/15248372.2011.563481>
- Gelman, R. (1969). Conservation acquisition: a problem of learning to attend to relevant attributes. *Journal of Experiment Child Psychology*, 7, 167-187. [https://doi.org/10.1016/0022-0965\(69\)90041-1](https://doi.org/10.1016/0022-0965(69)90041-1)
- Georgouli, K. (2011). Virtual learning environments-An overview. In *2011 15th Panhellenic Conference on Informatics* (pp. 63-67). IEEE. <https://doi.org/10.1109/PCI.2011.13>
- Gibbs, R. W. (2005). *Embodiment and cognitive science*. Cambridge University Press.
- Gijbels, L., Cai, R., Donnelly, P. M., & Kuhl, P. K. (2021). Designing virtual, moderated studies of early childhood development. *Frontiers in Psychology*, 12, 740290.
<https://doi.org/10.3389/fpsyg.2021.740290>
- Gkatzios, N., Koumaras, H., Fragkos, D., & Koumaras, V. (2024, June). A Proof of Concept Implementation of an AI-assisted User-Centric 6G Network. In *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)* (pp. 907-912). IEEE.
- Goldschmid, M. L., Bentler, P. M., Debus, R. L., Rawlinson, R., Kohnstamm, D., Modgil, S., Nicholls, J. G., Reykowski, J., Strupczewska, B., & Warren, N. (1973). A cross-cultural investigation of conservation. *Journal of Cross-Cultural Psychology*, 4(1), 75-88.
<https://doi.org/10.1177/002202217300400106>

- Gordon, A. C., & Olson, D. R. (1998). The relation between acquisition of a theory of mind and the capacity to hold in mind. *Journal of experimental child psychology*, 68(1), 70-83.
<https://doi.org/10.1006/jecp.1997.2423>
- Grandjean, A. C., & Grandjean, N. R. (2007). Dehydration and cognitive performance. *Journal of the American College of Nutrition*, 26(sup5), 549S-554S.
<https://doi.org/10.1080/07315724.2007.10719657>
- Grazzani, I., Ornaghi, V., Conte, E., Pepe, A., & Caprin, C. (2018). The relation between emotion understanding and theory of mind in children aged 3 to 8: The key role of language. *Frontiers in psychology*, 9, 724. <https://doi.org/10.3389/fpsyg.2018.00724>
- Grigoreva, A., & Grigorev, S. (2023). Prospects for the implementation of an affordable VR/AR-content management tool for Learning Management Systems. *arXiv preprint arXiv:2303.16723*. <https://doi.org/10.48550/arxiv.2303.16723>
- Grossmann, I., Feinberg, M., Parker, D. C., Christakis, N. A., Tetlock, P. E., & Cunningham, W. A. (2023). AI and the transformation of social science research. *Science*, 380(6650), 1108-1109.
<https://doi.org/10.1126/science.adi1778>
- Gruen, G. E. (1965). Experiences affecting the development of number conservation in children. *Child Development*, 36(4), 963-979. <https://doi.org/10.2307/1126937>
- Guckelsberger, C., Kantosalo, A., Negrete-Yankelevich, S., & Takala, T. (2021). Embodiment and computational creativity. *arXiv preprint arXiv:2107.00949*.
<https://doi.org/10.48550/arxiv.2107.00949>
- Guidotti, R., Monreale, A., Ruggieri, S., Turini, F., Giannotti, F., & Pedreschi, D. (2018). A survey of methods for explaining black box models. *ACM computing surveys (CSUR)*, 51(5), 1-42.
<https://doi.org/10.1145/3236009>
- Haduong, P. L., Wood, Z. E., Cortesi, S. C., Plunkett, L. A., Ritvo, D. T., & Gasser, U. (2015). Student privacy: The next frontier-emerging & future privacy issues in K-12 learning environments. *Berkman Center Research Publication Series*.
- Haley, S. B., & Good, R. G. (1976). Concrete and formal operational thought: Implications for introductory college biology. *The American Biology Teacher*, 38(7), 407-430.
<https://doi.org/10.2307/4445652>

References

- Hall, A. (2007). Vygotsky goes online: Learning design from a socio-cultural perspective. In *Learning and socio-cultural Theory: Exploring modern Vygotskian perspectives international workshop 2007* (Vol. 1, No. 1, p. 6).
- Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, 8(1), 1-32.
<https://doi.org/10.1007/s40692-020-00169-2>
- Harmes, J. C., Welsh, J. L., & Winkelman, R. J. (2016). A Framework for Defining and Evaluating Technology Integration in the Instruction of Real-World Skills. In Y. Rosen, S. Ferrara, & M. Mosharraf (Eds.), *Handbook of Research on Technology Tools for Real-World Skill Development* (pp. 137-162). IGI Global Scientific Publishing. <https://doi.org/10.4018/978-1-4666-9441-5.ch006>
- Hasse, A., Cortesi, S., Lombana-Bermudez, A., & Gasser, U. (2019). Youth and artificial intelligence: Where we stand. *Berkman Klein Center Research Publication*, (2019-3).
<https://doi.org/10.2139/ssrn.3385718>
- Hausfather, S. J. (1996). Vygotsky and schooling: Creating a social context for learning. *Action in teacher education*, 18(2), 1-10. <https://doi.org/10.1080/01626620.1996.10462828>
- Hayes, M. A. (2009). Into the field: naturalistic education and the future of conservation. *Conservation Biology*, 23(5), 1075-1079. <https://doi.org/10.1111/j.1523-1739.2009.01302.x>
- Hecht, M., Knutson, K., & Crowley, K. (2019). Becoming a naturalist: Interest development across the learning ecology. *Science Education*, 103(3), 691-713. <https://doi.org/10.1002/sce.21503>
- Hedley, C. N., & Ellsworth, N. J. (1992). What's New in Software? Computers and Educational Futures. *Reading and Writing Quarterly: Overcoming Learning Difficulties*, 8(2), 243-250.
<https://doi.org/10.1080/0748763920080207>
- Helding, L. (2009). Howard Gardner's Theory of Multiple Intelligences. *Journal of Singing*, 66(2).
- Heppner, P. P., & Krauskopf, C. J. (1987). An information-processing approach to personal problem solving. *The counseling psychologist*, 15(3), 371-447.
- Heylighen, F., & Vidal, C. (2008). Getting things done: the science behind stress-free productivity. *Long Range Planning*, 41(6), 585-605. <https://doi.org/10.1016/j.lrp.2008.09.004>

- Hochberg, M. E. (2023). A Theory of Intelligences: Concepts, Models, Implications. *arXiv preprint arXiv:2308.12411*. <https://doi.org/10.48550/arxiv.2308.12411>
- Honavar, V. G., Hill, M. D., & Yelick, K. (2016). Accelerating science: A computing research agenda. *arXiv preprint arXiv:1604.02006*. <https://doi.org/10.48550/arxiv.1604.02006>
- Hooper, F. H. (1969). Piaget's conservation tasks: The logical and development priority of identity conservation. *Journal of Experimental Child Psychology*, 8(2), 234-249. [https://doi.org/10.1016/0022-0965\(69\)90098-8](https://doi.org/10.1016/0022-0965(69)90098-8)
- Hopson, M. H., Simms, R. L., & Knezek, G. A. (2001). Using a technology-enriched environment to improve higher-order thinking skills. *Journal of Research on Technology in education*, 34(2), 109-119. <https://doi.org/10.1080/15391523.2001.10782338>
- Huamaní, C. G. A. (2014). Simulation and virtual learning environments: Tools for teaching psychology in higher education. *Psychology Research*, 4(5). <https://doi.org/10.17265/2159-5542/2014.05.006>
- Huang, X., & Soergel, D. (2013). Relevance: An improved framework for explicating the notion. *Journal of the American Society for Information Science and Technology*, 64(1), 18-35. <https://doi.org/10.1002/asi.22811>
- Huang, Y. C. (2021). Comparison and contrast of Piaget and Vygotsky's Theories. In *7th International Conference on Humanities and Social Science Research (ICHSSR 2021)* (pp. 28-32). Atlantis Press. <https://doi.org/10.2991/assehr.k.210519.007>
- Huang, Y., Zhang, H., Li, Y., Lau, C. T., & You, Y. (2022). Active-learning-as-a-service: an automatic and efficient MLOps system for data-centric AI. *arXiv preprint arXiv:2207.09109*. <https://doi.org/10.48550/arxiv.2207.09109>
- Huitt, W., & Hummel, J. (2003). Piaget's theory of cognitive development. *Educational psychology interactive*, 3(2), 1-5.
- Huo, Y. (2019). A Pedagogy-based framework for optimizing learning efficiency across multiple disciplines in educational games. *International Journal of Information and Education Technology*, 9(10), 704-709. <https://doi.org/10.18178/ijiet.2019.9.10.1290>
- IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.
- Iranmanesh, F., Haddad Narafshan, M., & Golshan, M. (2021). A brain-based model of language instruction: from theory to practice. *Research and Development in Medical Education*, 10(1), 17-17. <https://doi.org/10.34172/rdme.2021.017>

References

- Irum, S., Bhatti, T., Abbasi, W. A., & Dilshad, M. (2020). Blended Learning: Innovative challenge faced by students at University level in Pakistan. *Indian Journal of Science and Technology* 13, 42, 4386-4395. <https://doi.org/10.17485/ijst/v13i42.1212>
- Jacobucci, R., & Grimm, K. J. (2020). Machine learning and psychological research: The unexplored effect of measurement. *Perspectives on Psychological Science*, 15(3), 809-816. <https://doi.org/10.1177/1745691620902467>
- Jamet, F., Masson, O., Jacquet, B., Stilgenbauer, J. L., & Baratgin, J. (2018). Learning by teaching with humanoid robot: a new powerful experimental tool to improve children's learning ability. *Journal of Robotics*, 2018. <https://doi.org/10.1155/2018/4578762>
- Jardine, D. W. (1984). The Piagetian picture of the world. *Phenomenology+ Pedagogy*, 224-239. <https://doi.org/10.29173/pandp14952>
- Javed, A. R., Saadia, A., Mughal, H., Gadekallu, T. R., Rizwan, M., Maddikunta, P. K. R., ... & Hussain, A. (2023). Artificial intelligence for cognitive health assessment: state-of-the-art, open challenges and future directions. *Cognitive Computation*, 15(6), 1767-1812.
- Jeong, S. (2017). *The impact of social robots on young patients' socio-emotional wellbeing in a pediatric inpatient care context* (Doctoral dissertation, Massachusetts Institute of Technology).
- Jiao, L., Ma, M., He, P., Geng, X., Liu, X., Liu, F., ... & Tang, X. (2024). Brain-Inspired Learning, Perception, and Cognition: A Comprehensive Review. *IEEE Transactions on Neural Networks and Learning Systems*.
- Johnson, E. S. (2018). Ecological systems, complexity, and student achievement: Towards an alternative model of accountability in education. *School Leadership Review*, 3(3), 4.
- Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., & Koziupa, T. (2014). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. *Journal of educational psychology*, 106(1), 86.
- Joseph, F. J. J., Nonsiri, S., & Monsakul, A. (2021). Keras and TensorFlow: A hands-on experience. *Advanced deep learning for engineers and scientists: A practical approach*, 85-111. https://doi.org/10.1007/978-3-030-66519-7_4
- Kahn Jr, P. H., Gary, H. E., & Shen, S. (2013). Children's social relationships with current and near-future robots. *Child Development Perspectives*, 7(1), 32-37. <https://doi.org/10.1111/cdep.12011>

- Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. A systematic review of the literature. *Education sciences*, 11(1), 22.
<https://doi.org/10.3390/educsci11010022>
- Kamii, C. (1979). Piaget's theory, behaviorism, and other theories in education. *Journal of Education*, 161(1), 13-33. <https://doi.org/10.1177/002205747916100104>
- Khalil, N., Aljanazrah, A., Hamed, G., & Murtagh, E. (2022). Exploring teacher educators' perspectives of play-based learning: a mixed method approach. *Education Sciences*, 12(2), 95.
<https://doi.org/10.3390/educsci12020095>
- Khan, F. A. (2005). Classics with commentary: vygotsky on mediated cognition. *Contemporary Education Dialogue*, 2(2), 225-244. <https://doi.org/10.1177/097318490500200205>
- Kihlstrom, J. F. (1987). The cognitive unconscious. *Science*, 237(4821), 1445-1452.
<https://doi.org/10.1126/science.3629249>
- Kiili, C., Laurinen, L., & Marttunen, M. (2008). Students evaluating Internet sources: From versatile evaluators to uncritical readers. *Journal of Educational Computing Research*, 39(1), 75-95.
<https://doi.org/10.2190/ec.39.1.e>
- Kim, H. J., Yi, P., & Hong, J. I. (2020). Students' academic use of mobile technology and higher-order thinking skills: The role of active engagement. *Education Sciences*, 10(3), 47.
<https://doi.org/10.3390/educsci10030047>
- Kim, M. (1987). *Cognitive development of Korean kindergarten children and its relationship to age, gender, social class, and maternal attitude*. [Doctoral dissertation, Oregon State University].
https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/kw52jc979
- Kingma, D. P., & Ba, J. (2014). Adam: A method for stochastic optimization. *arXiv preprint arXiv:1412.6980*. <https://doi.org/10.48550/arXiv.1412.6980>
- Kivunja, C. (2014). Theoretical perspectives of how digital natives learn. *International Journal of Higher Education*, 3(1), 94-109.
- Kleine, P. F., & Smith, L. M. (1989). Personal knowledge, belief systems, and educational innovators. *International Journal of Personal Construct Psychology*, 2(3), 301-313.
<https://doi.org/10.1080/08936038908404301>
- Kliziene, I., Taujanskiene, G., Augustiniene, A., Simonaitiene, B., & Cibulskas, G. (2021). The impact of the virtual learning platform EDUKA on the academic performance of primary school children. *Sustainability*, 13(4), 2268. <https://doi.org/10.3390/su13042268>

References

- Kok, B. C., & Soh, H. (2020). Trust in robots: Challenges and opportunities. *Current Robotics Reports*, 1(4), 297-309. <https://doi.org/10.1007/s43154-020-00029-y>
- Kosmas, P., & Zaphiris, P. (2018). Embodied cognition and its implications in education: An overview of recent literature. *International Journal of Educational and Pedagogical Sciences*, 12(7), 930-936.
- Kostaki, M., Vataakis, A., & Samartzi, S. (2019). Assisted spatial navigation: new directions. *Homo Virtualis*, 2(1), 21-24. doi:<http://dx.doi.org/10.12681/homvir.20190>
- Koumaras, V., Foteas, A., Papaioannou, A., Kapari, M., Sakkas, C., & Koumaras, H. (2018, September). 5G performance testing of mobile chatbot applications. In *2018 IEEE 23rd international workshop on computer aided modeling and Design of Communication Links and Networks (CAMAD)* (pp. 1-6). IEEE.
- Kozulin, A. (2004). Vygotsky's theory in the classroom: Introduction. *European Journal of Psychology of Education*, 3-7.
- Krug, D. H. (2004). Leadership and research: Reimagining electronic technologies for supporting learning through the visual arts. *Studies in Art Education*, 46(1), 3-5. <https://doi.org/10.1080/00393541.2004.11650064>
- Kuhlenschmidt, S., & Kacer, B. (2010). The promise of technology for college instruction: From drill and practice to avatars. *New Directions for Teaching and Learning*, 2010(123), 23-31. <https://doi.org/10.1002/tl.406>
- Kuhn, D. (1979a). The application of Piaget's theory of cognitive development to education. *Harvard educational review*, 49(3), 340-360.
- Kuhn, D. (1979b). The significance of Piaget's formal operations stage in education. *Journal of Education*, 161(1), 34-50. <https://doi.org/10.1177/002205747916100105>
- Kumar, N. S. (2019). Implementation of artificial intelligence in imparting education and evaluating student performance. *Journal of Artificial Intelligence*, 1(01), 1-9.
- Kuniyoshi, Y., Yorozu, Y., Suzuki, S., Sangawa, S., Ohmura, Y., Terada, K., & Nagakubo, A. (2007). Emergence and development of embodied cognition: A constructivist approach using robots. *Progress in brain research*, 164, 425-445.
- Kuzior, A., & Kwilinski, A. (2022). Cognitive technologies and artificial intelligence in social perception. *Management Systems in Production Engineering*, 30(2), 109-115.

- Kwok, K., Ghrear, S., Li, V., Haddock, T., Coleman, P., & Birch, S. A. (2016). Children can learn new facts equally well from interactive media versus face to face instruction. *Frontiers in psychology*, 7, 1603. <https://doi.org/10.3389/fpsyg.2016.01603>
- Kwong See, S. T., Rasmussen, C., & Pertman, S. Q. (2012). Measuring children's age stereotyping using a modified Piagetian conservation task. *Educational Gerontology*, 38(3), 149-165. <https://doi.org/10.1080/03601277.2010.515891>
- Lachman, R., Lachman, J. L., & Butterfield, E. C. (2015). *Cognitive psychology and information processing: An introduction*. Psychology Press.
- Lai, T., Xie, C., Ruan, M., Wang, Z., Lu, H., & Fu, S. (2023). Influence of artificial intelligence in education on adolescents' social adaptability: The mediatory role of social support. *Plos one*, 18(3), e0283170. <https://doi.org/10.1371/journal.pone.0283170>
- Lanjekar, P. D., Joshi, S. H., Lanjekar, P. D., & Wagh, V. (2022). The effect of parenting and the parent-Child relationship on a Child's cognitive development: a literature review. *Cureus*, 14(10).
- Lantolf, J P. (1994). Sociocultural theory and second language learning: Introduction to the special issue. *The modern language journal*, 78(4), 418-420. <https://doi.org/10.1111/j.1540-4781.1994.tb02058.x>
- Laureiro-Martinez, D. (2014). Cognitive control capabilities, routinization propensity, and decision-making performance. *Organization Science*, 25(4), 1111-1133. <https://doi.org/10.1287/orsc.2014.0899>
- Laurillard, D. (2010). An approach to curriculum design. *Institute of Education, London*, 14, 16.
- Lebiere, C., & Anderson, J. R. (2011). Cognitive constraints on decision making under uncertainty. *Frontiers in psychology*, 2, 305. <https://doi.org/10.3389/fpsyg.2011.00305>
- Leite, I., Castellano, G., Pereira, A., Martinho, C., & Paiva, A. (2012). Modelling empathic behaviour in a robotic game companion for children: An ethnographic study in real-world settings. *Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction* (pp. 367–374). <https://doi.org/10.1145/2157689.2157811>
- Leyzberg, D., Ramachandran, A., & Scassellati, B. (2018). The effect of personalization in longer-term robot tutoring. *ACM Transactions on Human-Robot Interaction (THRI)*, 7(3), 1-19.

References

- Lieberman, D. A., Bates, C. H., & So, J. (2009). Young children's learning with digital media. *Computers in the Schools*, 26(4), 271-283.
<https://doi.org/10.1080/07380560903360194>
- Light, P. H., Buckingham, N., & Robbins, A. H. (1979). The conservation task as an interactional setting. *British Journal of Educational Psychology*, 49(3), 304–310.
<https://doi.org/10.1111/j.2044-8279.1979.tb02430.x>
- Lindsay, P. H., & Norman, D. A. (2013). *Human information processing: An introduction to psychology*. Academic press.
- Listiana, N., & Jaharadak, A. A. (2019). Blended learning as instructional media: Literature review. In *Journal of Physics: Conference Series* (Vol. 1167, No. 1, p. 012066). IOP Publishing.
<https://doi.org/10.1088/1742-6596/1167/1/012066>
- Liu, W., Wang, Z., Liu, X., Zeng, N., Liu, Y., & Alsaadi, F. E. (2017). A survey of deep neural network architectures and their applications. *Neurocomputing*, 234, 11-26.
<https://doi.org/10.1016/j.neucom.2016.12.038>
- Liu, Y., Yang, X., Li, J., Kou, E., Tian, H., & Huang, H. (2018). Theory of mind development in school-aged left-behind children in rural China. *Frontiers in Psychology*, 9, 1819.
<https://doi.org/10.3389/fpsyg.2018.01819>
- Looks, M., & Goertzel, B. (2006). Mixing Cognitive Science Concepts with Computer Science Algorithms and Data Structures: An Integrative Approach to Strong AI. In *AAAI Spring Symposium: Between a Rock and a Hard Place: Cognitive Science Principles Meet AI-Hard Problems* (pp. 80-85).
- López-Belmonte, J., Pozo-Sánchez, S., Moreno-Guerrero, AJ, & Lampropoulos, G. (2023). Metaverse in Education: a systematic review. *Distance Education Journal (RED)* , 23 (73).
<https://doi.org/10.6018/red.511421>
- Lorusso, M. L., Giorgetti, M., Travellini, S., Greci, L., Zangiacomi, A., Mondellini, M., ... & Reni, G. (2018). Giok the alien: an AR-based integrated system for the empowerment of problem-solving, pragmatic, and social skills in pre-school children. *Sensors*, 18(7), 2368.
<https://doi.org/10.3390/s18072368>
- Lourenço, O., & Machado, A. (1996). In defense of Piaget's theory: A reply to 10 common criticisms. *Psychological Review*, 103(1), 143. <https://doi.org/10.1037/0033-295X.103.1.143>

- Lozada, M., & Carro, N. (2016). Embodied action improves cognition in children: Evidence from a study based on Piagetian conservation tasks. *Frontiers in Psychology*, 7, 393.
<https://doi.org/10.3389/fpsyg.2016.00393>
- Lu, Y., Shen, M., Wang, H., Wang, X., van Rechem, C., Fu, T., & Wei, W. (2023). Machine learning for synthetic data generation: a review. *arXiv preprint arXiv:2302.04062*.
<https://doi.org/10.48550/arxiv.2302.04062>
- Lucas Jr, H. C. (2017). Technology and the failure of the university. *Communications of the ACM*, 61(1), 38-41. <https://doi.org/10.1145/3163910>
- Luxton, D. D. (2014). Artificial intelligence in psychological practice: Current and future applications and implications. *Professional Psychology: Research and Practice*, 45(5), 332.
- Ma, X., & Jiang, C. (2023). On the Ethical Risks of Artificial Intelligence Applications in Education and Its Avoidance Strategies. *Journal of Education, Humanities and Social Sciences*, 14, 354-359.
<https://doi.org/10.54097/ehss.v14i.8868>
- Machado, M., & Tao, E. (2007). Blackboard vs. Moodle: Comparing user experience of learning management systems. In 2007 37th annual frontiers in education conference-global engineering: Knowledge without borders, opportunities without passports (pp. S4J-7). IEEE.
<https://doi.org/10.1109/FIE.2007.4417910>
- Maghsudi, S., Lan, A., Xu, J., & van Der Schaar, M. (2021). Personalized education in the artificial intelligence era: what to expect next. *IEEE Signal Processing Magazine*, 38(3), 37-50.
<https://doi.org/10.1109/msp.2021.3055032>
- Maia, T. V., & Frank, M. J. (2011). From reinforcement learning models to psychiatric and neurological disorders. *Nature neuroscience*, 14(2), 154-162. <https://doi.org/10.1038/nn.2723>
- Malanchini, M., Rimfeld, K., Shakeshaft, N. G., McMillan, A., Schofield, K. L., Rodic, M., ... & Plomin, R. (2020). Evidence for a unitary structure of spatial cognition beyond general intelligence. *npj Science of Learning*, 5(1), 9. <https://doi.org/10.1038/s41539-020-0067-8>
- Malatesta, M., & Quintana, Y. (2006). Multiple Intelligences and quotient spaces. *arXiv preprint math/0611042*. <https://doi.org/10.48550/arxiv.math/0611042>
- Malle, B. F., & Scheutz, M. (2019). Learning how to behave: Moral competence for social robots. *Handbuch maschinenethik*, 255-278.
- Mallon, E. J. (1976). Cognitive development and processes: Review of the philosophy of Jean Piaget. *The American Biology Teacher*, 38(1), 28-47. <https://doi.org/10.2307/4445437>

References

- Manik, S. ., Sembiring, M. ., Padang, I. ., & Manurung, L. . (2022). Theory of Bandura's Social Learning in The Process Of Teaching at SMA Methodist Berastagi Kabupaten Karo . *Jurnal Visi Pengabdian Kepada Masyarakat*, 3(2), 85-96. <https://doi.org/10.51622/pengabdian.v3i2.729>
- Marchetti, A., Di Dio, C., Manzi, F., & Massaro, D. (2022). Robotics in clinical and developmental psychology. *Comprehensive Clinical Psychology*, 121. <https://doi.org/10.1016/B978-0-12-818697-8.00005-4>
- Marín, V. I., & Castaneda, L. (2023). Developing digital literacy for teaching and learning. In *Handbook of open, distance and digital education* (pp. 1089-1108). Singapore: Springer Nature Singapore.
- Marsh, G. E., & Iran-Nejad, A. (1992). Intelligence: Beyond a monolithic concept. *Bulletin of the Psychonomic Society*, 30, 329-332. <https://doi.org/10.3758/bf03330482>
- Martin, A., & Grudziecki, J. (2006). DigEuLit: Concepts and tools for digital literacy development. *Innovation in teaching and learning in information and computer sciences*, 5(4), 249-267.
- Martinsone, B., Supe, I., Stokenberga, I., Damberga, I., Cefai, C., Camilleri, L., ... & Grazzani, I. (2022). Social emotional competence, learning outcomes, emotional and behavioral difficulties of preschool children: parent and teacher evaluations. *Frontiers in psychology*, 12, 760782. <https://doi.org/10.3389/fpsyg.2021.760782>
- Mascolo, M. F., Kanner, B. G., & Griffin, S. (1998). Neo-Piagetian systems theory and the education of young children. *Early Child Development and Care*, 140(1), 31-52. <https://doi.org/10.1080/0300443981400104>
- Mason, R. A., & Just, M. A. (2016). Neural representations of physics concepts. *Psychological science*, 27(6), 904-913. <https://doi.org/10.1177/0956797616641941>
- Masson, O., Baratgin, J., & Jamet, F. (2017). NAO robot, transmitter of social cues: what impacts? The example with "endowment effect". In *Advances in Artificial Intelligence: From Theory to Practice: 30th International Conference on Industrial Engineering and Other Applications of Applied Intelligent Systems, IEA/AIE 2017, Arras, France, June 27-30, 2017, Proceedings, Part I 30* (pp. 559-568). Springer International Publishing. https://doi.org/10.1007/978-3-319-60042-0_62

- Matsuda, N., Cohen, W. W., Sewall, J., Lacerda, G., & Koedinger, K. R. (2007). Predicting students' performance with simstudent: Learning cognitive skills from observation. *Frontiers in Artificial Intelligence and Applications*, 158, 467.
- Mayer, R. E. (1996). Learners as information processors: Legacies and limitations of educational psychology's second.. *Educational psychologist*, 31(3-4), 151-161.
<https://doi.org/10.1080/00461520.1996.9653263>
- McGarrigle, J., & Donaldson, M. (1974). Conservation accidents. *Cognition*, 3(4), 341-350.
[https://doi.org/10.1016/0010-0277\(74\)90003-1](https://doi.org/10.1016/0010-0277(74)90003-1)
- McQuaid, R. W., & Lindsay, C. (2005). The Concept of Employability. *Urban Studies*, 42(2), 197-219.
<https://doi.org/10.1080/0042098042000316100>
- Mertoglu, E. (2010). A study on the relationship between the rhythm and mathematics skills of 5–6 year old children. *Gifted Education International*, 26(1), 26-34.
<https://doi.org/10.1177/026142941002600105>
- Michaud, F., Salter, T., Duquette, A., Mercier, H., Lauria, M., Larouche, H., & Larose, F. (2007). Assistive technologies and child-robot interaction. In *AAAI spring symposium on multidisciplinary collaboration for socially assistive robotics*.
- Mielonen, A., & Paterson, W. (2009). Developing literacy through play. *Journal of Inquiry and Action in Education*, 3(1), 2.
- Mills, K. A., Scholes, L., & Brown, A. (2022). Virtual reality and embodiment in multimodal meaning making. *Written Communication*, 39(3), 335-369.
<https://doi.org/10.1177/07410883221083517>
- Mnih, V., Heess, N., & Graves, A. (2014). Recurrent models of visual attention. *Advances in neural information processing systems*, 27. <https://doi.org/10.48550/arxiv.1406.6247>
- Moll, H., & Tomasello, M. (2007). Cooperation and human cognition: the Vygotskian intelligence hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362(1480), 639-648. <https://doi.org/10.1098/rstb.2006.2000>
- Mollenkopf, D., Gaskill, M., Nelson, R. M., & Diaz, C. C. (2020). Navigating a “new normal” during the COVID-19 pandemic: college student perspectives of the shift to remote learning. *Revue internationale des technologies en pédagogie universitaire*, 17(2), 67-79.
<https://doi.org/10.18162/ritpu-2020-v17n2-08>

References

- Montebello, M. (2014). Artificial intelligence to the rescue of elearning. In *EDULEARN14 Proceedings* (pp. 7029-7038). IATED.
- Moolayil, J. (2019). *Learn Keras for Deep Neural Networks: A Fast-Track Approach to Modern Deep Learning with Python*. Apress. <https://doi.org/10.1007/978-1-4842-4240-7>
- Moore, J. (1996). On the relation between behaviorism and cognitive psychology. *The Journal of Mind and Behavior*, 345-367.
- Motamedi, V. (2019). The promises of presentational technology for teaching and learning. *Journal of Education and Learning (EduLearn)*, 13(3), 416-419. <https://doi.org/10.11591/edulearn.v13i3.13175>
- Moutoussis, K. (2016). The machine behind the stage: A neurobiological approach toward theoretical issues of sensory perception. *Frontiers in Psychology*, 7, 1357. <https://doi.org/10.3389/fpsyg.2016.01357>
- Mozer, M. C., Wiseheart, M., & Novikoff, T. P. (2019). Artificial intelligence to support human instruction. *Proceedings of the National Academy of Sciences*, 116(10), 3953-3955. <https://doi.org/10.1073/pnas.1900370116>
- Mubin, O., Stevens, C. J., Shahid, S., Al Mahmud, A., & Dong, J. J. (2013). A review of the applicability of robots in education. *Journal of Technology in Education and Learning*, 1(209-0015), 13.
- Murcia, K., Campbell, C., & Aranda, G. (2018). Trends in Early Childhood Education Practice and Professional Learning with Digital Technologies. *Pedagogika*, 68(3), 249-264. <https://doi.org/10.14712/23362189.2018.858>
- Murray, F. B., & Johnson, P. E. (1969). Reversibility in no conservation of weight. *Psychonomic Science*, 16(6), 285-287. <https://doi.org/10.3758/BF03332691>
- Myers, G. J., Sandler, C., & Badgett, T. (2011). *The art of software testing*. John Wiley & Sons. <https://doi.org/10.1002/9781119202486>
- Nambeye, T. (2020). *The influence of Jean Piaget's conservation tasks on the academic performance of pupils in the concrete operational stage of Kitwe District*. [Doctoral dissertation, University of Zambia]. [http://dspace.unza.zm/bitstream/handle/123456789/7074/FINAL%20DESSERTATION%20DR%20KABA GHE%20JANUARY.pdf](http://dspace.unza.zm/bitstream/handle/123456789/7074/FINAL%20DESSERTATION%20DR%20KABA%20GHE%20JANUARY.pdf)

- Din, M. N. U., Qadeer, M. Z., & Khan, M. G. (2019). A Study to adopt the primary school children on number conservation ability through Piaget cognitive theory. *Global Social Sciences Review, IV(III)*, 364-374. [https://doi.org/10.31703/gssr.2019\(IV-III\).46](https://doi.org/10.31703/gssr.2019(IV-III).46)
- Nelson, L. N. (1974). The development of cognitive operations in young children. *The Journal of Educational Research, 68*(3), 116-123. <https://doi.org/10.1080/00220671.1974.10884721>
- Nicolopoulou, A. (1993). Play, cognitive development, and the social world: Piaget, Vygotsky, and beyond. *Human development, 36*(1), 1-23. <https://doi.org/10.1159/000277285>
- Nicolopoulou, A., Barbosa de Sa, A., Ilgaz, H., & Brockmeyer, C. (2009). Using the transformative power of play to educate hearts and minds: From Vygotsky to Vivian Paley and beyond. *Mind, culture, and activity, 17*(1), 42-58. <https://doi.org/10.1080/10749030903312512>
- Nießen, D., Danner, D., Spengler, M., & Lechner, C. M. (2020). Big five personality traits predict successful transitions from school to vocational education and training: a large-scale study. *Frontiers in psychology, 11*, 1827. <https://doi.org/10.3389/fpsyg.2020.01827>
- Nourbakhsh, I., & Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and autonomous systems, 42*(3-4), 143-166. [https://doi.org/10.1016/S0921-8890\(02\)00372-X](https://doi.org/10.1016/S0921-8890(02)00372-X)
- O'loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of research in science teaching, 29*(8), 791-820. <https://doi.org/10.1002/tea.3660290805>
- Oakley, D. A., & Halligan, P. W. (2017). Chasing the rainbow: the non-conscious nature of being. *Frontiers in psychology, 8*, 1924. <https://doi.org/10.3389/fpsyg.2017.01924>
- Ojha, S., Narendra, A., Mohapatra, S., & Misra, I. (2023). From robots to books: An introduction to smart applications of AI in education (AIED). *arXiv preprint arXiv:2301.10026*. <https://doi.org/10.48550/arxiv.2301.10026>
- Onyango, G., & Gitonga, R. (2017). Exploring how technology complements constructivism using a lesson plan. In *2017 IST-Africa Week Conference (IST-Africa)* (pp. 1-11). IEEE. <https://doi.org/10.23919/istafrica.2017.8102351>
- Ortenzi, V., Cosgun, A., Pardi, T., Chan, W. P., Croft, E., & Kulić, D. (2021). Object handovers: a review for robotics. *IEEE Transactions on Robotics, 37*(6), 1855-1873. <https://doi.org/10.48550/arxiv.2007.12952>

References

- Palaiologou, I. (2016). Children under five and digital technologies: Implications for early years pedagogy. *European Early Childhood Education Research Journal*, 24(1), 5-24.
<https://doi.org/10.1080/1350293X.2014.929876>
- Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual review of psychology*, 49(1), 345-375. <https://doi.org/10.1146/annurev.psych.49.1.345>
- Pantelimon, F. V., Bologa, R., Toma, A., & Posedaru, B. S. (2021). The evolution of AI-driven educational systems during the COVID-19 pandemic. *Sustainability*, 13(23), 13501.
- Papakostas, G. A., Sidiropoulos, G. K., Papadopoulou, C. I., Vrochidou, E., Kaburlasos, V. G., Papadopoulou, M. T., ... & Dalivigkas, N. (2021). Social robots in special education: A systematic review. *Electronics*, 10(12), 1398.
- Papert, S. (1984). New theories for new learnings. *School Psychology Review*, 13(4), 422-428.
- Papert, S. (1985). Different visions of logo. *Computers in the Schools*, 2(2-3), 3-8.
- Papert, S. (1996). An exploration in the space of mathematics educations. *Int. J. Comput. Math. Learn.*, 1(1), 95-123.
- Papert, S. A. (1973). *Uses of technology to enhance education*. <http://hdl.handle.net/1721.1/6213>
- Park, D., Tsukayama, E., Goodwin, G. P., Patrick, S., & Duckworth, A. L. (2017). A tripartite taxonomy of character: Evidence for intrapersonal, interpersonal, and intellectual competencies in children. *Contemporary educational psychology*, 48, 16-27.
<https://doi.org/10.1016/j.cedpsych.2016.08.001>
- Pashevich, E. (2022). Can communication with social robots influence how children develop empathy? Best-evidence synthesis. *AI & SOCIETY*, 37(2), 579-589.
- Paterson, S. J., Heim, S., Friedman, J. T., Choudhury, N., & Benasich, A. A. (2006). Development of structure and function in the infant brain: Implications for cognition, language and social behaviour. *Neuroscience & Biobehavioral Reviews*, 30(8), 1087-1105.
- Pathan, H., Memon, R. A., Memon, S., Khoso, A. R., & Bux, I. (2018). A critical review of Vygotsky's socio-cultural theory in second language acquisition. *International Journal of English Linguistics*, 8(4), 232. <https://doi.org/10.5539/ijel.v8n4p232>
- Peirce, N. (2013). *Digital game-based learning for early childhood. A state of the art report*.
<http://dx.doi.org/10.13140/RG.2.2.25305.42087>

- Peppler, K. A., Sedas, R. M., & Thompson, N. (2023). Paper circuits vs. breadboards: Materializing learners' powerful ideas around circuitry and layout design. *Journal of Science Education and Technology*, 32(4), 469-492. <https://doi.org/10.1007/s10956-023-10029-0>
- Perry, B., & Dockett, S. (2008). Young children's access to powerful mathematical ideas. *Handbook of international research in mathematics education*, 2, 75-108.
- Peters, D., Vold, K., Robinson, D., & Calvo, R. A. (2020). Responsible AI—two frameworks for ethical design practice. *IEEE Transactions on Technology and Society*, 1(1), 34-47.
- Peterson, G. R. (1997). Cognitive science: What one needs to know. *Zygon*®, 32(4), 615-627. <https://doi.org/10.1111/0591-2385.00115>
- Phillips, D. C. (2012). Behaviorism and behaviorist learning theories. *Encyclopedia of the Sciences of Learning*, 438-42. https://doi.org/10.1007/978-1-4419-1428-6_750
- Piaget, J. (1936). *Origins of intelligence in the child*. London: Routledge & Kegan Paul.
- Piaget, J. (1951). *Play, dreams and imitation in childhood*. Routledge & Kegan Paul.
- Piaget, J. (1954). *The construction of reality in the child*. Basic Books. <https://doi.org/10.1037/11168-000>
- Piaget, J. (1962). The stages of the intellectual development of the child. *Bulletin of the Menninger clinic*, 26(3), 120.
- Piaget, J. (1973). Cognitive development. *The Journal of the Jean Piaget Society*.
- Piaget, J., & Inhelder, B. (1974). *The child's construction of quantities: Conservation and atomism*. Routledge & Kegan Paul. <https://doi.org/10.4324/9781315006253>
- Piccinini, G., & Scarantino, A. (2011). Information processing, computation, and cognition. *Journal of biological physics*, 37, 1-38. <https://doi.org/10.1007/s10867-010-9195-3>
- Pietschnig, J., & Voracek, M. (2015). One century of global IQ gains: A formal meta-analysis of the Flynn effect (1909–2013). *Perspectives on Psychological Science*, 10(3), 282-306. <https://doi.org/10.1177/1745691615577701>
- Pisoni, D. B. (2000). Cognitive factors and cochlear implants: Some thoughts on perception, learning, and memory in speech perception. *Ear and hearing*, 21(1), 70-78. <https://doi.org/10.1097/00003446-200002000-00010>
- Pivetti, M., Di Battista, S., Agatolio, F., Simaku, B., Moro, M., & Menegatti, E. (2020). Educational Robotics for children with neurodevelopmental disorders: A systematic review. *Heliyon*, 6(10), e05160. <https://doi.org/10.1016/j.heliyon.2020.e05160>

References

- Plunkett, K., Karmiloff-Smith, A., Bates, E., Elman, J. L., & Johnson, M. H. (1997). Connectionism and developmental psychology. *Journal of Child Psychology and Psychiatry*, 38(1), 53-80.
- Prabhakar, A., & Billard, A. (2022). User-specific, Adaptable Safety Controllers Facilitate User Adoption in Human-Robot Collaboration. *arXiv preprint arXiv:2210.08137*.
<https://doi.org/10.48550/arxiv.2210.08137>
- Prescott, T. J., & Robillard, J. M. (2021). Are friends electric? The benefits and risks of human-robot relationships. *Iscience*, 24(1), 101993. <https://doi.org/10.1016/j.isci.2020.101993>
- Prinstein, M. J., & Roberts, M. C. (2006). The Professional Adolescence of Clinical Child and Adolescent Psychology and Pediatric Psychology: Grown Up and Striving for Autonomy. *Clinical Psychology: Science and Practice*, 13(3), 263. <https://doi.org/10.1111/j.1468-2850.2006.00035.x>
- Puerta, M. L. S., Valerio, A., & Bernal, M. G. (2016). *Taking stock of programs to develop socioemotional skills: A systematic review of program evidence*. World Bank Publications.
<https://doi.org/10.1596/978-1-4648-0872-2>
- Punchyk, V. N. (2019). The Organization of Studying and Research Activities of Students by the Methods of Pedagogical Intellectics. *European Journal of Behavioral Sciences*, 2(1), 39–47.
<https://doi.org/10.33422/EJBS.2019.05.13>
- Pundir, R., & Surana, A. (2016). Constructivism learning: A way to make knowledge construction. *The International Journal of Indian Psychology*, 3(10), 345-359.
<https://doi.org/10.25215/0302.190>
- Qadar, R., Mahdiannur, M. A., & Sulaeman, N. F. (2021). Admission Test Analysis of Pre-Service Math-Science Teacher Based on Its Related Factors. *Cypriot Journal of Educational Sciences*, 16(3), 1154-1174. <https://doi.org/10.18844/cjes.v16i3.5837>
- Qasem, M. (2015). Constructivist learning theory in physiotherapy education: a critical evaluation of research. *Journal of Novel Physiotherapies*, 5(2), 1-3.
- Rabindran, R., & 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>
- Rahmah, F., & Irawati, S. (2019). Mathematical representation analysis of students in solving mathematics problems. In *Journal of Physics: Conference Series* (Vol. 1200, No. 1, p. 012011). IOP Publishing. <https://doi.org/10.1088/1742-6596/1200/1/012011>

- Rahman, M. H. A., Ismail, D., Noor, A. Z. B. M., & Salleh, N. S. B. M. (2018). Gamification elements and their impacts on teaching and learning—A review. *The International Journal of Multimedia & Its Applications (IJMA) Vol, 10*. <https://doi.org/10.5121/ijma.2018.10604>
- Ramabaja, L. (2021). The Koha Code: A Biological Theory of Memory. *arXiv preprint arXiv:2109.02124*. <https://doi.org/10.48550/arxiv.2109.02124>
- Rasheed, R. A., Kamsin, A., & Abdullah, N. A. (2020, January). Students and teachers' challenges of using technology in blended learning environments. In *Proceedings of the 2020 the 3rd International Conference on Computers in Management and Business* (pp. 195-200). <https://doi.org/10.1145/3383845.3383875>
- Reimann, A. (2018). Behaviorist learning theory. *The TESOL encyclopedia of English language teaching*, 1-6. <https://doi.org/10.1002/9781118784235.eelt0155>
- Resnick, M. (2024). Generative AI and Creative Learning: Concerns, Opportunities, and Choices. *An MIT Exploration of Generative AI*. <https://doi.org/10.21428/e4baedd9.cf3e35e5>
- Roberts, N., Yap, D. A., & Prabhu, V. U. (2019). Deep connectomics networks: Neural network architectures inspired by neuronal networks. *arXiv preprint arXiv:1912.08986*. <https://doi.org/10.48550/arxiv.1912.08986>
- Rosen, M. L., Sheridan, M. A., Sambrook, K. A., Meltzoff, A. N., & McLaughlin, K. A. (2018). Socioeconomic disparities in academic achievement: A multi-modal investigation of neural mechanisms in children and adolescents. *NeuroImage*, 173, 298-310. <https://doi.org/10.1016/j.neuroimage.2018.02.043>
- Rothenberg, B. B. (1969). Conservation of Number among Four- and Five-Year-Old Children: Some Methodological Considerations. *Child Development*, 40(2), 383-406. <https://doi.org/10.2307/1127410>
- Rowland, T. (1968). Jerome S. Bruner: A philosopher of educational psychology. *Journal of Thought*, 107-115.
- Rubenstein, M., Cimino, B., Nagpal, R., & Werfel, J. (2015). AERobot: An affordable one-robot-per-student system for early robotics education. *2015 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6107–6113). IEEE. <https://doi.org/10.1109/ICRA.2015.7140056>
- Sack, A. T. (2009). Parietal cortex and spatial cognition. *Behavioural brain research*, 202(2), 153-161. <https://doi.org/10.1016/j.bbr.2009.03.012>

References

- Sadiku, M. N., Alam, S., & Musa, S. M. (2019). Social intelligence: A primer. *International Journal of Research*, 7, 213-217. <https://doi.org/10.29121/granthaalayah.v7.i9.2019.603>
- Sahin, A., & Özenç, E. G. (2021). The use of educational software in teaching initial reading and writing. *International Journal of Progressive Education*, 17(4), 373-389. <https://doi.org/10.29329/ijpe.2021.366.23>
- Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. *Educational psychology review*, 32(1), 77-112.
- Sailer, M., Bauer, E., Hofmann, R., Kiesewetter, J., Glas, J., Gurevych, I., & Fischer, F. (2023). Adaptive feedback from artificial neural networks facilitates pre-service teachers' diagnostic reasoning in simulation-based learning. *Learning and Instruction*, 83, 101620. <https://doi.org/10.1016/j.learninstruc.2022.101620>
- Sakkas, C., & Samartzi, S. (2023). Human-human versus human-robot interaction in Piaget's liquid and mass conservation performed by 5–6-year-old children. *International Journal of Psychological Studies*, 15(1), 1-60. <https://doi.org/10.5539/ijps.v15n1p60>
- Sakkas, C., & Samartzi, S. (2024). 5-Year-Old Children Performing Piaget's Liquid Conservation Tasks Demonstrated in Physical and Digital Environment. *International Journal of Psychological Studies*, 16(1), 1-61. <https://doi.org/10.5539/ijps.v16n1p61>
- Sakkas, C., Samartzi, S., & Koumaras, H. (2024). A Prototype Implementation of a Virtual Platform with Robotic Integration and Machine Learning Capabilities for the Execution of Cognitive Psychology Experiments in Children. *Journal of Educational and Developmental Psychology*, 14(1), 135-155.
- Salmina, N. G., & Sorhina, V. P. (1982). Teaching a General Approach to Problem Solving. *Programmed Learning and Educational Technology*, 19(1), 25-30. <https://doi.org/10.1080/0033039820190104>
- Samartzi, S. (1992). *Time and inference rules in the child, adolescent and adult* (pp. 85-88). Springer Netherlands.
- Samartzi, S. (2011). Children's cognitive development of lived-experienced time and physical time. *Studia Psychologica*, 53(3), 307.
- Samartzi, S. & Kazi, S. (2010). Children's mental representations of temporal relations: Number and figure as time's magnitude measures. *Journal of Science Education*, 2(11), 99-102.

- Samartzi, S. & Pavlou, A. (2009). Children's ideas about time, distance and speed concepts: The role of information presentation. *Journal of Science Education*, 2(10), 87-90.
- Samuelson, L. K., Horst, J. S., Schutte, A. R., & Dobbertin, B. N. (2008). Rigid thinking about deformables: do children sometimes overgeneralize the shape bias?. *Journal of Child Language*, 35(3), 559-589.
- Sanghvi, P. (2020). Piaget's theory of cognitive development: a review. *Indian Journal of Mental Health*, 7(2), 90-96. <https://doi.org/10.30877/ijmh.7.2.2020.90-96>
- Sani, Y., Wardany, O. F., Herlina, H., & Vernanda, G. (2021). The implementation of embodied learning: A literature review. *Edukasi*, 15(1), 8-18. <https://doi.org/10.15294/edukasi.v15i1.30008>
- Sanmugam, M., Abdullah, Z., & Zaid, N. M. (2014). Gamification: Cognitive impact and creating a meaningful experience in learning. In *2014 IEEE 6th Conference on Engineering Education (ICEED)* (pp. 123-128). IEEE. <https://doi.org/10.1109/iceed.2014.7194700>
- Sapounidis, T., & Alimisis, D. (2020). Educational robotics for STEM: A review of technologies and some educational considerations. In *Science and mathematics education for 21st century citizens: Challenges and ways forward* (No. September, 2020, pp. 167-190). Hauppauge, NY, USA: Nova Science Publishers.
- Schlesinger, M., & McMurray, B. (2012). The past, present, and future of computational models of cognitive development. *Cognitive Development*, 27(4), 326-348.
- Schonert-Reichl, K. A., Guhn, M., Gadermann, A. M., Hymel, S., Sweiss, L., & Hertzman, C. (2013). Development and validation of the Middle Years Development Instrument (MDI): Assessing children's well-being and assets across multiple contexts. *Social indicators research*, 114, 345-369. <https://doi.org/10.1007/s11205-012-0149-y>
- Schwartz, B., Cohen, Z. D., Rubel, J. A., Zimmermann, D., Wittmann, W. W., & Lutz, W. (2021). Personalized treatment selection in routine care: Integrating machine learning and statistical algorithms to recommend cognitive behavioral or psychodynamic therapy. *Psychotherapy Research*, 31(1), 33-51.
- Semeraro, F., Griffiths, A., & Cangelosi, A. (2023). Human–robot collaboration and machine learning: A systematic review of recent research. *Robotics and Computer-Integrated Manufacturing*, 79, 102432. <https://doi.org/10.48550/arxiv.2110.07448>

References

- Semmelmann K., Nordt M., Sommer K., Röhnke R., Mount L., Prüfer H., Terwiel S., Meissner T.W., Koldewyn K., & Weigelt S. (2016). U Can Touch This: How Tablets Can Be Used to Study Cognitive Development. *Frontiers in Psychology, 7*, 1021. <https://doi.org/10.3389/fpsyg.2016.01021>
- Shanmugasundaram, M., & Tamilarasu, A. (2023). The impact of digital technology, social media, and artificial intelligence on cognitive functions: a review. *Frontiers in Cognition, 2*, 1203077. <https://doi.org/10.3389/fcogn.2023.1203077>
- Sharkey, M., & Gash, H. (2020). Teachers' constructivist and ethical beliefs. *Behavioral Sciences, 10*(6), 96. <https://doi.org/10.3390/bs10060096>
- Sharp, D., Cole, M., Lave, C., Ginsburg, H. P., Brown, A. L., & French, L. A. (1979). Education and cognitive development: The evidence from experimental research. *Monographs of the society for research in child development, 1*-112.
- Shayer, M., Küchemann, D. E., & Wylam, H. (1976). The distribution of Piagetian stages of thinking in British middle and secondary school children. *British Journal of Educational Psychology, 46*(2), 164-173. <https://doi.org/10.1111/j.2044-8279.1976.tb02308.x>
- Shearer, B. (2018). Multiple intelligences in teaching and education: Lessons learned from neuroscience. *Journal of Intelligence, 6*(3), 38. <https://doi.org/10.3390/jintelligence6030038>
- Shiffrin, R. M. (1976). Capacity limitations in information processing, attention, and memory. *Handbook of learning and cognitive processes, 4*, 177-236.
- Shioiri, S., Kobayashi, M., Matsumiya, K., & Kuriki, I. (2018). Spatial representations of the viewer's surroundings. *Scientific Reports, 8*(1), 7171. <https://doi.org/10.1038/s41598-018-25433-5>
- Shleibik, Y., Alabi, E., & Reardon, C. (2024). Towards Human-Robot Teaming through Augmented Reality and Gaze-Based Attention Control. *arXiv preprint arXiv:2408.12823*. <https://doi.org/10.48550/arxiv.2408.12823>
- Shultz, T. R. (1998). A computational analysis of conservation. *Developmental Science, 1*(1), 103-126.
- Shultz, T. R. (2013). 17 Computational Models in Developmental Psychology. *The Oxford Handbook of Developmental Psychology, Vol. 1: Body and Mind, 1*, 477.
- Shuo, Z., & Chen, D. (2018). Application of Relevance Theory in College English Teaching. *Education Journal, 7*(05). <https://doi.org/10.11648/j.edu.20180705.15>

- Siegler, R. S. (1981). Developmental sequences within and between concepts. *Monographs of the Society for Research in Child Development*, 46, 1-84. <https://doi.org/10.2307/1165995>
- Siegler, R. S., & Alibali, M. W. (2019). *Children's thinking, 5th edition*. Upper Saddle River, NJ: Prentice Hall.
- Simmering, V. R., Triesch, J., Deák, G. O., & Spencer, J. P. (2010). A dialogue on the role of computational modeling in developmental science. *Child Development Perspectives*, 4(2), 152-158.
- Simon, H. A. (1979). Information processing models of cognition. *Annual review of psychology*, 30(1), 363-396.
- Singer, M. (2017). *Memory for Text and Discourse: Retrieval and Comprehension*. Elsevier BV, 357-381. <https://doi.org/10.1016/b978-0-12-809324-5.21065-1>
- Sinha, G. R., Raju, K. S., Patra, R. K., Aye, D. W., & Khin, D. T. (2018). Research studies on human cognitive ability. *International Journal of Intelligent Defence Support Systems*, 5(4), 298-304. <https://doi.org/10.1504/ijidss.2018.099891>
- Smagorinsky, P. (2018). Deinflating the ZPD and instructional scaffolding: Retranslating and reconceiving the zone of proximal development as the zone of next development. *Learning, culture and social interaction*, 16, 70-75. <https://doi.org/10.1016/j.lcsi.2017.10.009>
- Smith, A. B. (1993). Early childhood educare: Seeking a theoretical framework in Vygotsky's work. *International Journal of Early Years Education*, 1(1), 47-62. <https://doi.org/10.1080/0966976930010105>
- Solomon, C., Harvey, B., Kahn, K., Lieberman, H., Miller, M. L., Minsky, M., ... & Silverman, B. (2020). History of logo. *Proceedings of the ACM on Programming Languages*, 4(HOPL), 1-66.
- Spencer, C., & Darvizeh, Z. (1981). The case for developing a cognitive environmental psychology that does not underestimate the abilities of young children. *Journal of Environmental Psychology*, 1(1), 21-31.
- Spencer, K. S. (2011). Piaget's sensorimotor period. *Encyclopedia of child behavior and development*. Springer. https://doi.org/10.1007/978-0-387-79061-9_2578
- Stafford, T., & Vaci, N. (2022). Maximizing the potential of digital games for understanding skill acquisition. *Current Directions in Psychological Science*, 31(1), 49-55.

References

- Stanney, K. M., Schmorrow, D. D., Johnston, M., Fuchs, S., Jones, D., Hale, K. S., ... & Young, P. (2009). Augmented cognition: An overview. *Reviews of human factors and ergonomics*, 5(1), 195-224. <https://doi.org/10.1518/155723409x448062>
- Sternberg, R. J. (1999). The theory of successful intelligence. *Review of General psychology*, 3(4), 292-316.
- Sternberg, R. J. (2018). Theories of intelligence. In S. I. Pfeiffer, E. Shaunessy-Dedrick, & M. Foley-Nicpon (Eds.), *APA handbook of giftedness and talent* (pp. 145–161). American Psychological Association. <https://doi.org/10.1037/0000038-010>
- Stollery, P., & McPhee, A. (2002). Some perspectives on musical gift and musical intelligence. *British Journal of Music Education*, 19(1), 89-102. <https://doi.org/10.1017/s0265051702000165>
- Striano, T., & Reid, V. M. (2006). Social cognition in the first year. *Trends in cognitive sciences*, 10(10), 471-476. <https://doi.org/10.1016/j.tics.2006.08.006>
- Sui, J., Jiang, R., Bustillo, J., & Calhoun, V. (2020). Neuroimaging-based individualized prediction of cognition and behavior for mental disorders and health: methods and promises. *Biological psychiatry*, 88(11), 818-828. <https://doi.org/10.1016/j.biopsych.2020.02.016>
- Sung, Y. T., Chang, K. E., & Liu, T. C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education*, 94, 252-275. <https://doi.org/10.1016/j.compedu.2015.11.008>
- Suryawan, I. P. P., Sudiarta, I. G. P., & Suharta, I. G. P. (2023). Students' Critical Thinking Skills in Solving Mathematical Problems: Systematic Literature Review. *Indonesian Journal Of Educational Research and Review*, 6(1), 120-133. <https://doi.org/10.23887/ijerr.v6i1.56462>
- Suwastini, N. K. A., Ersani, N. P. D., Padmadewi, N. N., & Artini, L. P. (2021). Schemes of scaffolding in online education. *Retorika: Jurnal Ilmu Bahasa*, 7(1), 10-18. <https://doi.org/10.22225/jr.7.1.2941.10-18>
- Sweller, J., Van Merrienboer, J. J., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational psychology review*, 31, 261-292. <https://doi.org/10.1007/s10648-019-09465-5>
- Syafril, S., Aini, N. R., Pahrudin, A., & Yaumas, N. E. (2020). Spirit of mathematics critical thinking skills (CTS). In *Journal of Physics: Conference Series* (Vol. 1467, No. 1, p. 012069). IOP Publishing. <https://doi.org/10.1088/1742-6596/1467/1/012069>

- Takaya, K. (2008). Jerome Bruner's theory of education: From early Bruner to later Bruner. *Interchange*, 39, 1-19.
- Taye, M. M. (2023). Understanding of machine learning with deep learning: architectures, workflow, applications and future directions. *Computers*, 12(5), 91.
- Tayebinik, M., & Puteh, M. (2013). Blended Learning or E-learning?. *arXiv preprint arXiv:1306.4085*.
- Thomas, E., & Fam, A. (1984). Cross Cultural Methodological Problems in the Study of Singaporean Children's Cognitive Development. *Singapore Journal of Education*, 6(1), 30–36.
<https://doi.org/10.1080/02188798408548571>
- Topçiu, M., & Myftiu, J. (2015). Vygotsky theory on social interaction and its influence on the development of pre-school children. *European Journal of Social Sciences Education and Research*, 2(3), 172-179.
- Tran, C., Smith, B., & Buschkuehl, M. (2017). Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cognitive research: principles and implications*, 2, 1-18. <https://doi.org/10.1186/s41235-017-0053-8>
- Tschacher, W., Giersch, A., & Friston, K. (2017). Embodiment and schizophrenia: a review of implications and applications. *Schizophrenia bulletin*, 43(4), 745-753.
<https://doi.org/10.1093/schbul/sbw220>
- Tsolkas, D., & Koumaras, H. (2022). On the development and provisioning of vertical applications in the beyond 5G era. *IEEE Networking Letters*, 4(1), 43-47.
- Tuovinen, J. E. (2000). Optimising student cognitive load in computer education. In *Proceedings of the Australasian conference on computing education* (pp. 235-241).
<https://doi.org/10.1145/359369.359405>
- Ültanır, E. (2012). An epistemological glance at the constructivist approach: Constructivist learning in Dewey, Piaget, and Montessori. *International journal of instruction*, 5(2).
<https://dergipark.org.tr/tr/pub/eiji/issue/5139/70038>
- Van Merriënboer, J. J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational psychology review*, 17, 147-177.
- Van Oers, B. (2010). Emergent mathematical thinking in the context of play. *Educational studies in mathematics*, 74, 23-37. <https://doi.org/10.1007/s10649-009-9225-x>

References

- Van, P. V., Lam, H. T., Nguyen, L. T., & Le, T. P. (2021). Improving the effectiveness of students' progress assessment in a blended learning environment at Lac Hong University. *Journal of Technical Education Science*, 16(1), 43-49. <https://doi.org/10.54644/jte.62.2021.69>
- Vervaeke, J., & Ferraro, L. (2013). Relevance, meaning and the cognitive science of wisdom. In *The scientific study of personal wisdom: From contemplative traditions to neuroscience* (pp. 21-51). Dordrecht: Springer Netherlands.
- Villani, V., Pini, F., Leali, F., & Secchi, C. (2018). Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications. *Mechatronics*, 55, 248-266. <https://doi.org/10.1016/j.mechatronics.2018.02.009>
- Vygotsky, L. S. (1987). *The collected works of LS Vygotsky: The fundamentals of defectology* (Vol. 2). Springer Science & Business Media.
- Walker, S. F. (1990). A brief history of connectionism and its psychological implications. *AI & SOCIETY*, 4, 17-38.
- Warr, M. (2004). Paul Rollnd's Spiral Curriculum. *American String Teacher*, 54(4), 56-58. <https://doi.org/10.1177/000313130405400414>
- Watanabe, N. (2017a). Accelerated cognitive development-Piaget's conservation concept. *Journal of Educational and Developmental Psychology*, 7(2), 68-74. <https://doi.org/10.5539/jedp.v7n2p68>
- Watanabe, N. (2017b). Acquiring Piaget's conservation concept of numbers, lengths, and liquids as ordinary play. *Journal of Educational and Developmental Psychology*, 7(1), 210-217. <https://doi.org/10.5539/jedp.v7n1p210>
- Watanabe, N. (2019). Attachment play related to Piaget's conservation task with parent. *International Journal of Psychological Studies*, 11(2), 24-31. <https://doi.org/10.5539/ijps.v11n2p24>
- Watanabe, N. (2022). Conservation developmental process in early childhood: Impact of intrinsic motivation and practice effects. *Current Psychology*, 41(10), 7041-7048. <https://doi.org/10.1007/s12144-020-01217-x>
- Wattad, G., & Chen, D. (2023). Does Cognition Continue to Develop Throughout Life. *British Journal of Arts and Humanities*, 5(4), 185-191. <https://doi.org/10.34104/bjah.02301850191>

- Wei, C. W., Hung, I., Lee, L., & Chen, N. S. (2011). A joyful classroom learning system with robot learning companion for children to learn mathematics multiplication. *Turkish Online Journal of Educational Technology-TOJET*, 10(2), 11-23.
- Wellman, H. M. (2017). The development of theory of mind: Historical reflections. *Child Development Perspectives*, 11(3), 207-214. <https://doi.org/10.1111/cdep.12236>
- Wells, G. (1999). The zone of proximal development and its implications for learning and teaching. *Dialogic inquiry: Towards a sociocultural practice and theory of education*, 313-334. <https://doi.org/10.1017/cbo9780511605895.012>
- Werner, H., & Kaplan, E. (1950). The acquisition of word meanings: A developmental study. *Monographs of the society for research in child development*, i-120.
- Werner, H., & Wapner, S. (1952). Toward a general theory of perception. *Psychological review*, 59(4), 324.
- Wilson, D., & Sperber, D. (2012). *Meaning and Relevance*. Cambridge: Cambridge University Press. <https://doi.org/10.1017/cbo9781139028370>
- Wu, J., & Kraemer, P. (2016). Virtual psychology: An overview of theory, research, and future possibilities. *Handbook on 3D3C Platforms: Applications and Tools for Three Dimensional Systems for Community, Creation and Commerce*, 293-307.
- Wu, X. (2021). On the Role of Students' Subjectivity From the Perspective of Constructivism. In *2020 International Conference on Modern Education Management, Innovation and Entrepreneurship and Social Science (MEMIESS 2020)* (pp. 50-53). Atlantis Press. <https://doi.org/10.2991/assehr.k.210206.011>
- Wu, Y. T., & Tsai, C. C. (2007). High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analyses. *International Journal of Science Education*, 29(9), 1163-1187. <https://doi.org/10.1080/09500690601083375>
- Xia, L., & Zhong, B. (2018). A systematic review on teaching and learning robotics content knowledge in K-12. *Computers & Education*, 127, 267-282. <https://doi.org/10.1016/j.compedu.2018.09.007>
- Xiong, A., & Proctor, R. W. (2018). Information processing: The language and analytical tools for cognitive psychology in the information age. *Frontiers in psychology*, 9, 1270.

References

- Yang, P., & Liu, Z. (2022). The influence of immersive virtual reality (IVR) on skill transfer of learners: The moderating effects of learning engagement. *International Journal of Emerging Technologies in Learning (IJET)*, 17(10), 62-73.
- Yarkoni, T., & Westfall, J. (2017). Choosing prediction over explanation in psychology: Lessons from machine learning. *Perspectives on Psychological Science*, 12(6), 1100-1122.
<https://doi.org/10.1177/1745691617693393>
- Yin, J., Hinchet, R., Shea, H., & Majidi, C. (2021). Wearable soft technologies for haptic sensing and feedback. *Advanced Functional Materials*, 31(39), 2007428.
<https://doi.org/10.1002/adfm.202007428>
- Ying, X. (2019). An overview of overfitting and its solutions. In *Journal of physics: Conference series* (Vol. 1168, p. 022022). IOP Publishing. <https://doi.org/10.1088/1742-6596/1168/2/022022>
- Yu, H., Miao, C., Leung, C., & White, T. J. (2017). Towards AI-powered personalization in MOOC learning. *npj Science of Learning*, 2(1), 15. <https://doi.org/10.1038/s41539-017-0016-3>
- Zeuli, J. P. (1986). The Use of the Zone of Proximal Development in Everyday and School Contexts: A Vygotskian Critique.
- Zhang, J. (2019). Cognitive functions of the brain: perception, attention and memory. *arXiv preprint arXiv:1907.02863*. <https://doi.org/10.48550/arxiv.1907.02863>
- Zhang, K., & Aslan, A. B. (2021). AI technologies for education: Recent research & future directions. *Computers and Education: Artificial Intelligence*, 2, 100025.
- Zhang, L., & Nouri, J. (2018). *A systematic review of learning and teaching with tablets*. International Association for Development of the Information Society.
- Zhang, Y., Luo, R., Zhu, Y., & Yin, Y. (2021). Educational robots improve K-12 students' computational thinking and STEM attitudes: Systematic review. *Journal of Educational Computing Research*, 59(7), 1450-1481. <https://doi.org/10.1177/0735633121994070>
- Zhang, Z. J. (2014). Influence of modern technology on the educational system. *Advanced materials research*, 1030, 2746-2749. <https://doi.org/10.4028/www.scientific.net/amr.1030-1032.2746>
- Zhao, Z., Chai, W., Hao, S., Hu, W., Wang, G., Cao, S., ... & Wang, G. (2023). A survey of deep learning in sports applications: Perception, comprehension, and decision. *arXiv preprint arXiv:2307.03353*. <https://doi.org/10.48550/arxiv.2307.03353>
- Zimiles, H. (1963). A note on Piaget's concept of conservation. *Child Development*, 691-695.

- Zimmerman, B. J., & Kleefeld, C. F. (1977). Toward a theory of teaching: A social learning view. *Contemporary educational psychology*, 2(2), 158-171. [https://doi.org/10.1016/0361-476x\(77\)90018-2](https://doi.org/10.1016/0361-476x(77)90018-2)
- Złotowski, J., Proudfoot, D., Yogeewaran, K., & Bartneck, C. (2015). Anthropomorphism: opportunities and challenges in human–robot interaction. *International journal of social robotics*, 7, 347-360.
- Zulkarnain, I., Kusumawati, E., & Mawaddah, S. (2020). Critical Thinking Skills of Students in Teaching Mathematics Using Model Problem-Based Learning. In *SEMANTIK Conference of Mathematics Education (SEMANTIK 2019)* (pp. 56-60). Atlantis Press. <https://doi.org/10.2991/assehr.k.200827.117>