Proceedings of ICEIPI 2026 Symposium: Inclusive Education, Cultural Transformation, and the Ethical Dimensions of Learning
DOI: 10.54254/2753-7048/2026.LD35702

The Role of Metacognitive Instruction in Adolescents' Transition to Abstract Thinking

Xinhuan Zhang

College of Education, Shanghai Normal University, Shanghai, China
xinz29562@gmail.com

Abstract. Adolescence is widely recognized as a critical stage in cognitive development, during which individuals gradually undergo a transition from concrete, experience-based reasoning to more abstract, logical, and systematic thinking, which is essential for advanced learning across academic domains. However, this developmental shift is not always fully achieved in a stable manner, and many adolescents still fail to develop consistent abstract reasoning abilities, which may hinder their academic performance and higher-order problem-solving. Metacognition has been identified as a key factor supporting higher-order thinking and learning. This paper, through a literature review, explores how metacognitive instruction facilitates adolescents' transition to abstract thinking, with a particular focus on the Cognitive Acceleration through Science Education (CASE) project. The study investigates the ways in which metacognitive methods impact cognitive development, drawing on developmental psychology, neuroscience, and empirical educational research. The findings indicate that planning, monitoring, and evaluation significantly enhance reasoning ability, problem-solving skills, and learning transfer. The study concludes that integrating metacognitive instruction into classroom practice provides an effective and practical approach to promoting adolescents' cognitive development and supporting their progression toward formal operational thinking.

Keywords: Metacognitive instruction, abstract thinking, adolescents, self-regulated learning

1. Introduction

Piaget's theory identifies early adolescence as a key transitional stage toward formal operational thinking [1]. During this period, individuals gradually acquire the ability to reason abstractly, formulate hypotheses, and engage in systematic problem-solving. However, research has shown that not all adolescents naturally reach a stable level of formal operations; many students still rely heavily on concrete experiences and surface features when learning abstract concepts [1]. This suggests that instructional support is as important as biological maturation.

Neuroimaging studies have revealed that the rostrolateral prefrontal cortex (RLPFC), a brain region critical for relational integration and abstract reasoning, undergoes prolonged structural and functional maturation throughout adolescence and into early adulthood [2]. The RLPFC facilitates the integration of abstract, self-generated ideas, and during adolescence, its functional specialization, especially for relational integration, continues to grow. The extended period of neural malleability

DOI: 10.54254/2753-7048/2026.LD35702

implies that thoughtfully planned teaching strategies may work together with natural brain maturation to support the development of abstract reasoning.

In recent decades, educational psychology has increasingly focused on metacognition as a key factor in higher-order thinking. Flavell originally coined the term "cognition about cognition" to describe metacognition, meaning the capacity to observe, interpret, and direct one's own thinking [3]. Metacognitive strategies such as planning, monitoring, and evaluating help learners manage their cognitive activities. Paris and Paris have shown that students who are taught to reflect on what they are learning and how they are learning perform better in tasks requiring reasoning and conceptual transfer [4]. Large-scale meta-analyses have confirmed that metacognitive teaching strategies have a significant positive impact on students' academic performance [5]. These findings suggest that metacognition is not merely a subsidiary skill but a core facilitator of abstract thinking.

This paper employs a literature review method to investigate how metacognitive instruction can support adolescents' transition to abstract thinking. By synthesizing existing theoretical frameworks and empirical studies, the paper analyzes the relationship between metacognition and abstract thinking, presents a case study of a successful metacognitive intervention (the CASE project) [6], and discusses the implications for educational practice. The findings of this research have practical value. They can direct curriculum creation and classroom instruction, which helps teachers better assist adolescents' cognitive growth.

2. Literature review

2.1. Piaget's theory and the challenge of abstract thinking

Piaget's theory posits that children aged 7 to 11 are in the concrete operational stage, where logical reasoning depends on tangible objects and direct experiences [1]. After the age of about 11, individuals should enter the formal operational stage, when they can carry out abstract reasoning, hypothetical thinking and systematic problem solving. However, subsequent research has revealed that many adolescents and even adults do not fully attain or consistently use formal operational thinking. The National Academies of Sciences, Engineering, and Medicine have highlighted that socioeconomic disparities, discrimination, and lack of access to supportive learning environments can severely curtail adolescents' cognitive development [7]. This gap indicates that cognitive development is not solely determined by biological maturation; instructional methods and learning experiences play a crucial role.

Neurodevelopmental research points to RLPFC maturation as a key factor underlying the ability to think abstractly. Dumontheil reviewed evidence showing that this region supports the integration of self-generated, abstract thoughts, and that its functional specialization continues to increase during adolescence [2]. This suggests that instructional interventions targeting metacognitive processes may interact with ongoing neurodevelopmental changes to facilitate abstract thinking. To grasp abstract concepts, learners must first assemble separate pieces of information into coherent mental frameworks. If this process is not explicitly supported, many students will continue to think only in concrete terms.

DOI: 10.54254/2753-7048/2026.LD35702

2.2. Metacognition

2.2.1. Definition and components of metacognition

Flavell defined metacognition as the knowledge and regulation of one's own cognitive processes [3]. Metacognition is commonly divided into three components: planning (e.g., goal setting, predicting difficulties), monitoring (e.g., self-testing, checking comprehension), and evaluation (e.g., reflecting on outcomes, adjusting strategies). Brown was among the first to elaborate on these regulatory processes [8]. Schraw and Moshman further distinguished between metacognitive knowledge (declarative, procedural, and conditional knowledge about learning) and metacognitive regulation (the online control of learning processes) [9].

Recent empirical work by Chidley and colleagues demonstrated that individual differences in metacognitive ability among adolescents aged 11 to 15 predict their spontaneous adoption of strategies to enhance cognitive flexibility, such as allocating more preparation time to more demanding tasks [10]. These findings indicate that metacognitive regulation is an observable and measurable ability rather than a purely theoretical construct, which learners can flexibly apply in learning contexts.

2.2.2. Metacognition and abstract thinking

Several studies have established a positive correlation between metacognitive ability and abstract reasoning performance. Veenman and colleagues conducted a comprehensive review and found that students who received systematic metacognitive training significantly outperformed untrained controls in complex problem-solving and higher-order cognitive tasks [11].

Abstract thinking requires learners to identify gaps in understanding, generate alternative possibilities, and evaluate the consistency of reasoning. Each of these processes is inherently metacognitive in nature.

Furthermore, Cornaggia and colleagues explored the relationship between theory of mind (ToM), a specific form of metacognitive reasoning about mental states, and definitional competence in adolescents aged 14 to 19 [12]. They found that ToM performance predicted the ability to define non-emotional mental state words, suggesting a specific link between metacognitive understanding of others' minds and metalinguistic abstraction.

Overall, these findings suggest that metacognition is not merely an accompaniment to abstract thinking but a key cognitive foundation supporting its development.

2.3. Research gap

Despite the evidence above, there remains a clear gap between cognitive development theory and actual adolescent performance. Piaget's theory predicts that by around age 11, individuals should enter the formal operational stage, capable of abstract reasoning [1]. However, many adolescents and even adults fail to consistently achieve this level of thinking.

The National Academies have emphasized that socioeconomic disparities and lack of supportive learning environments can significantly restrict cognitive development [7], suggesting that instructional conditions matter alongside maturation. Neurodevelopmental evidence indicates that RLPFC maturation supports abstract thinking and continues through adolescence [2], implying that appropriate instructional strategies may align with brain development. Without explicit support, many learners remain at concrete reasoning.

DOI: 10.54254/2753-7048/2026.LD35702

Although interventions such as the CASE project [6] and meta-analyses [5] demonstrate the effectiveness of metacognitive instruction, there is still a need to clarify how specific metacognitive processes contribute to adolescents' transition to formal operational thinking across different educational contexts.

3. Case analysis: the CASE project

To illustrate how metacognitive instruction works in practice, this section analyzes the Cognitive Acceleration through Science Education (CASE) project, a well-documented intervention aimed at developing adolescents' abstract thinking [6].

3.1. Program design

The CASE project was designed for students aged 11 to 13 and implemented in science classrooms. Instead of teaching additional content, CASE lessons focused on thinking processes. Each lesson followed a five-step structure. First, concrete preparation activated prior knowledge through hands-on activities. Second, cognitive conflict presented problems that could not be solved by routine methods, prompting a state of disequilibrium. Third, social construction encouraged small-group discussion to share and debate strategies. Fourth, metacognitive reflection guided students to verbalize and evaluate their thinking processes. Fifth, bridging explicitly connected the thinking strategies used to other subjects and real-life situations.

3.2. Implementation and outcomes

The program was delivered over two years, with approximately one lesson every two weeks. A large-scale evaluation involving over 1,000 students compared CASE participants with control groups. Results showed that CASE students made significant gains in abstract reasoning tests (e.g., Piagetian formal operations tasks) and performed better in national science and mathematics examinations at age 16. Long-term follow-up studies indicated that the effects persisted, with CASE students choosing more advanced science courses and achieving higher grades [6].

Key features of the CASE project include its focus on early adolescents (11-13 years), its embedding in science instruction with bridging to mathematics and everyday reasoning, its core mechanisms of cognitive conflict, metacognitive reflection, and social construction, its low frequency (about one lesson every two weeks), and its long-term outcomes of improved abstract reasoning and academic achievement.

3.3. Why CASE works: a metacognitive explanation

The success of CASE can be attributed to its explicit emphasis on metacognitive processes. By asking students to reflect on "How did we solve this" and "What if we tried another approach," the program trains students to monitor and evaluate their own thinking. The bridging component further promotes transfer, a hallmark of abstract reasoning. Moreover, cognitive conflict creates a need for metacognitive regulation: when familiar strategies fail, learners must consciously revise their approaches. In line with meta-analytic findings, CASE combines multiple metacognitive strategies, which explains its large effect size [5]. Thus, CASE exemplifies how metacognitive instruction can be systematically embedded into subject teaching without adding extra content.

DOI: 10.54254/2753-7048/2026.LD35702

4. Discussion

4.1. Mechanisms linking metacognitive instruction to abstract thinking

Traditional teaching often assumes that presenting abstract concepts explicitly (e.g., through definitions and examples) is sufficient for students to internalize them. Many students stay at the concrete level without metacognitive support; they can memorize definitions but cannot apply concepts in novel contexts. Metacognitive instruction shifts focus from teacher-led transmission to learner-led regulation, embedding reflective questions into existing lessons. The CASE project showed that a modest frequency (one lesson every two weeks) can produce lasting cognitive gains when lessons are designed metacognitively [6].

Metacognitive instruction facilitates thinking through three mechanisms. First, planning—defining objectives, decomposing activities, and anticipating challenges—aids adolescents in tackling complex issues crucial for hypothetical-deductive reasoning. Second, monitoring allows learners to detect deviations in real time, prompting them to re-examine hypotheses or find other strategies, resembling hypothesis testing in formal operations. Third, evaluation consolidates successful strategies and modifies ineffective ones, enabling transfer.

The developing RLPFC, which integrates abstract relational information and exhibits greater functional specialization during adolescence, supports these processes. Adolescents with higher metacognitive ability devote more preparation time to demanding tasks, enhancing cognitive flexibility—a core component of abstract thinking. Moreover, Odejimi and Clark found that explicit metacognitive training contributes positively to cognitive competence and self-efficacy [13]. Thus, metacognitive instruction not only enhances abstract thinking but also fosters broader positive outcomes.

4.2. Implications for educational practice and equity

For classroom teachers, simple strategies can be introduced gradually: before a lesson, ask students to set a goal and predict difficulties; during a lesson, use think-pair-share with prompts like "How are you solving this?"After a lesson, assign a one-minute reflection log on what worked and what to change.

For curriculum designers, the CASE model suggests that embedding metacognitive activities within existing subjects is more effective than stand-alone "thinking skills" courses. Professional development should train teachers to model their own thinking.

Neurodevelopmental evidence supports these strategies. The RLPFC matures throughout adolescence and is influenced by educational experiences [2]. Thus, early to middle adolescence (ages 11-15) may be a particularly impactful window for metacognitive instruction.

Structural and social inequalities must also be considered. The National Academies have highlighted that socioeconomic disparities, discrimination, and lack of supportive learning environments can severely curtail cognitive development [7]. Therefore, implementing metacognitive instruction in under-resourced schools is both a pedagogical improvement and an equity imperative.

5. Conclusion

This study aimed to investigate how metacognitive instruction supports adolescents' transition to abstract thinking. Through a literature review and analysis of the CASE project, the findings indicate

DOI: 10.54254/2753-7048/2026.LD35702

that metacognitive strategies—planning, monitoring, and evaluation—effectively facilitate abstract reasoning, hypothesis testing, and learning transfer. The hypothesis that metacognition plays a causal role in formal operational thinking is supported, as metacognitive instruction helps learners move beyond concrete experiences by making cognitive processes explicit and controllable.

This study bridges cognitive developmental theory and metacognitive instruction, demonstrating that metacognitive reflection is a teachable mechanism supporting adolescents' transition to abstract thinking. The neurodevelopmental plasticity of the RLPFC supports this process. From a practical perspective, teachers can integrate low-cost strategies such as learning logs and guided questioning into daily instruction, while curriculum design should embed metacognitive processes within subject teaching, as illustrated by the CASE project.

The findings should be interpreted in light of several limitations. First, the study relies on previously published research rather than primary empirical data, which may limit causal inference. In addition, most reviewed studies were conducted in Western contexts, restricting generalizability. As noted by Odejimi and Clark, inconsistencies in metacognition measurement and limited attention to socio-emotional dimensions remain important gaps.

Future research should examine how metacognitive instruction operates across different cultural and educational contexts, and develop more ecologically valid measures of abstract thinking. Building on this review, the author plans to conduct a classroom-based empirical study to investigate whether specific metacognitive strategies directly impact adolescents' abstract reasoning abilities.

Overall, this study highlights the importance of teaching students how to think, not just what to think, and demonstrates that structured metacognitive instruction can meaningfully support adolescents' transition toward abstract reasoning.

References

[1] Piaget, J., & Cook, M. (1952). *The origins of intelligence in children*. International Universities Press.

[2] Dumontheil, I. (2014). Development of abstract thinking during childhood and adolescence: The role of rostrolateral prefrontal cortex. *Developmental Cognitive Neuroscience, 10*, 57–76.

[3] Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist, 34*(10), 906–911.

[4] Paris, S. G., & Paris, A. H. (2003). Classroom applications of research on self-regulated learning. In *Educational Psychology* (pp. 89–101). Routledge.

[5] Shi, L., Zheng, Z., Zheng, X., & Liu, D. (2023). The effects of metacognitive teaching on student academic performance: A meta-analysis of experimental or quasi-experimental studies in past 20 years. *Global Education, 52*(9), 62–71.

[6] Adey, P., Shayer, M., & Shayer, M. (2006). *Really raising standards: Cognitive intervention and academic achievement*. Routledge.

[7] National Academies of Sciences, Engineering, and Medicine. (2019). *The promise of adolescence: Realizing opportunity for all youth*. The National Academies Press.

[8] Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65–116). Lawrence Erlbaum.

[9] Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review, 7*(4), 351–371.

[10] Chidley, K., Dux, P. E., Fox, A. J., Carroll, A., MacMahon, S., & Matthews, N. (2025). Adolescent metacognitive ability predicts spontaneous task strategy adjustment. *Journal of Experimental Psychology: Human Perception and Performance, 51*(5), 601–611.

[11] Veenman, M. V. J., Van Hout-Wolters, B. H. A. M., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and Learning, 1*(1), 3–14.

[12] Cornaggia, A., Bianco, F., Castelli, I., & Belacchi, C. (2024). Assessing metarepresentational abilities in adolescence: An exploratory study on relationships between definitional competence and theory of mind. *Frontiers in Psychology, 15*, 1456432.

DOI: 10.54254/2753-7048/2026.LD35702

[13] Odejimi, O. A., & Clark, L. F. (2025). Metacognition and the 5Cs of positive youth development programs: A review of metacognitive interventions. *Journal of Youth Development, 20*(1), 46–62.