Review Paper

Looking at Philosophy for Children and Its Outcomes Through a Neuroscience Lens

Fariba Khodagholi[1], Maryam Alsadat Mousavi[1*], Yahya Ghaedi[2], Shakiba Salarvandian[3], Fatemeh Vosoughian[1], Mobina Javadi[3], Fereshteh Khodagholi[3], Solmaz Khalifeh[4], Roohollah Karimi[5], Masoud Seddighfar[1], Shima Barzin[3], Leila Dargahi[1*]

1. Neuroscience Research Center, Institute of Neuroscience and Cognition, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
2. Department of Educational Philosophy, Faculty of Psychology and Education, Kharazmi University, Tehran, Iran.
3. Neurobiology Research Center, Institute of Neuroscience and Cognition, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
4. Cognitive and Neuroscience Research Center (CNRC), Amiralmomenin Hospital, Tehran Medical Sciences Branch, Islamic Azad University, Tehran, Iran.
5. Institute for Humanities and Cultural Studies, Ethics and Training, Tehran, Iran.

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ABSTRACT

Introduction: Philosophy for Children (P4C) is one of the most effective teaching methods, having various educational, cognitive, and emotional benefits for children. This method is based on three types of thinking: critical (logic), caring (ethics), and creative (aesthetics). This study aimed to review the various outcomes of applying this strategy in people with different genders, ages, and socioeconomic statuses (SESs) from a neuroscience perspective.

Methods: This is a narrative review study. The related studies were selected for review based on relevance to gender, age, and SES, and findings were categorized to highlight patterns and divergences in outcomes.

Results: Evidence suggests that gender and SES can affect the effectiveness of P4C in certain aspects. However, the interaction between gender, age, and SES seems to shape the overall efficacy of P4C in nuanced ways.

Conclusion: The P4C has shown promising benefits for diverse populations. However, demographic variables such as gender, age, and SES may modulate its impact. Further interdisciplinary research is needed to clarify these interactions and optimize implementation strategies.

*** Corresponding Authors:**
Maryam Alsadat Mousavi, MD.
Address: *Neuroscience Research Center, Institute of Neuroscience and Cognition, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*
Tel: *+98 (21) 22429768*
E-mail: *maryamalsadatmousavi@yahoo.com*

Leila Dargahi, Professor.
Address: *Neuroscience Research Center, Institute of Neuroscience and Cognition, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*
Tel: *+98 (21) 22429768*
E-mail: *l.dargahi@sbmu.ac.ir*

Highlights

● Cognitive/emotional-related outcomes of the P4C might well be influenced by the combination of gender, age, and SES factors.

● Caring thinking and socioemotional characteristics related to the P4C tend to be improved more in girls than in boys.

● The gender-dependent results of the P4C are possibly due to gender differences in the amygdala and prefrontal cortex.

● The SES likely has a greater impact on the hippocampus and prefrontal cortex, which are also affected by P4C-related thinking.

Plain Language Summary

Among all educational methods worldwide, philosophy for children (P4C) has been introduced as an effective method with various advantages for children. This study aimed to review the various outcomes of applying this strategy in different genders, ages, and socioeconomic statuses (SESs) from a neuroscience perspective. It seems that gender and SES can affect the results of this educational method in certain ways. However, the combination of sex, age, and SES appears to influence P4C outcomes.

1. Introduction

Children are taught a variety of educational methods to improve their skills and knowledge worldwide. Each of these methods has advantages and limitations. Reliable evidence in the literature highlights the influence of education on individuals' cognitive abilities during development (Ceci, 1991; Lövdén et al., 2020). The primary purpose of conventional schooling approaches is more focused on teaching a wide range of declarative and procedural knowledge, which leads to improved crystallized cognitive abilities (vocabulary, literacy, numeracy, etc.) (Ceci, 1991). To some extent, these approaches may enhance fluid cognitive abilities (such as memory, judgment, and problem-solving) by improving cognitive strategies and test-taking skills (Baker et al., 2015; Wenger & Lövdén, 2016). Various educational cognitive stimulations influence cognitive abilities by inducing neurobiological changes throughout development (Lövdén et al., 2020). This may explain why schooling with various qualities can impact the interaction between education and a child's cognition (Cliffordson & Gustafsson, 2008). Childhood is a critical period when neurobiological elements and experiences combine to influence the normal developing brain and permanently affect behavior (Marek et al., 2015; Simmonds et al., 2014). Furthermore, studies have shown that during this time window, the association cortices continue to develop structurally and functionally in an experience-dependent manner (Blakemore & Mills, 2014; Larsen & Luna, 2018). In summary, the temporal co-occurrence of cognitive growth and increased exposure to environmental experiences suggests a critical period of development for shaping children's personalities and behaviors through education (Larsen & Luna, 2018).

Among all educational approaches, philosophy for children (P4C) has been introduced as an effective method, featuring different educational, cognitive, and behavioral advantages, such as improved executive functions and academic performance (Ab Wahab et al., 2022; Leng, 2020a; Säre et al., 2016; Vansieleghem & Kennedy, 2011). This method also has the potential to positively influence teachers (known as facilitators) both professionally and emotionally, as well as to promote constructive changes in pupils (Lam, 2021; Roberts, 2006).

Here, we discuss the topic of "neuroeducation," a field that aims to optimize knowledge transmission and comprehension by integrating information about brain processes related to cognitive abilities involved in learning with the efforts of the education community (Hardiman et al., 2011; Rueda, 2020). Cognitive neuroscience research can extend our understanding of how learning affects the brain and cognition (Ansari et al., 2012). Before neuroeducation research became widely available, educators and the public had several incorrect assumptions regarding the brain and the learning process.

While they acknowledged the significance of plasticity, they did not apply it to instructional approaches (Hardiman et al., 2011). However, many instructors now agree that it is fundamental to comprehend the neural foundation of cognition, behavior, and learning (Serpati & Loughan, 2012). Moreover, non-invasive brain imaging modalities, such as magnetoencephalography, structural and functional magnetic resonance imaging (MRI), electroencephalography, and near-infrared spectroscopy, have become widely available in recent years. As a result, measurements have been taken to establish which brain areas are involved in school-taught abilities (such as math and reading) together with broader cognitive abilities (such as working memory), and how their neural correlates vary as children learn and develop. It has been demonstrated that all these alterations could be observed in both brain functioning and anatomy (Ansari et al., 2012; Hardiman et al., 2011).

In this study, we sought to analyze the impacts of gender, age, and socioeconomic status (SES) on students' emotions and cognition, focusing on potential brain-related regions without optimism. Moreover, hypotheses regarding the influence of this training course on neuroplasticity are discussed.

2. A Brief Outline of the P4C Method

The P4C program focuses on educating young people on questioning, reasoning, creating arguments, and collaborating with others (Trickey & Topping, 2004). P4C is a learning-to-think approach developed by American philosopher Matthew Lipman in the early 1970s (Vansieleghem & Kennedy, 2011). Lipman claimed that involving youngsters in philosophical debates may help them improve their thinking skills. He argues that by merging children's innate curiosity and willingness to learn about the world with philosophy, they may become more adaptable as well as effective and thoughtful persons (Trickey & Topping, 2004).

Alternative materials have emerged since Lipman's original materials were introduced. For example, Fisher and Cleghorn published a series of resources in the United Kingdom and Scotland, respectively (Cleghorn, 2002; Fisher, 1996). Various types of resources are now available in several languages. It should be noted that methods, such as "philosophy with children" are sometimes cited alongside the "P4C" method. However, these methods differ from the "P4C" (Naji & Hashim, 2017). To be accurate, this study reviewed only research with the designation "P4C," not similar methodologies.

The P4C approach is primarily designed for children aged 4-18 years. From the ages of 4 to 12, children acquire fundamental thinking abilities, and from the age of 12, they apply these skills to ethical, aesthetic, and societal issues (Garcia Moriyon et al., 2005). This program consists of clearly structured philosophical novels, accompanied by teaching manuals, each designed for a specific age group. In each story, children and teenagers engage in conversations about the philosophical aspects of their lives (Lipman, 1988), and these discussions are accompanied by a wide range of follow-up tasks, games, and discussion plans (Murris, 2016; Trickey & Topping, 2004).

P4C engages students in the development and investigation of issues and potential solutions. Throughout this educational approach, the facilitator and pupils are regarded as co-participants. The facilitator offers a stimulus (for example, a tale, a poem, a painting, or a sketch) to start a P4C session. Students are asked to create philosophical questions after having time to ponder this stimulation. Philosophical questions can be, for example, "What is fair?" " What qualities distinguish someone as a best friend?" and "What exactly does being good entail?" or other similar ones. To create a favorable environment for the development of thinking skills, facilitators should consider factors, such as establishing general principles beforehand, respecting each student's perspective, using non-threatening assignments, embracing individual diversity, and encouraging children to communicate actively (Gur, 2011). The goals of this educational method are attempted to be achieved through this process, including facilitating knowledge acquisition, empowering students to make independent decisions, enhancing reasoning ability, improving critical thinking, developing creativity, instilling ethical values, and raising self-awareness (Lipman, 1981; Marashi, 2008).

The program aims to engage students in exploring the philosophical aspects of their experiences, focusing on the logical, ethical, and aesthetic components. These philosophical constitutions are linked to thinking types, including critical (logic), caring (ethical), and creative (aesthetic) thinking (Garcia Moriyon et al., 2005). Critical, creative, and caring thinking are categorized into two main areas: Cognitive and affective. While critical and creative thinking is mostly cognitive, caring thinking is primarily affective (Bacanlı et al., 2011). Although these three types of thinking (critical, caring, and creative) are regarded as the three important "C" in P4C, some refer to collaborative thinking as the fourth "C" (Topping et al., 2019). However, in this study, we review only the three main types. It is also worth noting that P4C emphasizes the integration of all three types of thinking; the separation of thinking types and their related brain regions in the following text is for discussion purposes only.

3. Main Sets of Thinking Involved in P4C

Critical thinking

Numerous studies have shown that P4C promotes critical thinking (Daniel & Auriac, 2011; Falah Mehnehj et al., 2020; Işıklar, 2022; Karadağ & Demirtaş, 2018; Lomaca & Chiado, 2019; Marashi, 2008; Naseri et al., 2017; Rahdar et al., 2018; Wu, 2021; Yan et al., 2018; Zulkifli & Hashim, 2020). For instance, in 2020, Falah Mehneh et al. reported that applying the P4C method decreased negative metacognitive and irrational beliefs (Falah Mehnehj et al., 2020). However, what precisely is critical thinking? Critical thinking, also known as reflective thinking by certain authors, is a focused, reasoned, and purposeful approach. Critical thinking is a broad term with several definitions (Lai, 2011), but the most general definition is "analysis of facts to form a judgment." "Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. In its exemplary form, it is based on universal intellectual values that transcend subject matter divisions: Clarity, accuracy, precision, consistency, relevance, sound evidence, good reasons, depth, breadth, and fairness." As stated by Michael Scriven and Richard Paul at the eighth Annual International Conference on Critical Thinking and Education Reform in Summer 1987 (Michael Scriven, 1987).

Brain areas related to critical thinking

It has been suggested that the majority of the neurological basis of critical thinking is rooted in the neural foundations of the prefrontal cortex (PFC) (Sanz de Acedo Lizarraga et al., 2012). The PFC is well recognized for its role in executive functions, such as working memory, attention, sensory organization, reasoning, planning, goal-directed behavior coordination, and language processing (Davidson et al., 2006; Jurado & Rosselli, 2007; Miller, 2001; Miller & Cohen, 2001; Moriguchi & Hiraki, 2013; Uytun, 2018). The dorsolateral PFC (dlPFC) follows the hippocampus and retrieves information (declarative memory) along with the memories it contains (episodic memory). The results suggest a critical function for the dlPFC in updating established memories, most likely through its interplay with the hippocampus. The dlPFC creates and regulates higher-level processes, such as creativity, problem-solving, and decision-making, rather than transforming direct stimuli (Kirsch et al., 2006; Kluen et al., 2019; Lang et al., 2006; Luna et al., 2010; Stuss & Alexander, 2000). The ventromedial PFC, also known as the socioemotional cortex, is associated with the limbic system (LeDoux, 1996) and seems to be involved in decision-making, reasoning, and conflict resolution. However, it should be noted that the indicated relationships between these structures and psychological processes must be interpreted with caution because it appears that a widely accepted truth among neuroscientists that all critical thinking skills involve numerous brain areas (Sanz de Acedo Lizarraga et al., 2012).

In the process of neuroplasticity, the PFC is one of the cortical structures that takes the longest to mature (Arain et al., 2013). This process continues in the PFC region into the third decade of life but not in all parts of the frontal cortex (Arain et al., 2013). Many functional MRI (fMRI) studies have found that in school-aged children and adolescents, the relevant areas in the PFC exhibit age-related increases in activity as they mature (Kwon et al., 2002; Rubia et al., 2006; Tamm et al., 2002). The connections in this area become stronger each time a route is triggered by studying or applying knowledge (Kennedy, 2013; Owens & Tanner, 2017). The development of executive functioning is influenced by the improvement of these networks throughout the preschool years (Best & Miller, 2010).

Creative thinking

Creative thinking is one type of thinking that can be defined as "observing the same and thinking various," "the capacity to resolve aesthetic difficulties," "collecting the problems which were not put together in the past," "being sensitive to difficulties, concerns, lack of information, parts of the missing, non-compliance and recognize challenges, explore solutions and to make estimations" and "bringing unique answers to the daily difficulties" (Bacanlı et al., 2011). Therefore, people who study the arts are not the only ones who have creative minds; all prospective professions and circumstances require innovative thinking (Koontz, 2019).

Guilford, who coined the modern meaning of "creativity," differentiates between two types of creative thinking: Convergent and divergent thinking (Cropley, 2006). Convergent thinking is based on awareness of what is already known. Divergent thinking, on the other hand, involves generating several or alternative responses from given evidence. This necessitates the creation of unexpected combinations, the identification of relationships among distant associates, and the transformation of data into novel forms (Cropley, 2006).

Brain areas related to creative thinking

Creativity is a vital and complex human process that engages sophisticated areas of the brain, including the hippocampus (Beaty, 2020), frontal cortex (Fink et al., 2009), parietal lobe (Fink et al., 2009), and basal ganglia (Cavdarbasha & Kurczek, 2017). The hippocampus is critical for piecing together elements of experiences, including people, locations, things, and actions, to flawlessly recreate past experiences and create prospective future occurrences. The hippocampus is also fundamental not only in remembering but also in imagining the future (Beaty, 2020).

Fink et al. (2009) reported increased activity in the frontal cortex (the left hemisphere) and parietal lobes while coming up with innovative thoughts. Creative thinking refers to the ability to deviate from well-established, conventional concepts in novel and unpredictable contexts, and to develop alternative notions. From this perspective, creativity is a form of adaptation or problem-solving (Runco, 2004; Sternberg, 2006). According to this theoretical perspective, creativity is based on critical cognitive functions, including attention (Posner, 1994; Sarter et al., 2001), cognitive flexibility (Lhermitte, 1983; Lhermitte et al., 1986), abstract thinking (Rylander, 1948), planning (Norman & Shallice, 1986; Shallice & Burgess, 1991), and working memory (Baddeley, 1996; Fuster, 2000; Goldman-Rakic, 1992), which are largely dependent on PFC integrity (Dietrich, 2004). Imagination plays a crucial role in creative activities, such as brainstorming and daydreaming (Koontz, 2019). The posterior medial cortex (primarily the posterior cingulate cortex and parts of the precuneus), medial PFC (mPFC), and bilateral inferior parietal lobule, which expands to the posterior temporal region near the temporoparietal junction, lateral temporal cortex extending toward the temporal pole, and hippocampus and its adjacent areas in the medial temporal lobe are typically recognized as significant regions involved in imagination (Andrews-Hanna et al., 2010; Buckner et al., 2008; Shulman et al., 1997). The last region is the basal ganglia, which is involved in creativity as it interacts with affective, cognitive, and motivational functions (Greenberg, 2002). Also, numerous studies have been conducted to thoroughly study the brain regions associated with convergent and divergent thinking (Razoumnikova, 2000; Takeuchi et al., 2020).

Caring thinking

Caring can be considered a cognitive process that causes individuals to appreciate things (Shaari & Aswati, 2018). Caring thinking involves passionate and forceful reasoning, attention to oneself and others, and letting go of the claims' conclusiveness regarding various issues. This entails collaborating with others and delegating duties, rather than making decisions on their behalf (Ghaedi, 2016). Two principles can be highlighted in caring thinking: Understanding what we think and understanding how we think. Caring thoughts can be categorized into five types: Appreciative, emotional, active, normative, and empathic (Ghaedi, 2016). According to Lipman's perspective on caring thinking, encouraging individuals to develop a sense of humanism is an effective approach to teaching and learning guidance (Lipman, 2003; Shaari & Aswati, 2018). "To care is to focus on that which we respect, to appreciate its worth, to value its value. " To improve teaching appropriately and wisely, we must prioritize caring as much as creativity and critical thinking. Lipman emphasized the importance of considering the transactivity and interdependence of multidimensional thinking (critical, creative, and caring) in teaching since their integration leads to an equilibrium among emotional and cognitive capacities, mental and physical aspects, perceptual and conceptual processes, and commandment and non-commandment processes (Lipman, 2003).

Empathy, as one of the most discussed aspects of caring thinking, is described as a fundamental capacity to recognize and react to the emotional feelings of another, and the desire to care for their well-being (Decety & Lamm, 2006; Singer & Lamm, 2009). The concept of empathy is classified into three categories: Emotional empathy, also known as affective empathy, empathic concern (the drive to care for the well-being of others), and cognitive empathy. Emotional empathy refers to the capacity to experience another person's feelings, while cognitive empathy involves the ability to comprehend others' perspectives (Salavera et al., 2021).

Brain areas related to caring thinking

Research on brain regions associated with caring thinking is limited. Among all characteristics, empathy is the most researched feature. Empathy is controlled by a network of brain regions, including the brainstem, hypothalamus, amygdala, insula, striatum, orbitofrontal cortex, and anterior cingulate cortex (ACC), as well as the autonomic nervous system and neuroendocrine hormones (Decety, 2015). Reviewing a substantial amount of research using various methods, such as neuroimaging (fMRI) and positron emission tomography [PET]), electrophysiological, and lesion studies, Light et al. (2009) specified the roles of the dorsolateral and frontopolar regions of the PFC in empathy. According to Ruby and Decety (2004) and Singer et al., (2004) increased activity is observed in the frontopolar cortex and lateral PFC during the empathic process. Empathic concern responding is identified in newborns as young as 6-8 months old and continues as they grow older (Decety, 2015). Therefore, considering evidence of affective empathy at early ages, it appears that the regions associated with empathy may be modified from a very young age, and various contexts and training in these early years may represent significant changes in the related type of thinking at older ages.

4. P4C and Gender

According to Topping and Trickey's study, the P4C approach led to significant improvements in verbal cognition, as well as gains in nonverbal and quantitative reasoning abilities, which were consistent across schools and largely independent of the child's gender or ability (Topping & Trickey, 2007).

P4C has been shown to increase the moral, social, emotional, and intellectual aspects of thinking (Fisher, 2013; Zulkifli & Hashim, 2020), educational achievement (Gorard et al., 2017a; Leng, 2020a), cognitive ability (Topping & Trickey, 2008; Topping & Trickey, 2007), and reduce anxiety (Malboeuf-Hurtubise et al., 2021) and neglect in both boys and girls, with no significant differences. However, a study reported that P4C can improve girls' social and emotional dimensions more than boys' (Mehta & Whitebread, 2004).

However, many studies have been conducted on critical, creative, and caring thinking. For instance, some studies have demonstrated that girls outperform boys in certain critical thinking-related skills (Walsh & Hardy, 1999). In contrast, other studies have found that boys perform better (Bataineh & Zghoul, 2006). Some researchers have claimed that gender has no statistically significant impact on creative thinking (Agarwal & Kumari, 1982; Bromley, 1956). However, other studies have confirmed gender differences. Overall, gender differences in creativity are attributed to social, cultural, and environmental factors (Ai, 1999; Romo, 2018). These differences can result from gender stereotypes regarding certain abilities, such as mechanical aptitude and sports strategy, or from the varying amounts of social support provided to each gender (Baer & Kaufman, 2008; Kaufman, 2006). It is also proposed that these gender differences can be associated with various barriers perceived by each gender (Morais & Almeida, 2019) and genetic factors (Nakano et al., 2021; Vernon, 1989). Well-known gender stereotypes have a major impact on self-perceptions of creativity (Baer & Kaufman, 2008). However, limited research has been conducted on the interaction between caring thinking and gender. However,gender differences in subfields of caring thinking range from little evidence of gender differences in empathy in individuals experiencing personal distress to the dominance of girls' reactivity over boys' in sympathetic responses, depending on the type of indirect emotion evaluated (Eisenberg & Strayer, 1990).

Gender: A neuroscience perspective

Sex variations in different brain regions may explain certain disparities in behavior, cognition, disease risk, and even disease outcomes between girls and boys (Ruigrok et al., 2014). Sex differences cause variations in the development of some brain areas, notably the PFC, amygdala, and striatum, which are involved in controlling and performing motivated behavior (Hammerslag & Gulley, 2016). According to gender variations in the development of the amygdala, boys have shown a greater peak volume than girls, although this peak occurs later in puberty (Goddings et al., 2013). However, throughout adolescence, boys and girls may not vary in total amygdala volume (Blanton et al., 2010). As previously stated, a large-scale longitudinal study showed a linear association between white matter volume and age. According to these changes, girls showed a lower rate of volume increase than boys. In contrast, changes in cortical grey matter volume demonstrated a sex- and region-specific pattern. Grey matter in the frontal and parietal lobes reached a maximum size at the ages of 12.1 and 11.8 years, respectively, 13 and 18 months later in men, followed by a decrease during post-adolescence. The maximum volume in the temporal-lobe grey matter changes curve for boys was estimated to be approximately 16.5 years and 16.7 years for girls, with a modest decrease thereafter. Unlike other regions, changes in grey matter in the occipital lobe show a linear trend throughout the age period, with no signs of substantial decline (Giedd et al., 1999).

Although the absolute volume of cortical grey matter was approximately 10% greater in boys, it peaked marginally sooner in girls, aligning with an earlier age of puberty initiation, which suggests a probable role of gonadal hormones. The curve patterns of the volume-age chart did not vary significantly between boys and girls (Giedd et al., 1999). Other studies have also reported these gender variations in cortical remodelling during adolescence

(Hammerslag & Gulley, 2016). They reported that the overall pattern of cortical development showed that boys matured later and had larger volumes, thicknesses, and surface areas. However, this is not entirely correct in all areas (Raznahan et al., 2014).

Some studies have investigated gender differences in specific brain regions. According to Raznahan et al., girls had faster thinning in the right orbitofrontal cortex, which is associated with decision-making. Meanwhile, boys have a focal delay in the maturation of frontal basal and dorsolateral subregions, which are critical for inhibitory control and impulsivity, compared to girls (Raznahan et al., 2010).

In a cross-sectional study involving 118 healthy children and adolescents, boys displayed faster developmental rates, as indicated by the size of the corpus callosum (De Bellis et al., 2001). Altogether, since no statistically significant age-by-gender interactions were found, it was assumed that the age-related decline in boys and girls is similar (Koikkalainen et al., 2007).

Based on the majority of the previously mentioned studies, it appears that sex has no characterized effect on the outcomes of this education system. Nonetheless, some studies have indicated that girls outgrow boys in terms of socioemotional functioning and caring thinking. Changes in the amygdala or PFC, two brain regions associated with empathy and socioemotional characteristics, may underlie these outcomes. Given the significant correlation between age and gender, as well as biological variations between the sexes, applying this approach, considering sex differences at different ages, can contribute to making this method as effective as possible.

5. P4C and Age

While reviewing papers on P4C, we noticed that most articles, which were also mentioned in previous sections, focused on children in elementary school, with far less research focusing on upper secondary school students. According to Fair et al., (2015) the results of their replicated study on the impacts of the P4C program revealed a substantial difference in the beneficial effects of cognitive abilities between seventh- and eighth-grade primary pupils. Contrary to the seventh-grade experimental group students, who showed substantial progress compared to students in the seventh-grade control group, the eighth-grade experimental group students did not demonstrate comparable improvements compared to students in the eighth-grade control group. However, they justified this apparent difference in the number of P4C program sessions attended by each group. Altogether, it seems that both age and duration of program attendance should be evaluated independently.

Giménez-Dasí et al. (2013) enrolled 60 children aged 4-5 years in a 9-month P4C program to enhance social skills and emotional comprehension throughout early childhood. Unlike 5-year-old children, who improved in both emotion comprehension and social skills, 4-year-olds improved only in social skills related to implicit knowledge.

Friend and Zubek (1958) empirically demonstrated a dynamic rise in critical thinking capacity from late childhood to the mid-20s, followed by a steady drop into the seventies.

Diverse studies have revealed various results of changing in creative thinking at different ages, addressing different aspects of this type of thinking. A lifespan developmental study demonstrated age-related reductions in thought flexibility and response quantity (fluency), but no change in response quality (originality), in divergent thinking tasks (Jaquish & Ripple, 1985). Roskos-Evoldsen et al. used the creative invention task (CIT) and the Torrance tests of creative thinking (TTCT) to study age-related differences in creative thinking and reported age-related differences, particularly in the CIT. However, these differences were primarily due to variations in working memory performance. After accounting for working memory, they confirmed the equivalency in originality among younger and older participants on both the TTCT and the CIT tests (Roskos-Ewoldsen et al., 2008).

Age: A neuroscience perspective

Age-related brain changes may be effective in developing diverse outcomes through the P4C program and vice versa (Huelke, 1998). In the first five years following birth, the brain expands rapidly, reaching approximately 80% of its adult size by the age of two and approximately 90% by the age of five (Huelke, 1998; Kennedy et al., 2002). Also, analyzing the brain MRI of 116 healthy individuals suggested that the size of the brain peaks in early adolescence and subsequently diminishes (Courchesne et al., 2000). The connections or synapses between neurons continue to develop, generating a complex network of neural pathways (Trachtenberg et al., 2002). Pruning also occurs as synaptic development progresses (Kolb & Gibb, 2011). The human brain undergoes substantial synaptic pruning during childhood, with approximately 50% of its synapses lost by puberty

(Chechik et al., 1999). Of course, the synaptic pruning timetable varies based on the region. As in the visual and auditory perception-related areas of the brain, pruning is completed between the ages of four and six. In comparison, through adolescence, pruning occurs in regions connected to higher cognitive functions (like inhibitory control and emotion regulation) (Tierney & Nelson, 2009). Therefore, appropriately modifying synapses (removing the weaker synapses) is necessary to preserve function when synapses are being removed (Chechik et al., 1999).

Exclusively cross-sectional pediatric neuroimaging studies have demonstrated linear declines in cortical grey matter, while white matter increases between the ages of 4 and 20 (Caviness Jr et al., 1996; Giedd et al., 1996; Jernigan et al., 1991; Pfefferbaum et al., 1994; Reiss et al., 1996). However, a longitudinal MRI study reported nonlinear alterations in regionally localized cortical grey matter, which increased before preadolescence and decreased after preadolescence. They stated that the curves of cortical grey matter alterations peak around age 12 for the frontal and parietal lobes and around age 16 for the temporal lobe (Giedd et al., 1999). In 2004, Sowell et al. verified increases in grey matter thickness in the frontal language regions (i.e. Broca's area on the left) and the temporoparietal cortex (Wernicke's area on the left). Additionally, they reported grey matter thinning in the right frontal. They also noted grey matter thinning in the bilateral parietal and occipital correlation cortices (Sowell et al., 2004).

A cohort study on age-related alterations of the human brain (4–18 years) reported a linear increase in the relative volume of the left hippocampus and hippocampal region CA1 with age, but no differences in the relative volume of the right hippocampus were found (Sussman et al., 2016). According to Dennison et al., adolescent girls (12–18 years old) experience a greater decline in volume in the caudate, putamen, and thalamus than boys (Dennison et al., 2013).

In 2000, Thompson et al. reported a rostrocaudal wave of peak growth rates in the corpus callosum. They found that neural structure involved in language function and associative thinking expanded faster than nearby areas both before and throughout puberty (6-13 years), while expansion thereafter slowed (11-15 years), coinciding with the final point of a well-established substantial time for language learning (Thompson et al., 2000). The relative volumes of many subcortical subregions show inverted U-shaped patterns, reaching their peak at approximately of 12 years (Sussman et al., 2016).

In light of age-related changes in cortical and subcortical areas, it has been suggested that many regions that matured in childhood participate in fundamental sensorimotor processing, which is essential for the later development of cognitive processes (Luna et al., 2004; Simmonds et al., 2014). Most of the other regions that mature in adolescence are involved in motor response and executive functions, such as language, spatial attention, and working memory. This finding consistent with other results indicating that cognitive and executive functions continue to develop into adolescence (Bedard et al., 2002; Luna et al., 2004; Simmonds et al., 2014; Williams et al., 1999). According to the delayed maturation of some regions of intracortical white matter, as mentioned earlier, the development of basal ganglia regional termination zones proceeded throughout adulthood, forming loops with the cortex and serving as a major relay in cognitive and affective processes (Middleton & Strick, 2000). The prolonged development of these regions may verify the required wide cortical-subcortical connections for the integration of cognition and emotion (Simmonds et al., 2014).

Neurobiology of P4C implications in the neuroplasticity process

Considering that the P4C-related courses are age-appropriate, age-related changes in brain structures play a significant role in developing varied outcomes by employing this teaching technique at different ages. Education and experience can modify neural structure and function, which is a definition of neuroplasticity, and vice versa (Johnston et al., 2001; Mundkur, 2005). In the field of neuroeducation, one of the most critical aspects of an educational approach is the extent to which it engages with neuroplasticity.

Throughout one's personal life, the developing brain is exposed to a variety of factors and is capable of remarkable plasticity changes that have behavioral consequences. Among these influences are early experiences in motor, sensory, and language, as well as caregiver interactions and peer relationships (Kolb et al., 2017). Neuroplasticity reaches its highest level in the first few years of life and declines with age (Mundkur, 2005).

A systematic review concluded that experience-dependent interventions related to various environmental experiences (sensory-motor training (i.e. music or motor-based training) or cognitive-based (i.e. academic and behavioral intervention or social skills training) result in functional and structural neuroplastic changes in the human brain in children and adolescents (Weyandt et al., 2020). Human training studies have revealed MRI alterations that can be induced by changes in axonal growth and myelination, as well as changes in synapses and astrocytes (Tymofiyeva & Gaschler, 2020). Cognitive changes in children and adolescents have been reported to be closely associated with neuroplastic alterations, including changes in neural connectivity, neuronal activity in various regions, and enhanced cortical thickness in functionally relevant cognitive skill areas (Everts et al., 2017; Iuculano et al., 2015; Maximo et al., 2017; Meyler et al., 2008; Romeo et al., 2018). P4C, an educational approach that develops cognitive capacities, is effective in improving brain neuroplasticity in children and adolescents. Furthermore, it may ameliorate the cognitive consequences of early-life adversities. Early-life social adversities are unfavorable experiences that appear to be relevant in reducing the volume of the hippocampus and PFC in adolescence, resulting in the precocial creation of redundant, immature synapses by delaying the initiation of synaptic pruning (Miskolczi et al., 2019). Considering that brain circuits governing cognition and social behavior are highly plastic during early life, evidence suggests that childhood adversity may influence the expression of this mediator (Miskolczi et al., 2019).

Remarkably, there are specific times when learning and experiences have the greatest impact on the brain. Suppose, the exposure to these experiences does not occur during this time frame. In that case, a similar experience will have a reduced or sometimes no effect on making significant alterations in neural connections. For example, the first 6 years of life are crucial for natural language learning; beyond that, the intrinsic capacity to learn language decreases progressively, and after 12 years, it slows considerably (Mundkur, 2005). As P4C is an educational program designed for children and adolescents that impacts brain neuroplasticity, it may work in tandem with the puberty processes to improve neuroplasticity in brain areas involved in higher-order cognitive functions, such as episodic memory and executive functions.

Ultimately, according to the provided details regarding neurological changes at different ages, a more precise use of the P4C approach based on age-related educational needs may lead to improved outcomes in future endeavors.

6. P4C and SES

According to research, parental investments in children are among the most substantial parameters in improving children's skills in their early stages of development (Attanasio et al., 2020; List et al., 2018), but it has also been demonstrated that these investments vary depending on SES (Hoff, 2003; Huttenlocher et al., 2010; Kalil, 2015). Some studies indicated that the cognitive performance (including memory and executive functioning (Noble et al., 2007) of children from high-income households tends to be better than their classmates from lower-income (disadvantaged) families (Farah, 2017). Compared to their higher SES peers, they exhibit poorer behavioral performance in the fields of language and social-emotional development, with some indicators suggesting correlated neural variations (Ursache & Noble, 2016).

SES: A neuroscience perspective

Multiple differences in brain structure have been reported between children from different socioeconomic backgrounds. Left hemisphere regions (such as the left inferior frontal gyrus, left superior temporal gyrus, and left fusiform [language-associated regions]) (Jednoróg et al., 2012; Noble et al., 2015; Noble et al., 2012), hippocampus (memory-associated region) (Raffington et al., 2019), PFC (executive function-related cortex) (Noble et al., 2015), and the amygdala (socioemotional processing-related region) (Luby et al., 2013) are among these different brain structures. Furthermore, Ursache and Noble (2016) have reported that worse cognitive flexibility in children from low-income backgrounds is associated with their lower white matter volume or fractional anisotropy. However, Jednoro'g et al. found no significant correlation between SES and white matter design (Jednoróg et al., 2012). Additionally, several studies have found that children and teenagers from higher socioeconomic backgrounds possess thicker cortexes than those from less affluent backgrounds (Alnæs et al., 2020; Lawson et al., 2013; Leonard et al., 2019; Mackey et al., 2015).

In addition, age-related changes in the relationship between SES and cortical thickness have been reported. According to some studies, SES in young individuals aged 3-20 years modulates the negative interaction between age and cortical thickness in developmental stages. These results reveal that compared to young individuals from higher SES, youth from lower SES undergo a more dramatic curvilinear decline in cortical thickness earlier in life (Khundrakpam et al., 2019; Piccolo et al., 2016). In contrast, two recent studies examined youth aged 5-25 years (McDermott et al., 2019) and 14-19 years (Judd et al., 2020) and found no SES-directed relationships between age and cortical thickness.

Particularly, poorer memory performance and smaller hippocampal volume have been reported to be associated with lower family wealth in middle childhood, and these correlations have been demonstrated to be stable over time (Raffington et al., 2019). Also, individuals with low SES have been reported to be less likely to retain executive network activity from early to late age compared to those with high SES; however, there is a greater possibility of improved activity in their reward-related areas. Grey matter volume also showed similar activity. Moreover, the meta-analysis findings support the theory of hypoactivity in the fronto-parietal/cinguloopercular executive network and hypoactivity in the right caudate nucleus, as well as the impact of age on children from disadvantaged families (Yaple & Yu, 2019).

Building on P4C, a few studies have acknowledged the role of SES in the efficacy of the P4C program. Concerning cognitive abilities, Gorard reported that while disadvantaged students made fewer gains from P4C, they showed greater improvement in math, reading, and writing than their advantaged peers. More than 3000 pupils participated in this study at the outset, which is a considerable number (Gorard et al., 2017a). In another study involving more than 2700 pupils, Siddiqui showed that disadvantaged P4C students outperform their peers in terms of self-confidence, empathy, sociability, communication, collaboration, resiliency, and social responsibility (Siddiqui et al., 2019). They also presented a modest advantage in terms of happiness, self-reported resiliency, and not being afraid to try new things. In this study, the first survey was conducted for the P4C group, and a follow-up survey was conducted 6 months later for the control group. Therefore, the P4C group was, on average, 6 months younger than the control pupils at the time of the first survey. Although the second survey included both groups of the same age, a six-month age difference may be critical for the outcomes. Therefore, there is room for discussion regarding children's brain development, especially at this age. In a study examining the effectiveness of P4C on critical thinking skills of preschool children (5 and 6 years old), it was shown that after the P4C intervention, the private school students scored better in terms of "question formation," "language and cognitive skills" and "general total" than the state school students. This might be due to the differences in SES between these two groups (Karadağ & Demirtaş, 2018).

A meta-analysis study has shown no significant difference in the effectiveness of P4C on pupils' cognitive outcomes between the two groups of high and low-SES pupils (Yan et al., 2018). This article examined research published from 2002 to 2016, and the data are insufficient to reach this conclusion. Altogether, according to two other recently discussed studies with large sample sizes, a relationship is observed between P4C and SES.

Advantaged pupils have improved more than disadvantaged pupils in a short period since the beginning of the classes; however, in the long term, disadvantaged pupils, on average, have shown greater improvement than advantaged pupils. This hypothesis should be investigated. The financial costs of the P4C program are one of the factors that prevent further research on this aspect from being conducted.

7. Conclusion, Limitations, and Future Directions

P4C is a contemporary educational strategy that, according to data, has a significant influence on children's cognition, emotions, and abilities. This educational program, like every other, both advantages and limitations (Colom et al., 2014). What is evident is that more research is required to investigate the more detailed effects of this program. However, reviewing the findings of previous studies suggests that the majority of the program's effects are at least partly due to some effects on the nervous system. The adoption of different educational programs tailored to various age groups, which can affect neuroplasticity, the ability to change the brain's structure and function, also supports this idea (Torrijos-Muelas et al., 2021).

Here, we attempted to evaluate the influence of the P4C educational approach on various situations and groups. According to most of the studies mentioned above, gender does not significantly impact the results of this educational method. However, some studies have shown that caring thinking and socioemotional dimensions progress more in girls than boys. This result may be attributed to changes in brain areas associated with empathy and socioemotional features, such as the amygdala or the PFC.

Additionally, due to the scarcity of research explicitly focusing on the effects of children's age on P4C, we could not verify any noteworthy effects of children's age on P4C outcomes. However, the outcomes cannot be regarded as age-independent, since age is considered in the instructional content of this program. Furthermore, given the prominence of neuroplasticity in the age groups mentioned above, an attempt was made to assess the degree of concordance of this educational program with critical ages in neuroplasticity as much as possible. Given the significant changes in the function and structure of many brain areas during the schoolage years, training programs adapted to these changes can significantly enhance educational outcomes.

From a socioeconomic perspective, P4C has diverse effects on children depending on their SES. In each of these SES categories, certain factors improved more significantly than others, although a strict conclusion cannot be drawn yet due to the limited number of studies.

It is worth mentioning that, alongside the promising findings about the P4C educational method, there are also challenges and limitations that both pupils and educators should address and improve. In implementing P4C, pupils may face challenges, such as a lack of interpersonal skills (Leng, 2020b) and insufficient knowledge (Cassidy & Heron, 2020). Also, educators may encounter obstacles, including classroom management (Gorard et al., 2017b; Rahdar et al., 2018; Siddiqui et al., 2019), optional methods (Gorard et al., 2017b; Siddiqui et al., 2019), and a shortage of ideas (Gorard et al., 2017b). P4C-related challenges have been extensively discussed in several studies, and further exploration could be the focus of future research (Ab Wahab et al., 2022; Farahani, 2014).

Finally, the impacts of gender, age, and economic conditions all appear to combine to affect the outcomes of P4C. Although there is evidence that this educational method influences several mental and behavioral features of children, more extensive studies concentrating on SES, age, and gender can evaluate the accurate efficacy of P4C. The intention is to develop a common language among neuroscientists, educational researchers, and educators, so that research directions can be developed and translated into practical instructional applications (Ansari et al., 2012). By describing different types of translation and applying a levels-of-organization framework, research and practice can be contextualized and guided more effectively (Horvath & Donoghue, 2016). It is crucial to note that establishing hypotheses about learning in everyday situations necessitates merging knowledge from neuroscience with insights from other fields (Jolles & Jolles, 2021).

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Conceptualization: Fariba Khodagholi, Maryam Alsadat Mousavi, and Fereshteh Khodagholi; Supervision: Fariba Khodagholi and Leila Dargahi; Data curation: Maryam Alsadat Mousavi, Leila Dargahi, Solmaz Khalifeh, Roohollah Karimi, and Yahya Ghaedi; Investigation: Shakiba Salarvandian, Fatemeh Vosoughian, Mobina Javadi, Fereshteh Khodagholi and Shima Barzin; Writing the original draft: Shakiba Salarvandian, Fatemeh Vosoughian, Mobina Javadi, and Masoud Seddighfar; Review and editing: Fariba Khodagholi, Maryam Alsadat Mousavi, and Leila Dargahi; Final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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