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Cognitive neuroscience and socio-emotional skills

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ABSTRACT: The average length of an individual's education has grown over time, driven by the promise of improving a person's job prospects and, consequently, their quality of life. However, several behavioural studies report that most skills needed to enhance job prospects are learned not in school but on the job. Related research also highlights the critical role of socio-emotional skills in human capital development. Nevertheless, researchers claim that there is a need for better measurement of such skills. Cognitive neuroscience research may play a pivotal role in addressing this gap by providing explanatory mechanisms and objective metrics, as well as by inspiring innovative human capital interventions. This review highlights how integrating socio-emotional neuroscience data into educational settings can improve individual and societal well-being.

Keywords: Cognitive neuroscience, Education, Socio-emotional skills, Human capital, Neuroscientific methods.

1.0 INTRODUCTION

Over the past 50 years, the average time devoted to education has tripled, driven by expectations of improved economic outcomes and quality of life (Hausman, 2015). Education generally enhances productivity and creativity, fosters entrepreneurship, and promotes technological innovation—all of which contribute to higher output and economic growth. However, most practical skills are not acquired in school but through work experience (Hausman, 2015). For example, adolescent academic test scores explain only about 15% of the variation in adult earnings (Heckman, 2013). Moreover, skill assessments—often based on self-reported tests—are susceptible to bias. Here, neuroscience offers valuable insights into how human capital develops. Applied cognitive neuroscience, in particular, can help clarify the origins of the skills gap and guide the design of interventions to strengthen human capital (Meewisse et al., 2007; Dessus, 2016; Durlak, 2011).

This challenge is critical because traditional economic indicators such as salary or occupational choice, long assumed to drive economic growth, have shown inconclusive results. Therefore, applied research on learning and human capital should explore new ways in which educational neuroscience can enhance the efficiency of human capital formation (Davidesco, 2021). Even a basic understanding of educational neuroscience can improve how teachers teach and how children's brains consolidate learning.

Addressing these challenges requires an interdisciplinary approach. Evidence from cognitive neuroscience shows that naps, breaks, nutrition, aerobic exercise, individualised instruction, and other environmental factors enhance academic performance (Sigman et al., 2014). Importantly, protecting socio-emotional brain networks helps individuals manage social adversity, fostering emotionally regulated adults with richer behavioural repertoires.

This gap presents an opportunity to harness neuroscientific findings to deepen our understanding of how improved educational outcomes can enhance both professional success and personal well-being. We begin by discussing socio-emotional skills through the lenses of cognitive neuroscience and social psychology in educational contexts. We then explore recent findings in educational neuroscience, focusing on practical strategies for teachers. Our goal is to reignite the conversation about how social skills, brain development, and academic performance are essential elements of human capital formation—with particular emphasis on the pivotal role of teachers.

2.0 METHODOLOGY

This mini-review was conducted following a structured narrative approach to synthesise interdisciplinary evidence at the intersection of cognitive neuroscience, socio-emotional skill development, and educational research. The objective was to identify neuroscientific methods that contribute to the understanding, assessment, and promotion of socio-emotional and cognitive skills relevant to human capital formation.

Between January and October 2024, we performed a targeted literature search across major scientific databases, including Web of Science, PubMed, PsycINFO, Scopus, and Google Scholar. Search terms included combinations of: "Cognitive neuroscience", "educational neuroscience", "socio-emotional skills", "human capital", "learning", "teacher–student neural synchrony", "EEG in classrooms", "eye tracking education", "cortisol learning stress", "oxytocin social learning", "neuroeconomics education", "emotion regulation training", "neural markers of learning". We also screened the reference lists of highly cited reviews and empirical papers to identify additional key studies.

3.0 SOCIO-EMOTIONAL SKILLS

Socio-emotional skills and academic achievement are deeply interconnected, each influencing and reinforcing the other throughout development. Evidence shows that these skills are not only predictors of academic outcomes but also of broader life trajectories (Caemmerer, 2015; Murray-Harvey, 2010). For instance, children who experience peer rejection are more likely to drop out of school (Kupersmidt, 1990; Parker, 1987), face unemployment in adulthood (Woodward, 2000), become victims or perpetrators of bullying (Murray-Harvey, 2010), and even engage in delinquent behaviour (Parker, 1987). Likewise, poor academic achievement predicts similarly adverse long-term outcomes (Barrington, 1989; Tainturier et al., 1992). The relationship between social skills and academic success is thus bi-directional and malleable (Walbrin et al., 2018; Caemmerer, 2015), making it a promising framework for early interventions that promote both learning and well-being.

Building on this foundation, economic and developmental research has emphasised the role of specific skill sets in shaping personal and professional success (Bowles, 2001; Heckman, 2006, 2007). Within the human capital framework, learning can be understood through two broad categories:

Cognitive skills—including attention, memory, language, mathematical reasoning, working memory, inhibition, cognitive flexibility, and higher-order thinking.

Socio-emotional skills—encompassing motivation, cooperation, trust, theory of mind, and emotional regulation in interpersonal contexts.

Understanding how these skills interact to influence economic outcomes—such as occupational choice, productivity, and income—has become increasingly central to human capital theory (Heckman, 2013). However, this growing interest also exposes a significant methodological challenge: how to measure these skills accurately.

Traditional assessments of socio-emotional skills rely on self-report questionnaires (e.g., the Big Five Inventory, Grit Scale, or Rosenberg Self-Esteem Scale) and teacher or parent ratings, which are often influenced by social desirability bias, cultural norms, and subjective interpretation. Cognitive skills, in turn, are typically measured through standardised achievement tests that may neglect creativity, emotional engagement, and contextual problem-solving. Consequently, these instruments only partially capture the complexity of real-world learning and adaptation.

This measurement error has serious implications. When proxies for cognitive or non-cognitive skills are unreliable, research and policy conclusions become distorted, leading to ambiguous evaluations of educational and social programs and, at times, misidentification of the most effective interventions (Heckman, 2013). Notably, qualitative evidence from interviews and focus groups often indicates significant socio-emotional gains from programs that quantitative psychometric tests fail to detect (Calero, 2017).

To address these limitations, cognitive neuroscience offers a promising complementary perspective. By observing neural and physiological indicators—such as attention-related EEG activity, emotional regulation networks, or pupil dilation—researchers can uncover objective markers of skill development that traditional instruments overlook. This integrative approach can help build predictive frameworks linking socio-emotional and cognitive skills to later job performance, productivity, quality of life, and economic outcomes. Importantly, it also supports early intervention strategies that strengthen human capital formation from the earliest stages of education.

4.0 COGNITIVE NEUROSCIENCE IN EDUCATIONAL ENVIRONMENTS

Identifying the neural substrates of learning remains challenging because the relationship between the brain and learning is reciprocal: learning modifies brain structure and function (Dehaene-Lambertz, 2018; Gouet, 2018), while brain organisation also shapes learning capacity (Borst, 2016). Recent advances in non-invasive and minimally invasive techniques have greatly enhanced our ability to study these processes, providing new tools to assess socio-emotional skills and cognitive development. These methods not only deepen our understanding of learning mechanisms but also have practical implications for education and human capital development.

Neuroscientific methods can be broadly grouped into four categories: (1) non-invasive techniques, such as EEG, MEG, fMRI, and eye tracking; (2) semi-invasive biochemical measurements of endogenous substances; (3) invasive or interventional methods, such as pharmacological and neurostimulation approaches; and (4) specialised interdisciplinary fields such as neuroeconomics, which integrate neuroscience and behavioural economics.

4.1 Non-invasive techniques

4.1.1 Electromagnetic and neuroimaging methods: EEG, MEG, and MRI

Principles.
Electroencephalography (EEG) and magnetoencephalography (MEG) record brain electrical and magnetic activity, offering millisecond temporal resolution. In contrast, magnetic resonance imaging (MRI) provides high spatial resolution for studying brain structures and functional connectivity.

Application in education.
EEG has become increasingly portable, enabling in-classroom studies of teacher–student neural coordination. Davidesco (2021) used wireless EEG to record brain activity in teacher–student and student–student dyads during lectures. In this observational classroom study, EEG synchrony predicted students' test performance one week later, highlighting the neural basis of social learning.

Strengths and limitations.
These methods capture brain dynamics during authentic learning experiences and link them to behavioural outcomes. However, EEG signals are sensitive to movement artefacts, and MRI studies are typically conducted in artificial settings, which limits ecological validity.

4.1.2 Eye tracking

Principles.
Eye tracking records gaze position and movement over time, mapping where attention is directed. It provides automatic, fine-grained indicators of visual attention and cognitive load.

Application in education.
In classroom contexts, eye tracking allows simultaneous observation of teacher and student gaze patterns. Dessus (2016) demonstrated that teachers' and students' gaze coordination predicts the quality of comprehension. In a guided inquiry science course, Rosengrant et al. (2021) conducted an observational study on attention spans, finding that contrary to the widespread belief that attention drops after 10–15 minutes, structured lessons with frequent interactions maintained students' vigilance throughout entire class sessions.

Strengths and limitations.

Eye tracking offers high temporal precision and direct indicators of attentional focus, but it cannot capture internal states like motivation or emotion. It is most effective when combined with EEG or self-report data.

4.2 Semi-invasive techniques

4.2.1 Measurement of endogenous substances

Principles.

Learning and social adaptation involve physiological responses measurable through endogenous biomarkers, such as cortisol (stress), oxytocin (social bonding), and related compounds. These are typically assessed through saliva samples, offering a minimally invasive window into the neuroendocrine basis of learning.

Application in education.

Acute stress assessments have shown that moderate increases in cortisol enhance memory encoding, whereas high levels impair retrieval (Andreano, 2006). Salmurri Trinxet and Skoknic Cvitanic (2003) implemented an emotional education program for primary school teachers in Barcelona. After training, teachers exhibited improved self-esteem, self-control, and interpersonal skills, which in turn enhanced their students' academic outcomes.

Strengths and limitations.

Biomarker measures provide objective indices of stress and emotion regulation, but results often vary by personality, gender, and baseline stress levels. Such variability reduces predictive power in group analyses and calls for longitudinal, within-person designs.

4.3 Invasive or Interventional Approaches

4.3.1 Psychopharmacological manipulations and brain stimulation

Principles.

Pharmacological interventions target neurotransmitter systems involved in attention, motivation, and emotion. Examples include modafinil, which enhances alertness, and tryptophan, a serotonin precursor influencing mood and cognition.

Application in education.

Battleday (2015) found that modafinil administration in healthy adults transiently improved mood and cognitive performance. In animal studies, Nardou et al. (2019) reported that oxytocin administration reopened a critical period for social reward learning, suggesting potential interventions for socio-emotional skill development.

Strengths and limitations.

While such methods reveal causal links between neurochemistry and learning, they are ethically and medically complex, as manipulating a single cognitive function can produce broad, long-lasting changes in brain organisation. Therefore, these studies are primarily exploratory and rarely applied in educational settings.

4.4 Specialised field: neuroeconomics

Principles.

Neuroeconomics combines neuroscience, psychology, and economics to study how the brain makes decisions under conditions of risk, reward, and uncertainty (Glimcher, 2013; Woodford, 2014).

Application in education and human capital.

Egana del Sol (2016) conducted a lab-in-the-field experiment evaluating entrepreneurship programs designed to strengthen emotional regulation and socio-emotional skills. Using EEG and survey data from adult participants, the study found: a significant reduction in dropout rates (program impact). Improved emotional regulation, reflected in decreased EEG valence indices (left vs right alpha/beta power) during emotional video tasks. These findings suggest increased resilience and adaptive emotion processing—core competencies for entrepreneurial success.

Strengths and limitations.

Neuroeconomics offers a unique bridge between brain data and real-world decision-making, but experiments are often small-scale and resource-intensive. Ethical considerations also limit their generalisation to minors or school contexts.

4.5 Integrative perspective

Each neuroscientific method provides a distinct yet complementary view of learning and socio-emotional development. EEG and eye-tracking reveal the dynamics of attention and engagement; biochemical measures capture emotional and stress-related processes; pharmacological and neurostimulation studies explore causal mechanisms; and neuroeconomics connects neural data with behavioural and economic outcomes. Together, these tools create a multi-level framework for understanding how educational experiences shape the developing brain—and, ultimately, human capital formation.

Table 1 summarises neuroscientific techniques by their level of invasiveness, including their principles, representative studies, sample characteristics, key findings, and methodological limitations. Studies were selected to illustrate applications of neuroscience to socio-emotional and cognitive skill development in educational contexts.

5.0 DISCUSSION

The integration of neuroscience into education offers an unprecedented opportunity to advance the development of cognitive, non-cognitive, and socio-emotional skills, thereby strengthening future human capital. Rather than proposing an alternative theory to human capital economics, this review advances a meta-methodological approach that bridges neuroscience, psychology, and economics to improve the conceptualisation and measurement of learning and skill development across the lifespan.

This approach departs from traditional single-theory models by promoting multidisciplinary data integration. It combines quantitative, qualitative, and cognitive neuroscience evidence to model how social, economic, and environmental factors interact dynamically with human biology. A key contribution of this framework is its emphasis on individual variability in neural and behavioural data, which complements and enriches group-level analyses. As noted by Marginson (2019), multivariate analyses should be applied cautiously and only when assumptions such as variable independence are met, thereby avoiding misinterpretations and enhancing the precision of human capital research.

At its core, integrating neuroscientific insights into education provides complementary evidence for a more comprehensive understanding of learning behaviour (see Fig. 1). Cognitive neuroscience and social psychology, when applied to socio-emotional skills in educational contexts, illuminate how early interactions with caregivers, teachers, and peers shape neural circuits involved in motivation, attention, and emotional regulation. These insights extend beyond traditional psychometric and self-reported measures, offering

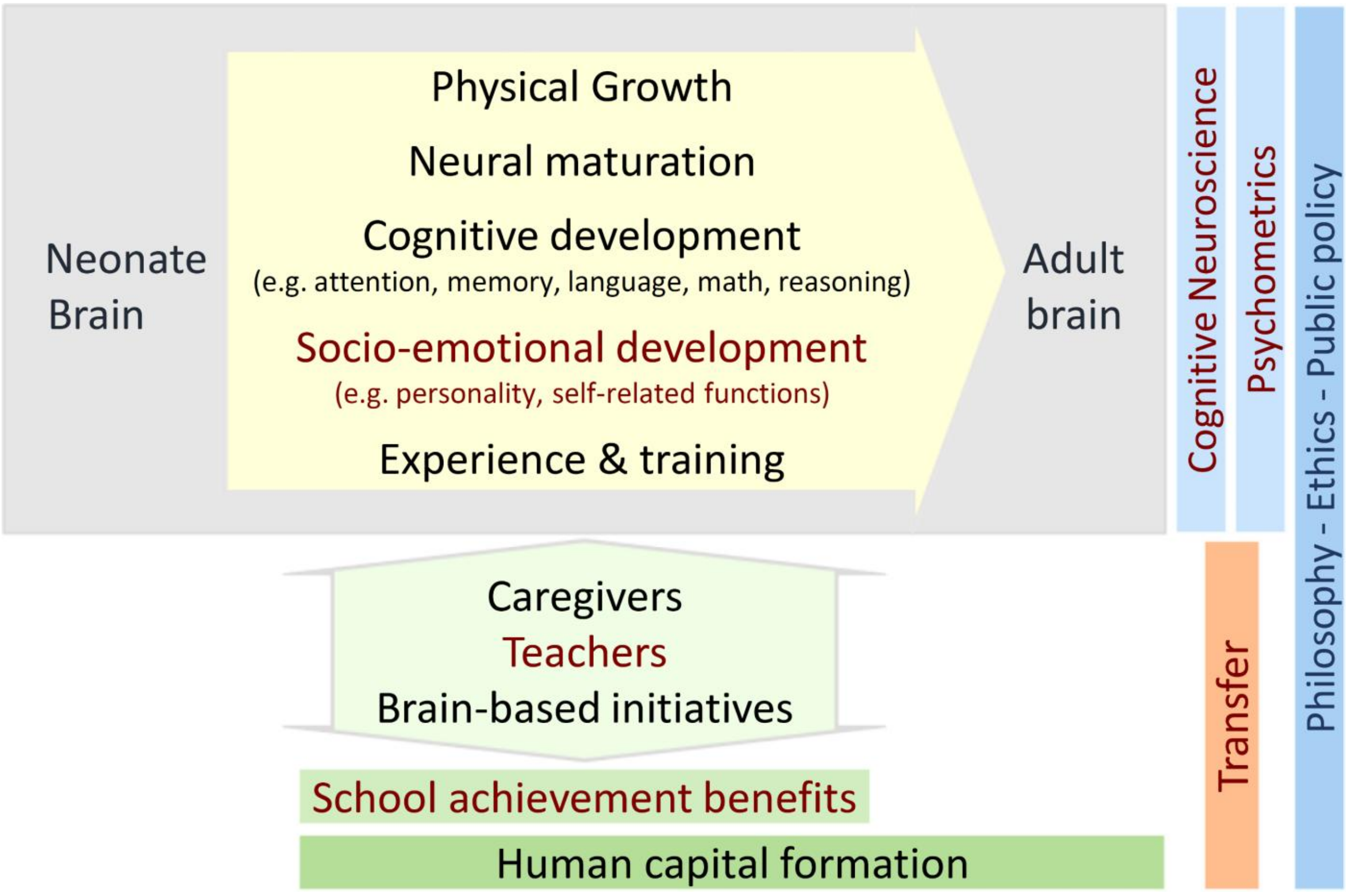

Figure 1. Human brain organisation, cognitive abilities, and socio-emotional capacities are tightly interrelated and influence one another. The transfer of such a multi-scale model is a challenge that may profit from cognitive neuroscience data.

Table 1. Summary of Neuroscientific Methods Applied to Education and Socio-Emotional Skill Research

Method type	Technique / principle	Representative studies	Sample / design / duration	Main findings / effect size	Strengths and limitations
Non-invasive: Electromagnetic and neuroimaging	**EEG / MEG / fMRI:** Record brain electrical or magnetic activity and map neural structure and connectivity.	Davidesco et al. (2021)	Observational classroom study; teacher–student dyads; test 1 week post-lecture.	Neural synchrony between students and teachers predicted later academic performance.	High temporal precision; feasible in real classrooms; sensitive to motion and environmental noise.
		Dehaene-Lambertz et al. (2018); Gouet et al. (2018); Borst et al. (2016)	Experimental and imaging studies on learning-related brain plasticity.	Show reciprocal relationship: learning modifies brain structure; brain structure constrains learning.	great spatial detail; costly and limited ecological validity.
Non-invasive: Eye tracking	**Visual attention mapping:** Tracks gaze position to infer focus and engagement.	Dessus et al. (2016); Rosengrant et al. (2021)	Observational classroom studies: primary and secondary students.	Gaze synchrony between teachers and students predicts comprehension; attention is sustained longer than expected in interactive classes.	Direct measure of attention; limited insight into emotion or motivation.
Semi-invasive: Endogenous substances	**Salivary cortisol/oxytocin:** Assess stress and emotional regulation.	Andreano & Cahill (2006); Salmurri & Skoknic (2003)	Cortisol measurement in adults (review); emotional education course for primary school teachers, longitudinal intervention.	Moderate cortisol boosts memory encoding; high cortisol impairs retrieval. Emotional education improved teachers' self-control and students' performance.	Objective stress index; large interindividual variability; contextual sensitivity.
Invasive/ interventional	**Psychopharmacology:** Administer modafinil, oxytocin, or neurotransmitter precursors to modulate learning.	Battleday & Brem (2015); Nardou et al. (2019)	Experimental trials; adults (modafinil) and animal models (oxytocin).	Modafinil enhances alertness and mood temporarily. Oxytocin reopened the critical social learning period.	Reveals causal neurochemical mechanisms; ethical constraints; uncertain long-term effects.
Specialised field: Neuroeconomics	**EEG + behavioural decision tasks: Study the** brain bases of economic and learning-related choices.	Glimcher & Fehr (2013); Woodford (2014); Egana del Sol (2016); Hughes et al. (2015)	Lab-in-the-field experiment; adult participants in the entrepreneurship program.	Improved emotional regulation and resilience (reduced EEG valence indices); lower dropout rates.	Links neural and behavioural data; small samples; resource-intensive.

explanatory mechanisms that clarify how and why skills develop.

From a developmental perspective, Figure 1 illustrates the continuum of human growth and learning beginning in prenatal stages. Prenatal and obstetric factors—such as neonatal complications, prenatal drug exposure, or exposure to toxins—can exert lasting effects on brain structure and function (Moon, 2020). Neural maturation then continues through dynamic processes of synaptic growth, pruning, and plasticity, shaping cognitive and socio-emotional capacities across the lifespan (Moon, 2020). These biological foundations interact continuously with educational and care environments, underscoring that schooling is not merely a site of knowledge transmission but an active driver of brain development.

Empirical research further supports this dynamic interplay between genetic predispositions and environmental influences. Studies on reading achievement, for example, show that although genetic factors contribute to individual differences, targeted environmental interventions—such as supportive classroom climates or structured reading programs—can substantially improve outcomes (Leve, 2022). Even among children at genetic risk for lower achievement, enriched educational and rearing environments can mitigate vulnerabilities and produce better-than-expected performance (Whiting, 2021).

Within this framework, teachers emerge as a central actor. Teachers play a pivotal role in translating neuroscientific insights into everyday educational practice. Awareness of individual differences in stress reactivity, emotional regulation, and attentional profiles enables more adaptive and inclusive instruction (Durlak, 2011). Teacher education and professional development programs that incorporate foundational principles from cognitive neuroscience may help prevent stress-related impairments and foster learning environments in which diverse learners can thrive.

Finally, it is important to acknowledge the scope and limitations of this review. As a narrative synthesis, it does not aim to provide a systematic meta-analysis but rather to integrate converging evidence across disciplines. While this approach enables conceptual integration, it may underrepresent emerging studies that fall outside the primary search terms or are published after the search period.

6.0 CONCLUSIONS

This review demonstrates that integrating cognitive neuroscience into education provides a powerful, complementary lens for understanding how socio-emotional skills develop and contribute to human capital formation. By advancing a meta-methodological framework that connects neural, psychological, and economic perspectives, the paper moves beyond fragmented models. It highlights the value of interdisciplinary integration for both research and practice.

Rather than replacing existing educational or economic theories, the proposed approach enriches them by offering explanatory mechanisms and objective indicators of learning and development. In particular, neuroscientific evidence clarifies how biological maturation, environmental conditions, and educational experiences jointly shape socio-emotional skills across the lifespan.

Looking forward, future research would benefit from longitudinal designs and meta-analytic approaches that integrate neuroscientific measures with educational and socio-emotional data (Immordino-Yang, 2015). Such efforts are essential for closing the persistent gap between neuroscience research and classroom practice (Spitzer, 2012; Privitera et al., 2023). Schools, curricula, teachers, parents, and policymakers must prioritise socio-emotional development alongside academic achievement, especially given the slow maturation of emotional regulation and related skills (Dienske, 1986; Kaplan, 2000) and the prolonged development of brain networks such as the prefrontal cortex and subcortical systems (Casey, 2015; Motzkin, 2015).

Overall, this mini-review offers a multi-level, interdisciplinary perspective that links cognitive neuroscience to education and human capital development. By integrating neural, social, and environmental evidence, it provides a coherent foundation for future research, policy design, and educational practices to promote lifelong learning, well-being, and societal resilience.

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