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# The neuroscience of emotion regulation development: implications for education

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Emotion regulation is a critical life skill that can facilitate learning and improve educational outcomes. Developmental studies find that the ability to regulate emotion improves with age. In neuroimaging studies, emotion regulation abilities are associated with recruitment of a set of prefrontal brain regions involved in cognitive control and executive functioning that mature late in development. In this review we discuss the regulation of both negative and positive emotions, the role of other people in guiding our emotional responses, and the potential applications of this work to education.

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## Introduction

How a student feels can profoundly shape how he or she thinks. For example, emotions can promote learning by capturing and holding attention as well as deepening encoding [1–3]. But they can also inhibit learning by blocking these cognitive processes in the face of threat [1,4]. Thus, what emotions are elicited and whether a student can adaptively manage those emotions can have a strong impact on his or her learning. Given the multiple important roles emotion can play in educational contexts, it is essential that we understand how to promote and maintain emotional states that foster optimal learning. The capacity to regulate emotion may be key in this regard. Emotion regulation involves active attempts to maintain or change emotions and is a critical life skill that predicts positive life outcomes in adulthood [5,6]. The ability to regulate one's emotions can serve many purposes: it can both increase emotional arousal or positive valence to enhance learning, and it can help to dampen emotional responses that might be blocking successful encoding of new information. Here we discuss how the neural systems underlying emotion regulation develop and consider their educational implications.

## Neural mechanisms supporting emotion regulation

While there are many strategies that can be used to actively regulate one's emotions (for review see [7], McRae this volume), in brain imaging studies the most commonly studied strategy is reappraisal [8], which involves deliberately changing the way one thinks about the meaning of an emotionally evocative stimulus or situation. There has been increasing interest in the distinction between explicit forms of emotion regulation, like reappraisal, where one has an active goal of regulating and uses effortful control processes to do so, and implicit forms of regulation, where there may be no conscious goal to regulate and automatic processes may support emotion change (see upcoming review by Martin Braunstein *et al.*, 2016, and [8,9]). It remains for future work to study how explicit and implicit forms of emotion regulation differ in their developmental trajectories.

Reappraisal has been shown to be effective at dampening or enhancing responses in systems associated with affective responding. Chief among them is the amygdala, a subcortical structure important for signaling the presence, and modulating the encoding, of affect-relevant stimuli [10]. Also impacted by reappraisal is the ventral striatum, another subcortical structure implicated in signaling the reward value of stimuli [11], and the insula, a cortical region representing information about the body states associated with affective responses [12].

Reappraisal is believed to modulate these regions via recruitment of a network of regions including the dorsolateral prefrontal cortex (dlPFC), posterior parietal cortex (PPC), ventrolateral prefrontal cortex (vlPFC), posterior medial prefrontal cortex (mPFC) and anterior cingulate cortex (ACC) [8,13•]. This set of regions is not specific to emotion regulation, but is also commonly activated in tasks involving cognitive control more generally. The dlPFC is commonly active during selective attention and working memory tasks, which may aid in holding emotion-regulation strategies in mind [14]. vlPFC is commonly active during response selection and inhibition, which may help with selecting an appropriate reappraisal tactic [15]. Finally, mPFC and ACC are commonly activated in tasks involving selection among competing responses, and may help in identifying when regulation is needed [16].

## Development of the neural systems supporting emotion regulation

While neuroscience research on emotion regulation in adults has exploded over the past 10–15 years, developmental research has emerged only more recently. A popular theory is that prefrontal control regions like dlPFC and vlPFC mature at a slower rate relative to affective response regions like the amygdala and ventral striatum [17,18]. This imbalance is represented by a pattern of stronger activations in subcortical relative to cortical regions peaking during adolescence, which may contribute to mood instability and greater emotional reactivity in this age group [19•]. The imbalance theory may be an oversimplification of a more complex series of interactions between cognition and emotion taking place during development, where they can mutually inform, help, or hinder one another [20–23]. Thus, more studies investigating the maturational patterns of cortical–subcortical circuitry are undoubtedly needed in order to better understand how affect and mood change with age.

What does this slower maturity mean for a child's ability to manage his or her emotions? The answer to this question depends on the context of the situation including whether a child is responding to a negative or positive situation.

## Regulation of negative emotions across development

To date, only a handful of studies have examined the ability to regulate negative emotion in children as compared to adults. From these few studies, however, two kinds of key findings emerge. The first concern a child's ability to engage prefrontal systems to decrease a current emotion. Data suggest that the behavioral ability to down-regulate negative emotion, decrease amygdala activation [24] and increase activity in lateral prefrontal regions tracks with age [25,26]. Amygdala-prefrontal functional connectivity also increases with age, suggesting that stronger cortical–subcortical relationships underlie age-related increases in successful emotion regulation [26,27].

The second concerns negative environmental influences that can affect one's ability to regulate emotions. For example, in some situations, moderate levels of stress can enhance learning by way of increasing attentional vigilance [28]. However, acute stress (e.g. test anxiety) and outside factors contributing to chronic stress (e.g. poverty) can have deleterious effects on one's cognitive abilities [4,29,30].

Importantly, these decreases in cognitive performance may be mediated by one's ability to regulate emotion. For example, one study found that adolescents who were maltreated demonstrated more reactivity to negative emotional scenes in the amygdala and insula and greater recruitment of dlPFC and ACC regions when reappraising those scenes, suggesting more reactivity and more effortful regulation [31]. Growing up in conditions of poverty also can have a negative effect on the developing brain and one's ability to regulate emotions. Kim *et al.*, found decreased dlPFC and vlPFC activation and increased amygdala activation during a reappraisal task in adults who had experienced poverty during childhood compared to adults whose families had higher incomes during childhood [30]. In both studies, the groups who had experienced greater adversity demonstrated greater neural reactivity to negative images in amygdala and different patterns of activation in prefrontal cortex compared to the groups experiencing less adversity.

At the classroom level, training students on emotion regulation strategies (e.g. distancing, mindfulness, reinterpretation of negative scenarios — for examples see Refs. [32–35]) could be an effective intervention approach particularly for individuals or populations exposed to situations of high stress and adversity. Additionally, teacher development or training programs emphasizing the effects negative environmental influences can have on attention, cognition, and the ability to regulate negative emotions could help teachers build more effective classroom management plans, and perhaps provide more optimal support and scaffolding to struggling students.

## Regulation of positive emotions across development

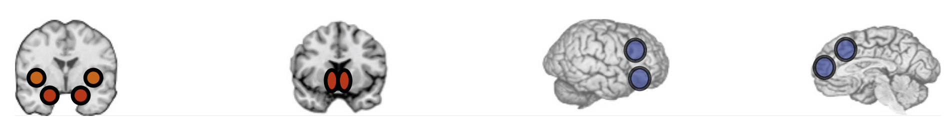
Another critical, yet less explored, area of research concerns the regulation of positive emotions. While negative emotions are thought to focus attention on and promote encoding of potential threats, positive emotions are believed to broaden one's attentional scope which can then facilitate enhanced learning and memory [36]. While developmental neuroimaging studies testing this hypothesis have yet to be done, there is a related literature on how children and adolescents respond to rewards. The role of ventral striatum in response to rewards across development is complex and in some cases conflicting, with some studies finding increases in activation in this region peaking during adolescence, whereas others find attenuations [19•,22,37]. Though few of these studies directly address regulation, in one reward domain — appetitive reactivity to foods — several studies found that application of reappraisal strategies led to decreased craving for rewarding foods and decreased activation in ventral striatum, and this decreased craving and activation improved linearly with age [38,39]. Interestingly, and in contrast to studies of regulating negative emotions, the key developmental differences were found in the degree to which children and adolescents craved the foods at baseline as compared to adults, rather than their skill in reappraising. Similarly, a study examining emotional reactivity to positive and negative scenes across age found that younger children showed greater activation in amygdala, ventral striatum, and vlPFC for positive pictures compared to negative [40]. Together these studies, though only a subset in a larger, more complex body of literature on reward processing, suggest that in certain positive domains, children's reward circuitry may be especially responsive to rewards and positive emotions, although they can successfully attempt to down-regulate these responses when desired.

These conclusions are echoed by studies of responses to feedback during learning, which is a fundamental component of any educational experience. Being rewarded for getting a good grade on an exam or experiencing the negative consequences of getting a bad grade can elicit an affective response and subsequent need for emotional management. Similar to the previously mentioned studies on reactivity to positive or rewarding stimuli, children may also be especially responsive to positive feedback. A study by Duijvenvoorde *et al.* comparing responses to positive and negative feedback across age found that all age groups performed better on a rule learning task when they received positive feedback compared to negative feedback, and this trend was the largest for eight to nine year olds [41•]. At the neural level, children in the eight to nine year old age group demonstrated greater brain activation during positive feedback compared to negative feedback, particularly in dlPFC and parietal regions, whereas adults showed the reverse trend, activating similar regions more than the other age groups when receiving negative compared to positive feedback. Similarly, in a belief-updating task on good and bad news by Moutsiana *et al.*, children were more likely to update accurately for good news compared to bad news, and with age, the differences in updating between good news and bad news decreased and lost significance in adulthood [42]. Responses to positive feedback activate different neural circuitry than responses to negative feedback and may follow different neurodevelopmental trajectories, which may explain why children learn better from positive feedback [43].

In sum, these findings suggest that while all ages are able to regulate positive emotions successfully, younger individuals may be especially responsive to positive rewards and feedback and therefore might need to deploy regulation more often. This knowledge can be harnessed in the classroom in a number of ways. For example, because

**Figure 1**

Type of Brain System



| | Emotional Reactivity | | Cognitive Regulation | |
|---|---|---|---|---|
| | amygdala & insula | ventral striatum | dlPFC & vlPFC | ACC & mPFC |
| **General Function** | • Encodes salient stimuli | • Signals reward value | • Selective attention, working memory & response inhibition | • Monitors need for control; directs affective signals |
| **Stimuli or Situations Where System Plays A Key Role** | • Responds to cues with negative or positive affective significance<br>• Tracks threat or exposure to stress and/or trauma | • Reacts to potential and/or actual rewards<br>• Responds to presence of peers particularly in adolescence | • Supports active self-regulation of emotion<br>• Supports attempts by caregiver to provide regulatory support | • Sensitive to conflict/ discrepancy between regulatory goals and current emotional state<br>• Involved in making judgments about emotional states |

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Overview of neural systems supporting emotion reactivity and regulation. Neuroimaging studies identify key brain systems involved in emotional reactivity and regulation along with their proposed function and the environmental stimuli and/or contexts where they may play key roles — affective systems are triggered by the presence of particular stimuli; regulatory systems are being brought online to actively implement strategies for regulating one's own or others' emotions.

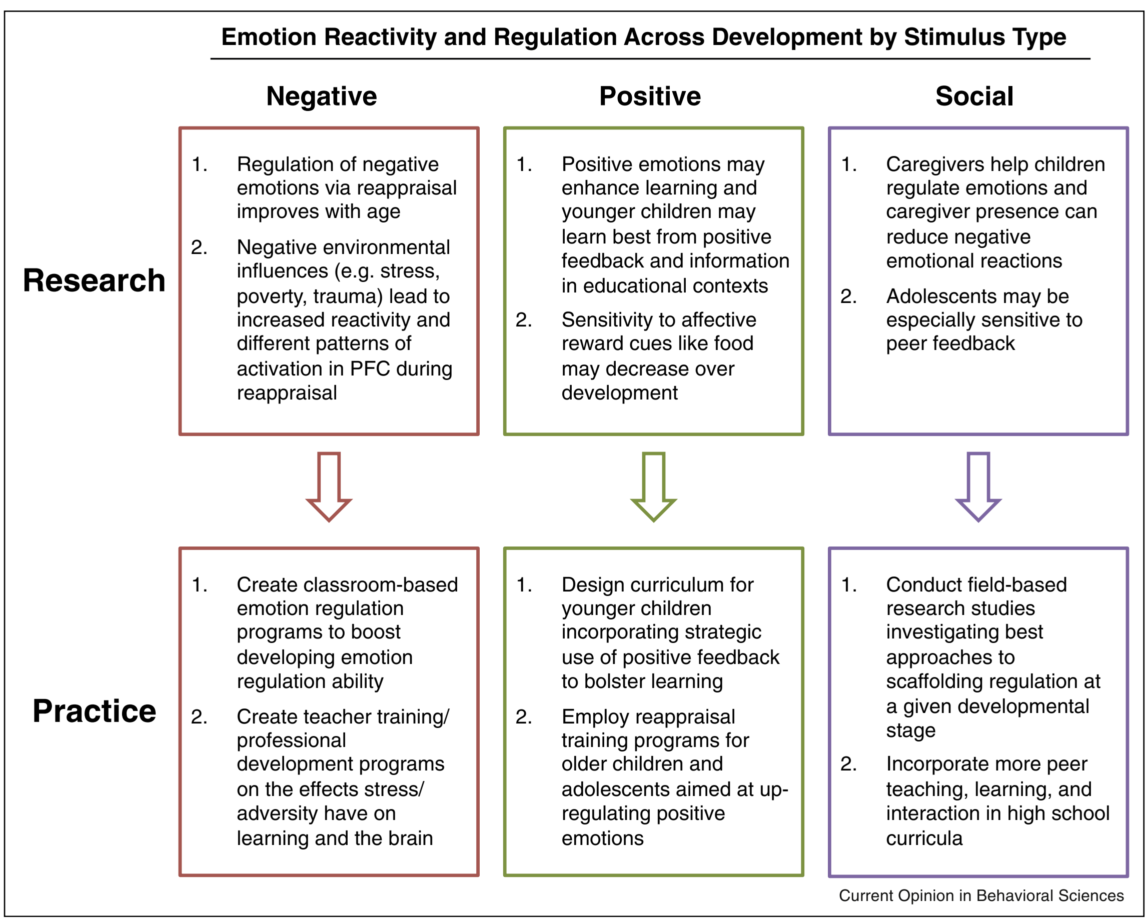
positive stimuli elicit stronger reward responses in young children and we know that they are capable of regulating them, curricula could be designed with rewards that incentivize learning as well as reminders to regulate when appropriate. And for older children and adolescents who may not be as engaged by rewards, curricula could attempt to teach them to effortfully attend to and elaborate the rewarding aspects of material they are learning (thereby up-regulating positive responses).

## The social regulation of emotion

Although our emotions are experienced individually, any parent or teacher knows that they can be heavily influenced by the words and actions of other people. Such social forms of regulation — which clearly are important — have seen little neuroscience research, although interest in them is growing (see, e.g. Reeck *et al.*, 2016, and [38]) and related research on the interaction of social cognition and emotion during development is increasing [23,45]. While to date, there are no imaging studies directly examining how other people can help us reappraise — across development or in adults, studies examining other forms of social regulation are beginning to emerge [44•,46•]. For example, in children, the presence of a caregiver can have a buffering effect, reducing emotional and stress responses to negative stimuli [47,48]. Similarly, in the reward domain, the presence of a caregiver during a risky decision task decreased risky choices and increased activation in control regions including vlPFC and mPFC, and decreased ventral striatum and amygdala activation in adolescents [49•]. In each case, the presence of a caregiver modifies the affect-eliciting situation, altering the affective value assigned to stimuli.

In analogous fashion, the presence of peers may influence recruitment of brain regions that trigger negative and positive emotions. In contrast to the role of parents, however, the presence of a similarly aged peer may increase risky decision making as well as ventral striatum and vlPFC activation in adolescents [50,51]. Similarly, in tasks involving peer rejection, adolescents show increased activation of ACC and mPFC, regions which have been

**Figure 2**




Linking research and practice. Summary of studies of the development of emotion regulation as a function of the type of emotion triggering stimulus. Top boxes describe key research findings and lower boxes describe potential educational applications based on research findings.

associated with depression and social pain; individual difference factors like rejection sensitivity, depression and resistance to peer influence may moderate these effects [52,53]. Taken together, this work shows how social regulation can modulate neural architecture and subsequent behavior.

## Discussion

Because emotions can enhance or impede learning, the ability to regulate one's own and others' emotions can facilitate successful educational outcomes. Emotion regulation is a type of emotion–cognition interaction where cognitive control systems are believed to aid in dampening or enhancing negative and positive emotions (Figure 1). Since brain regions associated with cognitive control structures — such as prefrontal cortex — may have a slower maturational trajectory relative to structures associated with emotional responding — like the amygdala and ventral striatum — children and adolescents may have a harder time regulating their emotions. Weaker or less organized functional and structural connectivity between these brain regions in childhood may also be contributing toward increased difficulty with emotion regulation [54–56]. That said, extant data suggest a dissociation between the negative and positive affective domains: children and adults respond similarly to aversive stimuli and children have greater trouble regulating responses to them; by contrast, children respond more strongly to rewards than do adults and all age groups can regulate responses to them. Of course, dispositional factors such as depression and anxiety and situational factors outside the classroom such as stress or abuse can enhance emotional reactivity or impair prefrontal function, either of which may make emotion regulation more effortful.

Importantly, these data could be leveraged to influence curricula and policy (Figure 2). For example, because positive emotions, feedback, and rewards may facilitate better learning, using regulation strategies to enhance positive emotions could be an effective approach in educational settings. And more generally, understanding how students regulate (or fail to regulate) emotions given their developmental stage and background can help educators better scaffold and manage their classrooms to enhance learning and successful student outcomes. Finally, a key direction for future work is understanding how other people play a role in helping students manage their emotions. While we know that educators and caregivers can help reduce negative emotions in children — and adolescents may be especially sensitive to the influence of their peers — little is known about how such behavioral effects relate to the development of underlying neural systems.

Attention, executive functioning, memory and learning are all cognitive constructs critical in understanding how to improve learning and teaching, however, often before any of these cognitive functions can happen, they have to pass through the filter of an individual's emotional experience. As such, helping students, teachers, and families better understand the mechanics behind emotion regulation development and learn how to employ appropriate strategies could make for a more engaging, dynamic, and effective educational experience for all.

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## Conflict of interest

Nothing declared.

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