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Bottom-up strategies for supporting self-regulation in schools: a scoping review

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Research suggests that embodied strategies—such as physical activity, yoga, and mindfulness—may support the development of regulation skills in educational settings. However, narrow scope of previous research, methodological inconsistencies and limited theoretical grounding across studies highlight the need for more research. This review aimed to provide an explorative overview of bottom-up strategies used in school-based interventions targeting self-regulation, and to examine associated outcomes. Guided by an integrated neurobiological perspective, a systematic scoping review was conducted. Findings show that a wide range of bottom-up strategies have been implemented, with most studies reporting positive effects. Nevertheless, the field is marked by significant variation in intervention types, target populations, theoretical frameworks, and outcome measures, making it difficult to identify which strategies are most effective and for whom. Introjective practices such as yoga and mindfulness have the strongest evidence base, while other approaches—including play, dance, gross motor activities, and classroom climate interventions—remain underexplored. Importantly, none of the reviewed studies employed a whole-school approach, which could offer a more comprehensive and sustainable model for fostering regulation across subjects and stakeholders. These gaps underscore the need for more context-sensitive, theoretically grounded research to better understand which strategies work best in specific educational settings and among diverse student groups.

KEYWORDS

self-regulation, bottom-up, movement, physical activity, adolescent, children

1 Introduction

Self-regulation refers to the individual's capacity to manage emotions, thoughts, and behaviors, adapt to changing situations and pursue personal goals. The concept encompasses a range of cognitive and behavioral processes, including the inhibition of impulsive actions, postponement of gratifications, sustained attention, problem solving, planning and task completion (Berger, 2011; Warner et al., 2020; Chen et al., 2024). It also involves employing strategies to maintain emotions on a manageable level and recover from overwhelming experiences (Butler, 2024). Among school-aged children and adolescents, brain structures and related self-regulation skills are still developing, making emotional and behavioral challenges common (Nelson et al., 2019). Moreover, many children and adolescents experience difficulties that adversely affect their learning and capacity to initiate and maintain social relationships (Berger, 2011; Robson et al., 2020; Butler, 2024). Over time, deficits in self-regulation may increase risk of various health issues including obesity, mental health disorders, anxiety, depression, hyperactivity and anti-social behavior. These individuals are also more vulnerable

to school drop-out, substance abuse, aggressive behavior and criminality (Berger, 2011; Robson et al., 2020).

The development of self-regulation is influenced by a complex interplay of factors, including genetics, maturation, life experiences, social interactions with peers and caregivers, and other environmental conditions (Berger, 2011). Protective factors such as sensitive caregiving and secure attachment support the development of regulation skills (Siegel, 2020), whereas adverse experiences—such as physical and emotional neglect, abuse, and exposure to war—are associated with increased risk of regulation difficulties. Additional contributing factors include congenital temperament and neurological conditions such as Attention Deficit Hyperactivity Disorder (ADHD), Attention Deficit Disorder (ADD), Autism Spectrum Disorder (ASD) and sensory processing disorder (Berger, 2011; Blair, 2018), as well as early and extensive exposure to digital devices and the use of such devices by early caregivers to regulate their children's emotions (Konok et al., 2024). Thus, to facilitate learning and social interactions, all children and adolescents require tailored support in developing regulation skills. This is particularly the case for the vulnerable ones.

Over the years, self-regulation has been examined from a variety of theoretical and methodological perspectives such as behavioral genetics, cognitive psychology, developmental psychology, and health psychology (Backer-Grøndahl and Nærde, 2015). Recently, increasing attention has also been directed toward neurobiological perspectives which has yielded insights into the underlying physiological mechanisms and processes. From an integrated, neurobiological perspective, self-regulation is understood as a dynamic process involving the prefrontal cortex alongside physiological, attentional, emotional and stress-related arousal systems (Blair, 2018; Meyes, 2000; Siegel, 2020). The prefrontal cortex facilitates voluntary, cognitive regulation of emotions, thoughts and actions, whereas the arousal systems govern fluctuations in bodily states. Within this framework, executive functioning, behavioral responses, neurochemical markers (i.e., cortisol) and physiological indicators (i.e., heart rate, blood pressure) are all considered reflective of an individual's regulatory state (Meyes, 2000).

A key factor of this system is its bidirectional interconnectivity. Cognitive stimuli and voluntary engagement in embodied activities can modulate arousal systems, while changes in arousal levels, in turn, influence the functioning of the prefrontal cortex (Blair, 2018; Porges, 2011, 2017; Siegel, 2020; Dana, 2021; Porges and Porges, 2023; Butler, 2024). Consequently, regulation can be supported through two pathways: top-down and bottom-up. Top-down strategies involve conscious, cognitive efforts such as self-talk or logic-based activities (jigsaw puzzles, sudoku) (Butler, 2024), whereas bottom-up strategies rely on sensory and relational experiences including pleasant human voice, facial expressions, play (Porges, 2011, 2017; Porges and Porges, 2023), contact with other people, animals or the nature (Butler, 2024), sensory stimulation (Williams and Shellenberg, 1996), sensorimotor activities, rhythm, (Cheatum and Hammond, 2000; Warner et al., 2020), deep breathing, mindfullness, yoga, dance, martial arts, team sports, drama (van der Kolk, 2014) and physical activity (Porges and Porges, 2023).

Compared to top-down approaches, bottom-up strategies are less reliant on cognitive maturity and conscious processing, making them more accessible to younger children and individuals experiencing distress. In educational settings, where cognitive skills are often prioritized, bottom-up strategies offer a complementary approach to supporting the development and functioning of regulatory systems. These strategies may benefit all students and particularly the vulnerable ones (Wilson, 2023; Butler, 2024).

Previous reviews (Caragea et al., 2017; Pandey et al., 2018; Murray et al., 2021) suggest that a variety of interventions may be effective. Caragea et al. (2017) identified five neuro-educationally informed school interventions targeting either academic motivation, attention orientation, self-perception, cognitive and emotional engagement in learning or regulation of social and task-related behaviors, which all reported some positive outcomes. Small sample sizes (n = 36–167) and other methodological limitations undermine the reliability of the findings.

Pandey et al. (2018) reviewed 50 studies, including 17 cluster randomized trials and 32 randomized clinical trials, focusing on interventions targeting regulation skills. These were categorized into curriculum-based (n = 21), mindfullness and yoga (n = 8), family-based (n = 9), exercise-based (n = 6), and social and personal skills interventions (n = 6). Of these, 33 interventions demonstrated improvements in following domains; academic achievement (11 of 13), substance abuse (4 of 5), conduct disorders (2 of 2), social skills (2 of 2), depression (2 of 2), behavioral problems (2 of 2) and school suspensions (1 of 1). Success rates varied by intervention type: curriculum-based (76%), mindfullness and yoga (50%), family based (56%), exercise based (67%) and social and personal skills (67%).

Murray et al. (2021) conducted a review of 33 studies, categorized into emotion regulation (n = 12), cognitive regulation (n = 9), parent training (n = 3), physical activity (n = 7) and working memory (n = 3) interventions. Notably, significant positive outcomes were observed only in interventions targeting emotion regulation, with the most substantial effects reported among adolescents experiencing emotional distress. The authors highlighted that many of the included studies were of low methodological quality and lacked a solid theoretical framework.

Additionally, none of the three reviews (Caragea et al., 2017; Pandey et al., 2018; Murray et al., 2021) presents the included interventions in detail making it difficult to evaluate specific characteristics of successful interventions within each category. Also, there is little information about the participants. The only specifications are found in Murray et al. (2021) who mentioned including samples with anxiety, depression and ADHD, and in Pandey et al. (2018) who discussed shortly populations with greater risk for conduct problems and racial/ethnic minorities. The distribution of results across different populations was not clarified.

More recent research (Chesnais et al., 2023) indicates that various populations might respond differently to same intervention. To understand more about what works, with whom and under what circumstances, more in-depth research is needed. Also, there is a need for more focus on bottom-up strategies. Despite the extensive range discussed in the literature (Williams and Shellenberg, 1996; Cheatum and Hammond, 2000; van der Kolk, 2014; Porges, 2011, 2017; Warner et al., 2020; Porges and Porges, 2023; Butler, 2024), such strategies had only a marginal role in previous reviews (Caragea et al., 2017; Pandey et al., 2018; Murray et al., 2021) offering limited insight into potential applications and effectiveness within school contexts.

The aim of this study is to investigate the use and outcomes of bottom-up strategies in school-based interventions targeting

self-regulation. Specifically, we seek to address the following research questions:

> What types of bottom-up strategies have been implemented in school-based interventions addressing self-regulation? And what are the defining characteristics of these interventions?
>
> What outcomes have been reported for school-based interventions utilizing bottom-up strategies? And do these outcomes vary according to context, participant characteristics, or the nature of the interventions?

2 Methods

To address the research questions, we adopted a scoping review methodology, which according to Arksey and O'Malley (2005) and Levac et al. (2010) is well-suited for exploring the '*extent, range and nature of research activity*' and for identifying *'potential gaps in existing literature and research*'. In line with their recommendations, the research questions of this study were developed through a series of preliminary searches designed to broadly explore the area of interest. We tested different search combinations and browsed results to get some overview of potential lines of research that could fit our aim of exploring school intervention studies addressing bottom-up strategies. The preliminary search indicated a fragmented and unevenly developed research field, which confirmed the suitability of a scoping review whose exploratory nature allows inclusion of a wide variety of articles. As the research questions were set, we conducted a systematic search using the databases ORIA (a shared search portal for Norwegian university, college and specialist libraries), PsycINFO, Web of Science, MEDLINE, PubMed and ERIC. Search terms were organized into five categories reflecting the theoretical foundations of the study: (1) *Phenomenon:* self-regulation, regulation, arousal, physiological regulation (2) *Context:* school, elementary school, secondary school, high school, physical education, education (3) *Design:* intervention, improving, model, application, program; (4) *Content:* vestibular, proprioception, tactile, sensory, movement, movement activities, sport, rhythm, dance, yoga, mindfulness, martial arts (5) *Theoretical foundation:* neurobiological, bottom-up, polyvagal, senso-motor, neuroeducation, educational neuroscience.

We included peer-reviewed articles published in English the last 20 years. Due to delays in the writing process, the period was later extended to a period of 21 years (2004–2025). Eligible studies had to present empirical data from school-based interventions, involving either general student populations or groups with known regulatory vulnerabilities. The age range was set between 6 and 18 years (grades 1 through high school). Two exceptions were made for studies where part of the participants were younger than six, provided that the majority of participants met the inclusion criteria.

Furthermore, studies were required to align with a neurobiological perspective on regulation, and to include measures involving physiological, neurochemical, behavioral or cognitive indicators of regulation. The intervention content had to be primarily composed of bottom-up strategies, and the type of activity had to be clearly presented. We excluded studies involving video games, information technology, clinical or therapeutical settings, and those in which cognitive strategies played an equal or greater role than bottom-up strategies. We made these exclusions to highlight our focus on body and physical movement as well as suitability of the interventions for the school context.

The first search phase 1 (Figure 1) was conducted in March 2024 and yielded a total of 1,023 matches in ORIA, PsycInfo and Web of Science. After removing duplicates, 985 sources remained. Of these, 64 met the inclusions criteria while 921 were excluded. Following abstract review, 28 more sources were excluded, leaving 36 articles for full-text review. Ultimately, 19 studies were included in the final analysis.

Due to long writing period, a second search phase was conducted in April 2025 (Figure 1). The second phase covered the months between March 2024 to April 2025, and it followed the same procedure using the same databases and search terms. This search returned 84 results, of which 81 were excluded based on title and abstract. The remaining 3 articles were reviewed in full text, but none met all the inclusions criteria. To strengthen the search, we included three additional databases (MEDLINE, PubMed, and ERIC) at the end of this phase. This supplementary search yielded 98 results, of which 91 were excluded based on title and abstract screening. Following full-text review, three additional articles were included, bringing the total number of articles to 22.

All four authors co-operated in defining inclusion and exclusion criteria and participated in the full-text review. The remainder of the search process was carried out by the first and fourth authors.

2.1 The analysis

Following the application of the inclusion and exclusion criteria, we began our search for a meaningful synthesis. As noted by Rennstam and Wästerfors (2015), sorting is a critical initial step in the analytical process, significantly influencing which fundamental dimensions and patterns emerge from extensive and complex material. This initial phase of analysis was led by the first author in close co-operation with the co-authors. The team's diverse academic backgrounds and ongoing discussions ensured a reflexive process where multiple perspectives and various interpretive angles were considered. Alongside the theoretical perspectives included earlier, we also incorporated elements from Conn and Groves (2011) framework for Essential Intervention Content in Research Report to align our inquiry with the field of intervention research. Through a systematic process of sorting and reduction (Rennstam and Wästerfors, 2015), the following five themes emerged: (1) Participants and context, (2) Content, (3) Duration, frequency and timing, (4) Measures and approach, and (5) Main findings.

3 Results

The subsequent synthesis offers an overview of bottom-up regulatory strategies and highlights the key findings derived from the reviewed literature. The included studies feature participants varying in nationality, age, and vulnerability to regulatory difficulties, and were conducted across a range of educational settings.

3.1 Participants and context

A significant proportion of the studies were conducted in the United States (Flook et al., 2010; Mendelson et al., 2010; Lakes et al.,

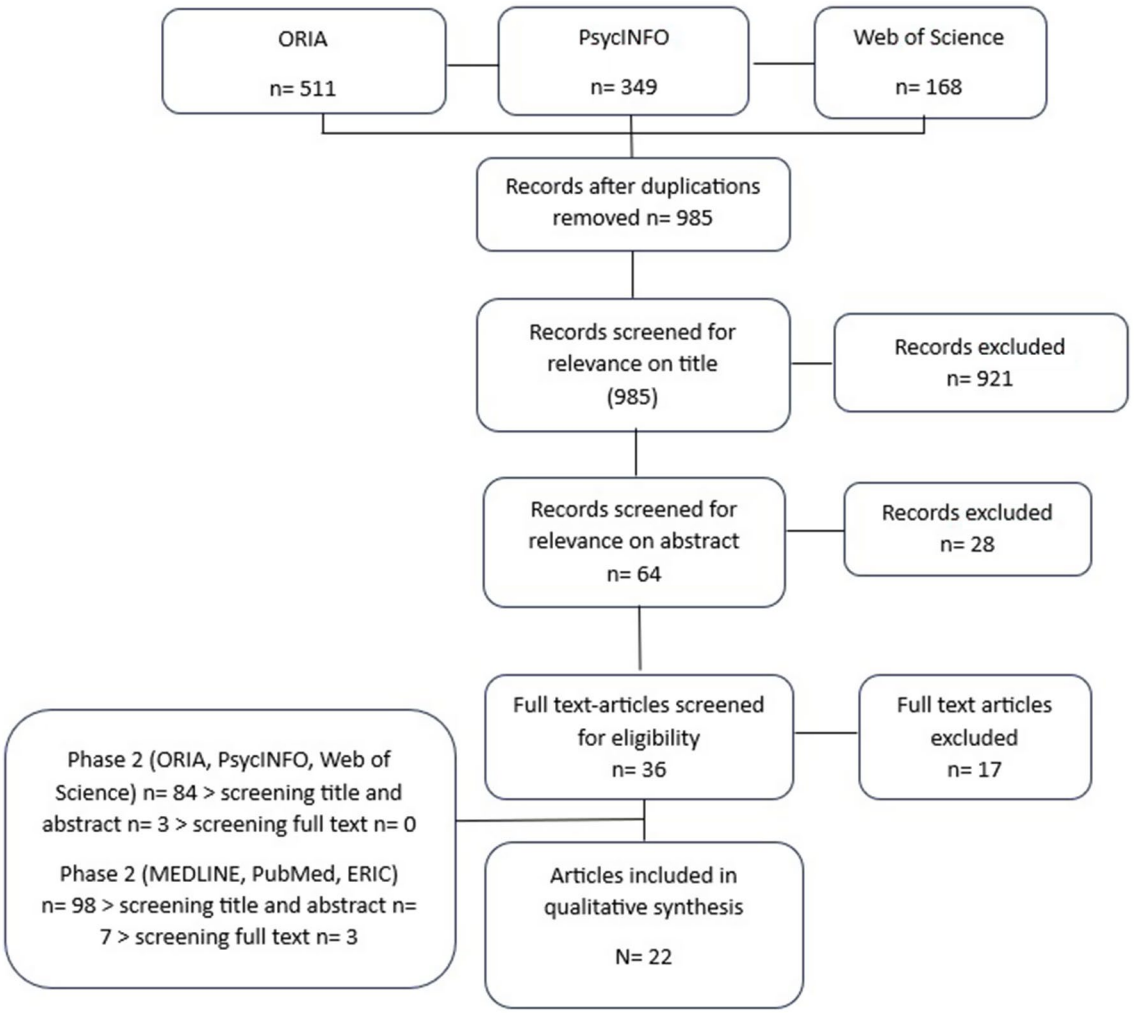

FIGURE 1
Flow chart, phase 1 and phase 2.

2013; Wisner and Starzec, 2016; Hagins and Rundle, 2016; Miller et al., 2017; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; McMahon et al., 2021; Rice et al., 2023). However, the geographical scope also includes studies from Spain (Cañabate et al., 2020), Argentina (Carro et al., 2023), Italy (Mastromatteo et al., 2023; Latino et al., 2025), China (Chen et al., 2014), Germany (Anzeneder et al., 2024), England (Leyland et al., 2018; Wassenaar et al., 2021); Denmark (Lind et al., 2018) and Vietnam (Nguyen and Dorjee, 2022).

Most studies (n = 14) were conducted in primary school setting (Flook et al., 2010; Mendelson et al., 2010; Kang et al., 2018; Chen et al., 2014; Leyland et al., 2018; Lind et al., 2018; Bauer et al., 2019; Cañabate et al., 2020; Mancini, 2020; Nguyen and Dorjee, 2022; Carro et al., 2023; Mastromatteo et al., 2023; Rice et al., 2023; Anzeneder et al., 2024), while four were conducted in secondary schools (Lakes et al., 2013; Fung et al., 2019; Wassenaar et al., 2021; Latino et al., 2025), and two in high schools (Wisner and Starzec, 2016; Hagins and Rundle, 2016). Additionally, two studies spanned both primary and secondary levels (Miller et al., 2017; McMahon et al., 2021). While two interventions were implemented in physical education setting (Hagins and Rundle, 2016; Cañabate et al., 2020) the remainder were carried out in classroom or extracurricular settings.

The sample sizes varied considerably. The largest study included 18,261 participants (Wassenaar et al., 2021). Eight studies involved 100–200 participants (Hagins and Rundle, 2016; Miller et al., 2017; Kang et al., 2018; Leyland et al., 2018; Fung et al., 2019; McMahon et al., 2021; Anzeneder et al., 2024), while 12 studies had fewer than 100 participants (Flook et al., 2010; Mendelson et al., 2010; Chen et al., 2014; Wisner and Starzec, 2016; Bauer et al., 2019; Cañabate et al., 2020; Mancini, 2020; Mastromatteo et al., 2023; Nguyen and Dorjee, 2022; Carro et al., 2023; Rice et al., 2023; Latino et al., 2025). The smallest study included 19 participants (Wisner and Starzec, 2016).

Participant ages ranged from 3 to 18 years, with emphasis on the 6–18 years. Seven studies specifically targeted children and adolescents with increased vulnerability to regulatory difficulties. Mendelson et al. (2010) and Rice et al. (2023) focused on at-risk youth aged 7–12 years, and Wisner and Starzec (2016) included adolescents from an alternative school serving students at high risk of dropout. Fung et al. (2019) studied 15-year-olds from ethnic minority backgrounds experiencing low mood, while Mancini (2020) included children aged

6–11 years with refugee, immigrant and trauma backgrounds. Moreover, McMahon et al. (2021), and Mastromatteo et al. (2023), involved participants aged 11–14 and 7 years, respectively, from medium-to-low socioeconomic (SES) families.

The remaining 15 studies did not specify any vulnerabilities. Overall, the reviewed articles report on interventions targeting relatively homogeneous samples. Notably, none of the studies examined interventions designed to engage interrelated, heterogenous groups of participants within an educational system.

3.2 Content

The interventions reviewed encompassed a broad spectrum of activities and strategies, with a notable emphasis on introjective practices. The most frequently implemented approaches were mindfulness and yoga, reported in 11 studies (Flook et al., 2010; Mendelson et al., 2010; Wisner and Starzec, 2016; Hagins and Rundle, 2016; Kang et al., 2018; Leyland et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; Nguyen and Dorjee, 2022; Carro et al., 2023) and six studies (Mendelson et al., 2010; Hagins and Rundle, 2016; Cañabate et al., 2020; Mancini, 2020; McMahon et al., 2021; Rice et al., 2023), respectively.

Other activities incorporating elements of mindfull awareness and/or introjective motor practice included tai chi (Cañabate et al., 2020; Carro et al., 2023; Rice et al., 2023), Qi Gong (Cañabate et al., 2020), Chi Kung (Carro et al., 2023), Eutonie (Cañabate et al., 2020), and active global stretching (Cañabate et al., 2020). Additionally, four studies included breathing exercises (Mendelson et al., 2010; Hagins and Rundle, 2016; Mancini, 2020; Carro et al., 2023).

Other identified strategies included play or playful activities (Flook et al., 2010; Miller et al., 2017; Leyland et al., 2018; Carro et al., 2023; Rice et al., 2023), somatic stimulation (Mancini, 2020), expressive dance (Cañabate et al., 2020), martial arts such as taekwondo (Lakes et al., 2013) and self-defense (Mancini, 2020), small-sided games and drills (Lind et al., 2018), gross motor activities including jogging (Chen et al., 2014), jumping, squatting and punching (Anzeneder et al., 2024), light aerobic movements such as dynamic stretching and balance games (Latino et al., 2025) and HIIT (High-intensity interval training) (Wassenaar et al., 2021; Latino et al., 2025).

Nine studies focused exclusively on introjective practices (Mendelson et al., 2010; Wisner and Starzec, 2016; Kang et al., 2018; Leyland et al., 2018; Bauer et al., 2019; Fung et al., 2019; Cañabate et al., 2020; McMahon et al., 2021; Nguyen and Dorjee, 2022). Five of these studies concentrate solely on mindfullness (Wisner and Starzec, 2016; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Nguyen and Dorjee, 2022), and one on yoga (McMahon et al., 2021).

Seven studies combined introjective practices with additional strategies. Flook et al. (2010) and Leyland et al. (2018) integrated mindfulness and play, while Hagins and Rundle (2016) and Mendelson et al. (2010) combined yoga and mindfullness. Cañabate et al. (2020) employed yoga, Tai Chi, active global stretching, Qi Gong and dance, whereas Carro et al. (2023), combined mindfullness, prosocial play, Tai Chi and Chi Kung. Mancini (2020) incorporated mindfulness, self-defense, relaxation and breathing exercises.

Moreover, one study focused solely on martial arts (taekwondo) (Lakes et al., 2013), one on jump, squat and punch (Anzeneder et al., 2024), one on jogging (Chen et al., 2014), one on small-sided games and drills (Lind et al., 2018), and one on HIIT (Wassenaar et al., 2021).

In addition to physical and sensory activities, several studies included didactic strategies or cognitive stimulation. In Mastromatteo et al. (2023) the intervention focused on maturation and awareness of classroom climate. Other studies, pedagogical elements were supplementary. Cañabate et al. (2020) emphasized rituals for entering and exiting the learning space and fostering motivational learning climate, while Carro et al. (2023) included sharing emotions, discomfort and amusement as part of the intervention. Mancini (2020) highlighted the importance of choice, slow tempo and recognition of small successes, and Anzeneder et al. (2024) and Latino et al. (2025) included cognitive challenge.

3.3 Duration, frequency and timing

The interventions varied widely in duration and frequency, ranging from a single 30-min session in Chen et al.'s (2014) experimental study to regular sessions conducted over extended periods. Among the interventions with recurring sessions, durations ranged from 1 to 2 months (Flook et al., 2010; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; Cañabate et al., 2020; McMahon et al., 2021; Anzeneder et al., 2024), to 3–5 months (Mendelson et al., 2010; Lind et al., 2018; Nguyen and Dorjee, 2022; Rice et al., 2023; Latino et al., 2025) and up to one full school year (Lakes et al., 2013; Hagins and Rundle, 2016; Wassenaar et al., 2021; Mastromatteo et al., 2023; Carro et al., 2023).

The length of individual sessions also varied, ranging from just a few minutes (Bauer et al., 2019; Nguyen and Dorjee, 2022; Anzeneder et al., 2024) to 60-min sessions (Wisner and Starzec, 2016; Carro et al., 2023). Shorter sessions were typically conducted more frequently than longer ones. For instance, Bauer et al. (2019) implemented daily sessions lasting 5–15 min, while Nguyen and Dorjee's (2022) used 2–10 min of daily mindfulness training. The 60-min sessions in Carro et al. (2023) and Wisner and Starzec (2016) were implemented once and twice a week, respectively, while Latino et al. (2025) implemented three 50-min sessions weekly. The most common format involved 30–45 min sessions held twice per week (Flook et al., 2010; Mendelson et al., 2010; Hagins and Rundle, 2016; Lind et al., 2018; Mancini, 2020; McMahon et al., 2021; Rice et al., 2023).

Several studies also emphasised timing ($n = 2$) and intensity ($n = 4$) as important design features. For example, Bauer et al. (2019) scheduled sessions at the end of the school day, while Lakes et al. (2013) conducted sessions between 10 and 11 a.m. Intensity was explicitly monitored in Chen et al. (2014) and Anzeneder et al. (2024), both of which aimed to maintain physical activity at 60–70% of maximum heart rate. The design in Wassenaar et al. (2021)'s study consisted of 10 min of vigorous physical activity (VPA) exclusively, while the aerobic exercises in Latino et al. (2025)'s study aimed to be at a moderate to vigorous physical activity (MVPA) and VPA level.

3.4 Approach and measures

The reviewed studies employed a diverse array of theoretical and methodological approaches to self-regulation. Six studies were explicitly centered on the underlying neurobiological processes

underlying regulation (Flook et al., 2010; Bauer et al., 2019; Mastromatteo et al., 2023; Nguyen and Dorjee, 2022; Carro et al., 2023; Rice et al., 2023). Among these, two referenced Polyvagal Theory (Carro et al., 2023; Mastromatteo et al., 2023).

Other studies grounded their interventions in empirical knowledge and theoretical frameworks related to specific practices or domains, including meditation (Mendelson et al., 2010), mindfulness (Wisner and Starzec, 2016; Kang et al., 2018; Fung et al., 2019; Cañabate et al., 2020), yoga (McMahon et al., 2021), executive functioning (Chen et al., 2014; Leyland et al., 2018; Lind et al., 2018; Wassenaar et al., 2021; Latino et al., 2025), cognitive functioning (Anzeneder et al., 2024), and sensorimotor processes (Miller et al., 2017). Lakes et al. (2013)'s study adopted a combined cognitive and behavioral framework to support behavioral regulation.

Accordingly, most studies aimed to influence multiple dimensions of regulatory functioning. Twelve studies targeted cognitive aspects of regulation such as initiative and working memory (Flook et al., 2010; Chen et al., 2014; Lind et al., 2018; Latino et al., 2025), cognitive control (Lakes et al., 2013; Wisner and Starzec, 2016; Rice et al., 2023), academic performance (Hagins and Rundle, 2016; Mancini, 2020; Latino et al., 2025), and attention alerting (Lind et al., 2018; Anzeneder et al., 2024), orientation (Anzeneder et al., 2024), relational memory and processing speed (Wassenaar et al., 2021).

Eleven studies focused on emotional regulation, including emotional symptoms (Wassenaar et al., 2021) emotional well-being and self-compassion (Kang et al., 2018), stress reduction and amygdala connectivity (Bauer et al., 2019), emotional attention, and repair (Cañabate et al., 2020), perceived stress (Latino et al., 2025) and anxiety and depression (Mancini, 2020). Others addressed broader emotional regulation in vulnerable populations (Wisner and Starzec, 2016; Miller et al., 2017; Fung et al., 2019; McMahon et al., 2021; Nguyen and Dorjee, 2022).

Twelve studies also aimed to improve cognitive, physiological or behavioral regulation, including global executive functioning (Flook et al., 2010; Lakes et al., 2013; Wisner and Starzec, 2016; Fung et al., 2019; Rice et al., 2023), social integration (Carro et al., 2023), conduct problems, peer relationships and pro-social behavior (Wassenaar et al., 2021), motor planning (Miller et al., 2017; Mancini, 2020), physical fitness (Lakes et al., 2013), cardiovagal tone (Mastromatteo et al., 2023), and heart rate variability (HRV) (Latino et al., 2025).

Only one study—Carro et al. (2023)—explicitly targeted a neurochemical marker, measuring hair cortisol concentration as an indicator of stress regulation.

In terms of methodology, the studies employed a wide range of assessment tools to evaluate intervention effects. The most commonly used method was pre- and post-intervention questionnaires completed by participants. In some cases (Flook et al., 2010; Lakes et al., 2013; Rice et al., 2023), the questionnaires were also completed by parents and teachers.

Six studies utilized alternative methods beyond questionnaires. Leyland et al. (2018) used a brief pre-recorded mindfulness induction and a 'sound in space' game to assess sensory experiences and executive function. Chen et al. (2014) employed computer-based tests to measure inhibition, working memory and shifting. Wisner and Starzec (2016) conducted phenomenological interviews to explore participants' experiences with the mindfulness program. Carro et al. (2023) and Nguyen and Dorjee (2022) used physiological measures, including hair cortisol concentration and EEG-signals, respectively. Miller et al. (2017) applied systematic observation using a coding system to assess emotional responses and behaviors in playground settings.

3.5 Main findings

All but two studies (Leyland et al., 2018; Wassenaar et al., 2021) reported improvements in various variables of self-regulation. Positive outcomes were observed across cognitive (Wisner and Starzec, 2016; Hagins and Rundle, 2016; Lind et al., 2018; Latino et al., 2025) psychological (Mendelson et al., 2010; Wisner and Starzec, 2016; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; Cañabate et al., 2020; McMahon et al., 2021; Nguyen and Dorjee, 2022), behavioral measures (Flook et al., 2010; Lakes et al., 2013; Chen et al., 2014; Wisner and Starzec, 2016; Hagins and Rundle, 2016; Fung et al., 2019; Rice et al., 2023; Anzeneder et al., 2024), physiological (Bauer et al., 2019; Mastromatteo et al., 2023; Latino et al., 2025) and neurochemical domains (Mastromatteo et al., 2023; Carro et al., 2023; Anzeneder et al., 2024). Several studies reported improvements across multiple domains (Mendelson et al., 2010; Wisner and Starzec, 2016).

Leyland et al. (2018) found no significant effect on executive functioning in 4-7-year-olds. The authors attributed this to methodological issues, particularly the choice of a comparison activity that may have elicited similar effects to the experimental condition. Also, Wassenaar et al. (2021) found no significant intervention effect on either physical or mental health variables and ascribes the null results to methodological issues (e.g., missing data). Further, Flook et al. (2010) noted uncertainty regarding the long-term effects and optimal duration of the intervention.

Studies involving introjective practices such as mindfulness (Flook et al., 2010; Mendelson et al., 2010; Wisner and Starzec, 2016; Hagins and Rundle, 2016; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; Nguyen and Dorjee, 2022; Rice et al., 2023) and yoga (Mendelson et al., 2010; Hagins and Rundle, 2016; Mancini, 2020; McMahon et al., 2021) consistently reported positive effects on emotional, cognitive, and behavioral regulation. Accordingly, Flook et al. (2010) and Fung et al. (2019) found significant improvements in behavioral control and emotion regulation (e.g., internalizing problems), particularly among their 7–9-year-old participants with lower regulation levels in baseline. In Mancini (2020)'s study, which involved weekly yoga-sessions for children aged 6–11 years with academic and regulatory challenges, teacher-reported improvements were observed in communication, social interaction, and academic functioning following a four-week intervention. Similarly, Rice et al. (2023) found that among at-risk urban children aged 7–9 years, only teacher-reported outcomes showed significant improvements after the intervention. Nguyen and Dorjee (2022) reported enhanced emotional regulation in Vietnamese children aged 7–11 years following mindfulness training program, while emphasizing the importance of cultural sensitivity when interpreting emotional responses to stress.

Further, both Mendelson et al. (2010) and Bauer et al. (2019) reported improved stress regulation in 10–12-years-old children, following introjective practices. In Mendelson et al. (2010)'s study, the improved stress regulation followed a 12-week intervention including multiple introjective practices, including breathing techniques, guided mindfullness, and yoga inspired postures and movements to strengthen muscle tone and flexibility. In Bauer et al. (2019)'s study,

12-year-old participants showed reduced amygdala activation, after 8 weeks og regular exposure to mildly stressful situations. Kang et al. (2018) observed improvements in emotional regulation, following a 4–5 h/weekly mindfullness-training program for 6 weeks, but only among 12-year-old girls.

In McMahon et al. (2021)'s yoga program for adolescents aged 11–14 from economically disadvantaged backgrounds, significant improvements were found in emotion regulation and psychological variables including anger, depression and fatigue. The meditation components were observed to be particularly effective in enhancing emotional awareness and long-term goal-directed behavior. Similar, Wisner and Starzec (2016) reported significant gains in emotional, cognitive, social and behavioral regulation among 15–17-year-old boys following mindfulness training. Hagins and Rundle (2016) hypothesized that yoga, as an alternative to traditional Physical Education, would enhance academic performance. This was supported only among high school students with high attendance, although the effect size was small. However, the anticipated mediating effects of self-regulation and executive functioning were not confirmed.

Lakes et al. (2013)'s one-year long taekwondo intervention with 13–14-year-old students, led to significant improvements in parent-rated inhibitory control, student-rated executive functioning and physical fitness.

In summary, these findings suggest that introjective practices may be particularly effective for participants with lower baseline self-regulation or from socioeconomically disadvantaged backgrounds. The success of these interventions appears to depend on participants' active engagement and commitment, while emotional regulation outcomes may be influenced by cultural context.

Interventions involving gross motor activities such as play and playful engagement (Flook et al., 2010; Miller et al., 2017; Carro et al., 2023; Rice et al., 2023), expressive dance (Cañabate et al., 2020), jogging (Chen et al., 2014), jumping, squatting and punching (Anzeneder et al., 2024) and smallsided games and drills (Lind et al., 2018) also yielded positive results. In Miller et al. (2017)'s study of children with and without disabilities, self-organized play in a playground led to improvements in social interaction, motor planning, self-esteem and emotion regulation.

Activities integrating mindful awareness and/or introjective motor practice such as Tai Chi (Cañabate et al., 2020; Carro et al., 2023; Rice et al., 2023), Qi Gong (Cañabate et al., 2020) Chi Kung (Carro et al., 2023), eutony (Cañabate et al., 2020), and active global stretching (Cañabate et al., 2020) also reported positive effects on psychological, neurochemical and behavioral variables. For example, Cañabate et al. (2020)'s intervention, consistant of multiple introjective practices, 4 days weekly for 6 weeks, improved the 9-year-old Spanish pupils' emotional attention, repair, and clarity of feelings. In addition, it revealed an 8.1% gender difference in favor of girls in post-test scores for emotional attention and repair. However, the study did not identify a consistent pattern indicating the superiority of either single-activity or multi-activity interventions.

The Mancini (2020)'s study of traumatized refugees, aged 6–11, reported improved psychological and academic functioning, and emotional regulation, following a multiactivity program consistent of both introjective practices, martial arts and sensomotor activities for 4 weeks.

Anzeneder et al. (2024) found improvements in executive functioning and mood following 4 weeks of cognitively challenging exercise at 65% of HRmax. Though, no changes were observed in attentional alerting and orientation.

Chen et al. (2014) reported significant improvements among pupils in the third and fifth grades in several executive functions following a 30-min jogging session performed at moderate to high intensity (60–70% of predicted HRmax). Notably, the study revealed age-related differences: third-grade students exhibited enhanced shifting abilities, whereas no significant improvements were observed among fifth-grade participants.

Longer-term interventions such as the year-long program implemented by Carro et al. (2023) demonstrated positive physiological and neurobiological outcomes. These included reductions in hair cortisol concentrations and enhancements in cardiac vagal tone. Additionally, the researchers reported improvements in social interactions. Lakes et al. (2013)'s one year intervention study, involving martial arts including taekwondo twice a week, reported improvements in parent-rated inhibitory behavioral control in 13–14 year-olds. Similarly, Mastromatteo et al. (2023) found that increased cardiac vagal tone was associated with an additional year of maturation.

Our analysis did not reveal consistent trends regarding the optimal duration, frequency, or timing of interventions. Furthermore, no clear relationship emerged between positive outcomes and specific objectives or levels of regulation. Both short-term interventions involving acute bouts of physical activity (e.g., Chen et al., 2014; Anzeneder et al., 2024) and long-term programs produced beneficial effects across various outcome measures. Nevertheless, individual studies highlighted notable variations. For instance, Chen et al. (2014) reported improvements in shifting abilities among third graders, but not among fifth graders. Beyond age-related differences, Kang et al. (2018) identified gender-based disparities in emotional outcomes. Moreover, studies by Mancini (2020) and Rice et al. (2023) underscored discrepancies between teachers' and participants' evaluations of intervention effectiveness. Finally, both Fung et al. (2019) and Nguyen and Dorjee (2022) emphasized the importance of cultural sensitivity when interpreting behavioral responses.

4 Discussion

The review demonstrates that a diverse array of bottom-up strategies has been implemented in school settings to support and enhance self-regulation among children and adolescents. The characteristics of these interventions vary considerably across contextual factors, participant demographics, content, dosage and timing, methodological approaches and outcome measures. Overall, the findings are predominantly positive with 20 of 22 studies reporting improvements in one or more variables. However, certain nuances warrant attention. For instance, Leyland et al. (2018) and Wassenaar et al. (2021) reported no significant improvements, while Anzeneder et al. (2024) found either negative or no significant improvements in some variables. Hagins and Rundle (2016), and Fung et al. (2019) highlighted effect sizes being low to moderate.

Moreover, a subset of studies indicated that intervention effects may vary according to age (Chen et al., 2014), gender (Cañabate et al., 2020) and cultural background (Fung et al., 2019; Nguyen and Dorjee, 2022). Flook et al. (2010) reported stronger effects among participants with pre-existing regulatory difficulties (Flook et al., 2010), while

Hagins and Rundle (2016) and Mendelson et al. (2010) emphasized the importance of attendance rates in determining intervention efficacy. Thus, the review suggests that a wide range of bottom-up strategies may be beneficial for supporting regulatory systems in school-aged populations. These strategies appear potentially effective across different subgroups and educational contexts. If so, bottom-up strategies could be used to foster learning and social relationships among vulnerable populations without disadvantaging others. Given the limited number of studies and participants included in the review and that no consistent patterns emerged linking specific intervention characteristics to positive outcomes, definitive conclusions cannot yet be drawn. More solid studies with a variety of populations are needed to better understand what works, and for whom.

Overall, the selection of articles in this review presents a somewhat more optimistic portrayal of the field compared to previous reviews which only partially supports the effectiveness of bottom-up strategies such as mindfulness, yoga, physical activity, and exercise (Pandey et al., 2018; Murray et al., 2021). In Murray et al. (2021), significant emotional improvements were observed exclusively among adolescents. One possible explanation for the more favorable outcomes in the present review is its emphasis on studies with a neurobiological foundation. As Murray et al. (2021) noted, a lack of robust theoretical foundation was a common limitation in many of the studies they reviewed. Addressing this issue may have potentially contributed to the identification of studies with more clearly articulated aims, content and measurement strategies. However, other factors may also be at play, including potential data bias. Despite utilizing multiple databases with broad coverage, some relevant studies may have been inadvertently excluded. Additionally, the relatively small number of total participants and the modes sample sizes within individual studies may have influenced the findings.

In accordance with the scoping review framework (Arksey and O'Malley, 2005), this review prioritized mapping the field rather than concluding a systematic evaluation of study quality. A more detailed statistical synthesis could have yielded a more nuanced understanding of intervention effects, but such an approach would have limited our opportunity to explore intervention characteristics in depth.

The review indicates that yoga, mindfulness and other introjective practices are the most commonly employed activities in school-based interventions targeting regulation. Other practices include play and playful activities, somatic stimulation, expressive dance, martial arts, gross motor activities and classroom climate interventions. Consequently, most of the activities proposed in the literature (Williams and Shellenberg, 1996; van der Kolk, 2014; Porges, 2011, 2017; Cheatum and Hammond, 2000; Warner et al., 2020; Porges and Porges, 2023; Butler, 2024) are presented. Notably, absent are, nature-based activities (Butler, 2024) and teachers' use of voice and facial expressions. These areas remain underexplored and warrant future investigation. Furthermore, the uneven distribution of activities across the reviewed studies highlights the need for further exploration of play, somatic stimulation, dance, martial arts, team sports, gross motor activities and classroom climate interventions. Given the diversity of populations experiencing regulatory difficulties and the inherent heterogeneity within any school class, broadening the scope of empirical research on bottom-up strategies is urgently needed. While yoga, mindfulness and other introjective practices are easy to implement in school and appeal to many people, they may not work for all. Also, introjective practices facilitate dominantly downregulation, whereas a healthy ANS needs to be capable of both down-, up- and sideways regulating (Gray, 2017).

No clear patterns emerged indicating that any single activity or strategy was consistently more effective than others, although the evidence supporting introjective practices appears most robust. However, given that many of the other activities and strategies were examined in only one or two studies—or in combination with other elements—no definitive conclusions can be drawn. Additionally, introjective practices were frequently implemented alongside other strategies, complicating efforts to isolate their specific effects. Based on prior literature (Warner et al., 2020) which suggests that a combination of several types of stimuli may be more effective compared to isolated stimuli, it is plausible that the observed benefits stem from the combination of strategies rather than a single component. This hypothesis is further supported by research on whole-school approaches, which integrate various activities with cultural and psychosocial initiatives and involve children, school staff, caregivers, and other stakeholders (Goldberg et al., 2019). None of studies included in this review employed such comprehensive model. Future research should investigate both individual strategies and combinations to enable meaningful comparisons and conclusions.

Furthermore, no consistent associations were found between specific activities and particular outcomes. For example, introjective practices were linked to cognitive (Wisner and Starzec, 2016; Flook et al., 2010; Hagins and Rundle, 2016; Mancini, 2020; Rice et al., 2023), emotional (Mendelson et al., 2010; Wisner and Starzec, 2016; Kang et al., 2018; Bauer et al., 2019; Fung et al., 2019; Mancini, 2020; Cañabate et al., 2020; Nguyen and Dorjee, 2022; McMahon et al., 2021), behavioral (Flook et al., 2010; Wisner and Starzec, 2016; Fung et al., 2019; Mancini, 2020; Carro et al., 2023; Rice et al., 2023), and neurochemical (Carro et al., 2023) outcomes. Conversely, cognitive outcomes were associated with introjective practices, martial arts (Lakes et al., 2013; Mancini, 2020), small-sided games and drills (Lind et al., 2018), light aerobic exercise, HIIT (Latino et al., 2025) and gross motor activities (Chen et al., 2014; Anzeneder et al., 2024), while emotional outcomes were observed in studies involving introjective practices, martial arts (Mancini, 2020), play (Flook et al., 2010; Hagins and Rundle, 2016; Miller et al., 2017; Carro et al., 2023; Rice et al., 2023), rituals of entering and leaving and classroom climate (Cañabate et al., 2020).

Thus, findings suggest that various bottom-up strategies can influence multiple dimensions of regulation, and that each regulatory domain—cognitive, emotional, behavioral and neurobiological—can be addressed through diverse approaches. From a neurobiological perspective, which conceptualizes the prefrontal cortex and the arousal systems as integrated and reciprocal components of regulation (Meyes, 2000; Blair, 2018; Porges, 2011, 2017; Dana, 2021; Porges and Porges, 2023; Butler, 2024), this multiplicity of effective strategies is theoretically coherent. Nonetheless, to understand more about the underlying mechanisms and to be able to create targeted interventions, further research is needed to determine whether specific strategies are better suited to particular aims, contexts, or participant groups.

Furthermore, the selection of measures and outcomes in reviewed studies is closely tied to their theoretical and/or empirical foundations. For instance, isolated gross motor activities were employed in only two studies, both which were theoretically grounded in the presumed relationship between physical activity and cognitive function. Consequently, these studies focused exclusively

on cognitive outcomes (Chen et al., 2014; Anzeneder et al., 2024). This illustrates how theoretical and methodological choices significantly shape the results, and by extension, influence what is known about the effects of each intervention strategy. To gain a more nuanced understanding of the potential of each strategy, it is essential to incorporate a broader range of perspectives in future research. To avoid the challenges identified in previous research, such a broadening of perspectives should be carried out in a systematic manner.

The theoretical and methodological foundations across the included articles exhibit considerable variation, reflecting a fragmented and heterogenous research landscape. Diverse conceptualizations of regulation are evident, accompanied by a wide array of measures and outcomes. This multiplicity of perspectives and methodological approaches complicated the synthesis process and limited the ability to draw definitive conclusions regarding the efficacy of specific strategies.

Accordingly, there is a need for a clearer terminological consensus and future research to be anchored in robust theoretical frameworks and to employ methodologically rigorous designs. Such efforts have been requested by others too (Chen et al., 2024) and are essential for building consensus within the field and advancing a deeper understanding of what works, how it works, and why it works in the context of improving regulation.

Notably, the cognitive, emotional and behavioral dimensions of regulation (Meyes, 2000) were prominently represented in the reviewed studies, whereas physiological and neurochemical measures were employed in only three (Bauer et al., 2019; Carro et al., 2023; Mastromatteo et al., 2023). This imbalance highlights the need for further exploration of the physiological and neurochemical aspects of regulation. Integrating these measures with cognitive, emotional and behavioral assessments could yield valuable insights into the interrelationships among different regulatory domains.

Studies that incorporate multiple levels of measurement, such as those by Wisner and Starzec (2016) and Carro et al. (2023), suggest potential overlaps and interactions between different domains of regulation. Such findings may contribute to the identification of the most appropriate and valid methods for assessing regulation in children and adolescents, as well as enhance our understanding of the mechanisms underlying development of regulatory skills and intervention efficacy. Effective, knowledge-based interventions could further benefit especially the vulnerable populations who run a risk of health and behavioral problems associated with low regulatory skills (Berger, 2011; Robson et al., 2020).

5 Conclusion

This review demonstrates that a wide array of bottom-up strategies has been implemented in school settings to support and enhance regulation among children and adolescents, with the majority of studies reporting positive outcomes. This indicates that such strategies could be used to facilitate learning and social relationships among vulnerable populations without disadvantaging others. However, the field is characterized by considerable heterogeneity in terms of intervention type, target populations, and outcome measures. No consistent patterns have emerged regarding the relative effectiveness of specific strategies.

Introjective practices, such as yoga and mindfulness, are the most extensively studied and currently possess the strongest evidence base. In contrast, other approaches—including play, dance, gross motor activities, and classroom climate interventions—remain underexplored. Expanding the scope of research is essential to capturing the complexity of regulatory processes and the multitude of difficulties and interests among children and adolescents. Notably, none of the reviewed studies employed a whole-school approach which could offer a more comprehensive understanding of regulation and facilitate the integration of intervention across subjects, activities and stakeholders.

The lack of theoretical and methodological coherence across studies further complicates the interpretation of findings and limits the generalizability of results. These inconsistencies underscore the need for more rigorous research, grounded in robust theoretical frameworks and encompassing a broader spectrum of strategies. Such research is essential to determine which approaches are most effective in specific contexts and for different student populations.

Author contributions

LI: Methodology, Project administration, Conceptualization, Writing – original draft, Investigation, Writing – review & editing, Data curation. TB: Data curation, Investigation, Writing – review & editing, Conceptualization. S-IN: Data curation, Conceptualization, Writing – review & editing, Investigation. HM: Data curation, Methodology, Conceptualization, Writing – review & editing, Writing – original draft, Investigation.

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