Inter-disciplinary Perspectives on Meta-cognition, Self-regulation and Self-efficacy

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Abstract

Definitions of meta-cognition typically have two components: (1) knowledge about one's own cognitive functioning; and, (2) control over one's own cognitive activities. Since Flavell and his colleagues provided the empirical foundation on which to build studies of autonoetic (self) knowledge, the intervening years have seen the extensive dissemination of theoretical and empirical research on meta-cognition which now encompasses a variety of issues and domains including neuroscience and educational psychology. Nevertheless, the psychological and neural underpinnings of meta-cognitive reflections and predictions that determine subsequent regulation of task performance remain ill understood. This article outlines the conception of meta-cognition, and reviews evidence from neuroimaging, psycho-physiological, and psychological literature to rigorously explore emerging research on the development and function of processes that: (a) control meta-cognition, self-regulation, and self-efficacy; (b) interact with the learning environment in ways which (c) improve task performance and support successful learning outcomes across the span of learners' lifetimes.

Keywords: meta-cognition, self-regulation, self-efficacy, self-reflection, neural architecture.

Introduction

Meta-cognitive processes were first discussed by psychologists interested in strategies for improving memory and the recall of information (Flavell, 1976; Flavell & Wellman, 1977; Flavell, 1979). The foundational work of Flavell and his colleagues provided an empirical scaffold upon which to build studies of self-knowledge (Fleming & Dolan, 2012). The intervening years have seen the extensive dissemination of theoretical and empirical research on meta-cognition that now includes a variety of issues and domains including educational psychology. Nevertheless, the psychological and neural underpinnings that determine the accuracy of meta-cognitive reflections, and predictions and the subsequent regulation of task performance are not well understood.

The development of self-regulatory strategies which permit individuals to exercise control over, and shape, their learning so that it leads to successful outcomes is the *sine qua non* of effective schooling. This is because much of the individual variation between learners with regard to task performance can be explained by their capacity of self-control and self-regulation (Hasselhorn & Labuhn, 2011). When learners are 'being meta-cognitive' they take charge of their own learning (Hacker et al., 2009), and consciously direct effort toward improving task performance (Harlen, 2006).

Meta-cognition is differentiated from cognition as the latter concerns performing a task (e.g. summing a column of numbers), and the former the regulation of that performance by concurrent processes of monitoring and evaluative reflection on the quality of the performance (Clark, 2012) often referred to as 'thinking about thinking'. This two-level framework has extended beyond studies on information recall to encompass the monitoring of perception (Rounis et al., 2010), decision-making (Fleming et al., 2010), sense of agency (Morsella et al., 2009), and learning (Dienes, 2008). This article outlines the conception of meta-cognition, and reviews evidence from neuroimaging, psycho-physiological, and psychological literature to rigorously explore emerging research on the development and function of neural processes that: (a) control meta-cognition, self-regulation, and self-efficacy; (b) interact with supportive learning environments in ways which; (c) improve task performance and support successful learning outcomes.

Neural Structures Recruited During Meta-cognition

The notion that the average person uses only approximately 10% of their brain's capacity is a myth. In reality, the performance of complex tasks entails the recruitment of the entire spatial extent of the brain and the vast range of mental facilities that it supports (Kounios et al., 2008; Chein & Schneider, 2012). Recent neuroscience indicates that the full extent of our brain's resources are available at any given moment, however we access them selectively. The brain recruits specific brain circuitry in a coordinated way so it may deal with momentary demands (Chein & Schneider, 2012). This selectivity and coordination are functions of the meta-cognitive architecture.

The prefrontal cortex (PFC) has been isolated as the region of the human brain recruited during the employment of meta-cognitive strategies. The proposition that meta-cognition is under neural control is supported by a burgeoning amount of neuropsychological literature (Fleming and Dolan, 2012). Neuroscientific studies have suggested that a defining function of the anterior PFC may be meta-cognitive awareness, or the process of reflection upon one's own mental contents (Stuss, 2011). Moreover, Schmitz et al. (2006) found that individuals with defects or injury in the PFC exhibited deficits in autonoetic knowledge.

More specifically, there exists a dynamic bi-directional relationship between the PFC and the learning environment, which interacts at increasingly optimum levels when the environment supports the use of meta-cognitive strategies. McCaig et al. (2011) used a neuroimaging technique called fMRI to demonstrate that participants can learn to regulate the rostrolateral PFC (RLPFC) by using a meta-cognitive awareness strategy. It was found that individuals can achieve improved regulation over the level of neural activity in their RLPFC by turning attention towards (or away) from their own thoughts by noticing the nature of any thoughts that appear, e.g. "planning", "rehearsal", "worrying", "judging" etc.

The PFC is made up of a number of structures. Fleming and Dolan (2012) found different areas of the PFC are recruited for prospective (i.e. looking forward) and retrospective (i.e. looking backward) judgement making. When making prospective judgements participants were observed to recruit the ventromedial pre-frontal contex (vmPFC) due to its role in imagining the future (Sharot et al., 2007). Further proof of the neural basis for self-knowledge was provided by Schyner et al. (2004). They found that damage to the vmPFC decreased the capacity to make accurate judgements about future performance while leaving the level of self-efficacy unaffected. In the case of retrospection (or meta-cognitive reflection) on past task performances the anterior and dorsolateral PFC is recruited. Evidently, the healthy development and functioning of the substrates within the PFC is essential for accurate self-knowledge and reflection. Environmental stress plays a key role in PFC development and functioning. It will be seen later in this article that environmental stress may "impede the development of reflective and goal-directed self-regulation of behavior such as that needed for success in schools" (Blair, 2010) (see a later section in this paper entitled

"The learning environment and self-efficacy").

The Development of the PFC Across Time

Foundational studies (e.g. Flavell, 1979) by developmental psychologists found that self-evaluation and control improved during the course of early childhood. Recent studies of neuroanatomical changes have revealed that the PFC continues to develop throughout childhood and adolescence (Dumontheil et al., 2008). Magnetic resonance imaging (MRI) research has revealed that the PFC changes a great deal during adolescence, as the brain's myelin matures and connects all regions of the brain together. This prolonged development is often advanced as the reason for otherwise intelligent and sensible adolescents engaging in high-risk or excessive behaviors even when they understand the potential dangers. Fecteau and colleagues (2007) demonstrated the influence of the PFC over risk-taking by diminishing risk-taking behaviour in healthy participants (n = 36) by modulating neural activity in that region.

An anatomical feature of particular significance is myelin, a fatty substance which coats the white matter in the human brain and improves signal transmission to the grey matter. White matter (60% of brain volume) is therefore made up of nerve cells full of myelin. It works in conjunction with grey matter (only 40% of brain volume, but uses more than 90% of total oxygen) in a way analogous to that of how a computer's CPU works with its cables. In this analogy grey matter is the CPU and white matter the cables connecting the CPU to other parts of the system. Structures within grey matter process signals originating in the sensory organs and other areas of grey matter.

Increased white matter volume has been observed in adults (mean age = 27) compared to children (m = 10) (Klingberg et al., 1999) demonstrating that maturation of the PFC continues into the second decade of life. Studies find the opposite case for grey matter inside the PFC. Sowell et al. (2004) scanned children (n = 45) 2 years apart between ages 5–11. The grey matter decreased significantly over the two year period. Similarly, Konrad et al. (2005) observed a reduction in grey matter during adolescence with a smaller grey matter volume in adults (20–34 years). The density of grey matter is associated with intelligence and unique skills. Such individuals tend to have high levels of grey matter in the parts of their brains which correlate to the performance of that particular task. A finding of particular significance regarding grey and white matter volumes is that meta-cognitive ability is correlated with grey matter volume in the anterior PFC, a region that shows marked evolutionary development in humans. Moreover, inter-individual variation in introspective ability is also correlated with white-matter micro-structure connected with this area of the PFC (Fleming et al., 2010). These findings point to a focal neuroanatomical substrate for meta-cognitive processes essential for "good learning".

Accurate Meta-Cognitive Judgement

Hasselhorn and Labuhn (2011), of the German Institute for International Educational Research, note that it is "hardly possible" to empirically separate the many different and complex aspects of meta-cognition. Consequently, experimental designs focus on the measurement of those processes essential to, and constitutive of academic achievement, including but not limited to: (a) the accurate selection of learning and thinking strategies in terms of their usefulness and limitation; (b) the accurate prediction of future task performance; (c) the allocation of learning time and so on.

Neuroscientific studies often attempt to measure meta-cognition by asking participants to make judgements before (prospective) and after (retrospective) task performance. Prospective 'feelings of knowing' (FOK) are studied by asking participants general knowledge questions, and where they do not know the answer then asking them if they believe that they will be able to select it from a multiple choice set. Another prospective measure of judgement is 'judgement of learning' (JOL). This elicits a belief on how much has been learned and will be recalled later. This personal belief that one's efforts will produce successful outcomes equates to self-efficacy. Participants in neuroscientific studies are also required to give retrospective reports on their confidence in their prior judgements regarding task performance. In healthy individuals meta-cognitive judgements are usually predictive of subsequent task performance (Schwartz & Metcalfe, 1996). However, where damage has occurred to the PFC the accuracy of prospective judgement is diminished, yet self-efficacy remains the same (Schyner et al., 2004). This indicates both a neural basis for accurate levels of self-efficacy and the very significant influence of self-efficacy over the quality of subsequent task performance for healthy learners.

Teaching Strategies for the Regulation of Task Performance

As Garvert and colleagues (2015) state in their study of the PFC, "learning induces plasticity in neural networks" (p. 1). Plasticity, or neuroplasticity, describes how experiences reorganize neural pathways in the brain. Long lasting functional changes in the brain occur when we learn new things or memorize new information. According to Nelson (1999) there are 3 mechanisms by which experience causes changes in the brain. The first is an anatomical change, which alters the capacity of existing synapses to modify activity by sprouting new axons, or by expanding the dendritic surface. A second is a neuro-chemical change, which causes existing synapses to modify activity by improving the synthesis and transmission of signals. Finally, changes in metabolic activity in the brain in response to experience (e.g. the use of oxygen and other nutrients).

These transformational processes are evident in non-human species, and there is some evidence to suggest that some animals (dolphins, pigeons, rats, monkeys and apes) do have the meta-cognitive potential to reflect on their cognitive states (Smith, 2009). For humans however, the plasticity to learn strategies that facilitate control over cognition permits leadership in collective settings (agency); of particular importance in what is "a difficult period of rapid change, in which the way ahead would be difficult to discern" (Central Council for Education, 1996). This evolving situation requires learners to become active agents who control and shape thinking and learning.

The Development of Agency and Control

"To be an agent is to intentionally make things happen by one's action ... The core feature of agency enables people to play a part in their self development, adaptation, and self-renewal with changing times" (Bandura, 2001, p. 2). Times are indeed changing, and curricula which drive didactic forms of instruction where students are mere passive recipients "do not function in the rapidly changing technological and globalized world of today where it is not possible to establish which type of knowledge is needed in the next 5 or 10 years let alone a lifetime" (Hoskins & Fredriksson, 2008, p. 11).

For learners to be agents they must first believe that they have a mind capable of meta-cognitive control over the performance of a particular cognitive task. For example, children do not try to retrieve events or names before they understand they have a mind able to remember (Carruthers, 2009). Further, when given new information, 3-year old children claim to have always known it (Sodian et al., 2006) and do not know the difference between secure knowledge and making a guess (Gopnik & Astington, 1988). As children develop beyond infancy, they continue to display sub-optimal autonoetic awareness, reporting an over optimism about their capabilities and only rarely reflecting on task performance. As the brain matures into a more "distributed" network (Fair et al., 2009), children as young as 8 begin to accurately self-assess their knowledge (Hasselhorn and Labuhn, 2011). The age range of 7–9 was also found to be a significant developmental milestone in lower order information processing (recall) and higher order meta-cognition (restructuring) in neuroscientific studies by Fair et al. (2009) and Supekar et al. (2010).

As children grow they experience more of the social world by verbally interacting with others. With the emergence of language they can then explicitly represent their role in a social group and begin to experience a sense of agency. Children also begin to realise that others may be wrong about the world, and use their nascent meta-cognitive skills to monitor and evaluate the accuracy of their own thinking and exercise control over their environment (Frith, 2012). Perhaps inevitably, the development of accurate self-knowledge is accompanied by a decrease in the pleasure derived from learning. This indicates that inaccurate self-awareness and self-efficacy protect achievement motivation in the early stages of neural development (Hasselhorn & Labuhn, 2011).

As neural structures mature, increasingly complex verbal interactions with others help learners to overcome the lack of direct access to their underlying cognitive processes, thus making their thinking transparent to themselves and also to others. However, it is worth noting, in the context of agency, that not all verbal interaction supports agency. Bandura (1997) emphasises that teachers should, as the starting point, de-emphasize social comparison and de-personalize feedback because "construal of low attainments as indicants of inherent personal deficiencies erodes a sense of efficacy" (p. 118). The erosion of self-efficacy pushes students into a spiraling pattern of disaffection, which diminishes students' potential to exercise control over task performance.

Shaping Minds and Strategy Acquisition

It is a fact that most young learners experience a challenging array of distractions and pressures both inside and outside school that often intensify as they travel along the educational pipeline and enter high school (see, Burrus & Roberts/Educational Testing Service, [ETS], 2012). The strategy of sustaining effort in the face of distraction is itself a key SRL strategy (Clark, 2012; Zimmerman & Pons, 1986). Indeed, where learners are unable to exercise control over environmental distractions it follows that other SRL strategies, while theoretically available, may not be accessible for use. Learners may therefore benefit from interventions designed to strengthen SRL strategy acquisition and use. One such program is the 'Self-regulation Empowerment Program' (SERP) devised by Cleary and Zimmerman (2004). SERP is an application of socio-cognitive theory, combining diagnostics and training in SRL.

The neural plasticity of the PFC means that programs such as SERP can be implemented in order to train learners how to monitor and reflect on the relationship between strategy selection and task performance. Lodico (1983) found that children who were taught to monitor strategy use chose more effective strategies, and understood that their selection would improve task performance. Evidence from foundational studies in neuropsychology (e.g. Lodico, 1983) and modern neuroscience (e.g. Garvert et al., 2015) indicate that learners may be trained to acquire and use new and potentially powerful self-regulatory learning strategies. If students are to become self-regulated learners they must first adopt a "growth mindset" as seen in the work of Dweck (1986; 2006) on fixed vs. growth mindsets. Dweck finds that individuals who believe that their minds are indeed plastic (growth) are more competent and effective learners than those who believe that they cannot improve with practice (fixed). The question then becomes one of exactly how can learners be given the power to oversee and steer their own learning?

Effective schools encourage plasticity by devising supportive learning environments (Clark, 2014) and delivering curricula that promote learning autonomy (Clark, 2015). Staff members model and scaffold "good learning" by providing written and particularly verbal feedback which explains *how* task performance may be improved, thus scaffolding the learners' control over the re-drafting and self-correction of learning-work (as seen in the work of Black and Wiliam on formative assessment). This kind of feedback is known as 'formative feedback' (Black & Wiliam, 2009). The objective of formative feedback is the deep involvement of students in meta-cognitive strategies such as personal goal-planning, monitoring, and reflection, which support SRL by giving learners "the power to oversee and steer one's own learning so that one can become a more committed, responsible and effective learner" (Black & Jones, 2006, p. 8).

Formative Feedback

Feedback is described by Winne and Butler (1994) as, "information with which a learner can confirm, add to, and overwrite, tune, or restructure information in memory, whether that information is domain knowledge, meta-cognitive knowledge, beliefs about self and tasks, or cognitive tactics and strategies" (p. 5740). Nicol and MacFarlane-Dick (2006) argue that formative feedback should be used to empower students as self-regulated learners, and contend that because formative feedback strategies enhance self-regulation all assessments should be restructured as formative assessments (Sadler, 1989; Nicol & Macfarlane-Dick, 2006). Butler and Winne (1995) underscore the centrality of feedback in regulating learning progression, "for all self-regulated activities, feedback is an inherent catalyst," (p. 246).

It is worthy of note that not everything that teachers believe to be feedback is in fact formative. For example, Hattie and Timperley (2007) derived effect sizes for formative and non-formative kinds of feedback. They obtain high effect sizes when students are given 'formative feedback'; that is, feedback on how to perform a task more effectively, and far lower effect sizes when students are given praise, rewards, or punishment. Simply telling a student to 'work harder' or 'recalculate your answer' does not possess the qualities of formative feedback or promote self-regulated learning because it does not strategically "scaffold" (Wood, Bruner & Ross, 1976) learning by informing the student how or why they need to do this.

Feedback becomes formative when the evidence of learning is used to adapt teaching to meet student needs (Black & Wiliam, 1998; Sadler, 1989). More specifically, students are provided with instruction or thoughtful questioning which scaffolds further inquiry and deepens cognitive processing. This instructional approach closes the gap between their current level of understanding and the desired learning goal (Vygotsky, 1978). This mutual process of continual readjustment causes learning to progress at a rate which is sufficient to motivate students to self-regulate the effort required to progress further (Butler and Winne, 1995). Feedback which informs the student of their current status and how to improve can boost self-efficacy and task performance, even after students experience initial difficulty performing the task (Assessment Reform Group, [ARG], 1999; Schraw & Moshman, 1995).

SRL Strategies

In summary, SRL is "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition," (Pintrich & Zusho, 2002, p. 250). Self-regulated students are meta-cognitively, socially, motivationally, and behaviourally active in problem solving processes. Students who have been exposed to teaching methods which reconstruct their identities as self-regulators typically deploy meta-cognitive strategies in order to exercise control over their work. Zimmerman and Pons (1986) conducted an important foundational study on female and male 10th grade students from a high achievement track (n = 40) and from other (lower) achievement tracks (n = 40). The researchers created 13 categories of SRL by which students monitored, regulated, and controlled task performance (see Table 1)

The students' membership in their respective achievement group was predicted with 93% accuracy, indicating that membership was determined by the extent to which they exercised accurate and effective control over their learning. Zimmerman and Pons (1986) conclude with the statement: "The present results suggest that theoretical conceptions of students as initiators, planners, and observers of their own instructional experiences have empirical and practical merit" (p. 626).

Table 1. The characteristics of self-regulated learners and the meta-cognitive strategies they use (Clark, 2012)

Characteristic	**Strategy**
These are students who:	
Self-evaluate	Assessing quality or progress
Keep records and monitor learning	Taking discussion notes or compiling a list of errors
Seek help from adults	Seeking social help from teacher or parents
Self-verbalize	Generating overt or covert prompts to guide learning
Adapt and invent new learning strategies	Using evidence to adapt and improve learning
Set goals and plan learning progression	Setting and prioritizing goals and sub-goals
Structure the learning environment	Choosing conditions which make learning easier
Manage time	Regulating progress to realize timely outcomes
Engage in peer learning	Seeking social assistance from peers
Use non-classroom resources	Seeking information, e.g., libraries, Internet
Are persistent and complete tasks	Maintaining activity despite difficulty or distraction
Use self-consequences	Giving self-rewards or sanctions
Memorize and rehearse information	Using strategies designed to improve recall
Are self-aware	Being non-judgmentally aware of own shortcomings

Meta-Cognition, Self-Efficacy and Self-Regulation

As already noted, the PFC continues to mature into adulthood. Accordingly, both metacognition and self-regulated learning are late developing higher-order competencies that are particularly useful when explaining individual differences between young learners (Hasselhorn & Labuhn, 2011). Inter-individual difference in meta-cognitive competence may be explained by three influential variables: (1) social influence; (2) the extent and intensity of individual activity; and, (3) the maturity of neural networks. In healthy brains the PFC matures throughout adolescence. This explains why many adolescents demonstrate a sub-optimal grasp of potentially powerful SRL strategy use, which become more developed as they approach early adulthood.

The effective use of SRL strategies is not only central to academic achievement. Autonoetic knowledge and control over thinking and learning is also essential to meet the demands of a rapidly developing society. Zimmerman and Moylan (2009) define SRL as a sequence of planning, performance and reflection. The planning phase entails task analysis and sources of motivation, especially self-efficacy. It is the level of self-belief and confidence, which determines the difficulty of the learning goals that learners pursue. Implicit to the performance phase is monitoring via processes of self-control and self-observation.. Reflection is of particular importance. The essence of meta-cognition is reflection on the individual learning process by comparing the learning outcome with a goal or standard followed by the performance of strategic activities (Hasselhorn & Labuhn, 2012). Reflection creates a pathway toward the use of SRL strategies, and links meta-cognition with learning achievement as seen in the work of Zimmerman and Pons (1986), and Kitsantas and Zimmerman (2002).

A theory of particular importance to the development of meta-cognates and competence in SRL is Bandura's (1986) Social Cognitive Theory (SCT), which emphasizes meta-cognition and self-efficacy as fundamental to the development of SRL. Coutinho (2008) found that the relationship between meta-cognition and the regulation of task performance was fully mediated by self-efficacy. This finding supports the proposition that learners with effective meta-cognitive strategies are driven by accurate assessments of self-knowledge which helps them to set realistic goals. Such learners hold a strong belief in their capabilities to perform a task successfully (Coutinho, 2008; Sadi & Uyar, 2013). These empirical findings indicate a need for training and practice in SRL strategies because the regular experience of such meta-strategies increases self-efficacy, which leads to the more active recruitment of the PFC (McCaig et al., 2011), which creates a virtuous cycle by strengthening subsequent meta-cognition. The existence, and then level of self-efficacy are central to SRL because children need to believe that their minds are capable performing meta-cognitive processes before they will make even fledgling attempts to regulate their own learning (Carruthers, 2009).

Hasselhorn and Labuhn (2011) note that an increasing body of empirical research has proved the strong link between the capacity to self-regulate learning, and key variables of personal development, such as self-efficacy. From a socio-cognitive perspective, as seen in Bandura's SCT, self-efficacy plays a key role. It is widely held that the level of self-efficacy influences the use of self-regulatory processes such as planning, goal-setting, accurate strategy selection and self-evaluation; all of which influence academic performance. For example, Zimmerman and Kitsantas (2005) found that the level of self-efficacy among adolescent girls (n = 179) predicted their use of SRL strategies (e.g. organizing, memorization and rehearsal, monitoring).

Black and Wiliam (2009) in their work on formative feedback emphasise that effective classroom dialogue "is concerned with the creation of, and capitalization upon, 'moments of contingency' in instruction for the purpose of the regulation of learning processes" (p. 10). The development of a 'moment' into a genuine opportunity for learning is dependent on the meta-cognitive awareness of students' and the accurate self-belief that their efforts will result in success (self-efficacy). A concept of particular relevance is 'reflection-in-action'; that blend of monitoring and reflection which together permit the *reshaping* of that being worked on while working on it (Schön, 1987).

There are also inter-individual differences in the sensitivity of self-reactive judgment to external feedback. This then impacts the level of effort they invest in a completing a task. It can be seen in Table 1 that being non-judgmentally aware of one's own shortcomings is a characteristic of successful learners. Similarly, Bandura and Cervone (1983) found that the increase in effortful behavior following feedback on substandard performance is greater for individuals who have high self-efficacy than in their non-self-regulated counterparts. It follows from this finding that if instructional feedback is to contribute jointly to self-regulation and achievement, teachers should carefully plan for how they will use questioning and feedback which supports the self-efficacy of the student, i.e., scaffolds their learning so it is the students who believe that they are leading, or at least participating in, the discussion or solving the problem as an active agent in their own learning. If this is done regularly, the learner will generate internal feedback which makes them more self-efficacious and self-regulated (Clark, 2012).

The Learning Environment and Self-Efficacy

Evidence from neuroscience reveals that a functional PFC supports predictions about future task performance, and establishes a neural basis for accurate self-efficacy. This (of course) does not imply that learners with healthy PFCs have high-levels of self-efficacy. Indeed, students' brains react strongly to the school environment, reporting emotions that range from apathy to anger (Gilman & Anderman, 2006) Therefore healthy neurological functioning needs to take place in a social and learning environment in which students feel supported psychologically because negative emotional states "can lower efficacy beliefs; the lowered beliefs, in turn, weaken motivation and spawn poor performance" (Bandura, 1997, p. 113). Bandura (1997) connects a high sense of self-efficacy with a forward looking outlook and the tendency to set personal goals. As an individual's perception of their self-efficacy becomes more definite the goals become higher and are more persistently pursued as realizable opportunities.

Environmental Stress and the Self-regulation of Learning

A number of studies on interactive learning environments emphasise the need for supportive environments that reduce psychological stress and distress (Bandura, 1997; Clark, 2012; Nicol & Macfarlane-Dick, 2006). The negative impact of stressful environments is elucidated upon by recent neuroscientific studies. For example, Holmes and Wellman (2009) found that exposure to even brief periods of intense stress is sufficient to cause significant structural remodelling of the neurons within the PFC, impairing cell communication and causing a significant degree of dysfunction to the regulation and control of cognition. These findings confirmed earlier studies by Weinstock (2001) and Meaney and Szyf (2005). Chronic early stress alters neural functioning and connectivity among various structures which results in lower performance on tasks requiring meta-cognition (Cerqueira et al., 2007); a finding of particular relevance for 'at-risk' students (Clark, 2014).

Further, a large sample study among first grade students (n = 10,700) found that students experience the stress of exhausted or anxious teachers vicariously, causing emotional and behaivoural problems (Milkie & Warner, 2011). This is a manifestation of "emotional-motor resonance" (Preston & de Waal, 2002); a phenomenon that neuroscientists propose to be a "phylogenetically early system for empathy" (Molnar-Szakacs & Uddin, 2013). The term "resonance" implies a cognitive tension 'between' human brains as they seek mutual insights, and jointly monitor social interaction. This shared tension is represented as brains activating in the same areas as they interact (Dumas, et al., 2012; Jackson et al., 2006).

One view of stress in the classroom is to view it as a "psychological lesion" (Nelson, 1999, p. 43), which promotes maladaptive learning and diminishes the self-efficacy required to drive meta-cognitive learning strategies. It has already been noted that environmental stress impedes healthy PFC development and functioning. However, it is important to note that a high reaction to stress does not of itself create risk. Indeed, it may enhance learning in supportive contexts (Boyce & Ellis, 2005), underscoring the influence of supportive learning environments. The relationship between the learning environment, PFC connectivity and meta-cognition is important because meta-cognitive information processing skills allow learners to acquire and use SRL strategies predictive of successful learning outcomes (Diamond, 2002). In summary, the PFC develops in a way that is conducive to reflective self-regulation in supportive learning environments (Blair, 2010).

Conclusion

Chein and Schneider (2012) note that the meta-cognitive architecture of the human brain has evolved across the last 150,000 years, expanding by 300–700% over the course of human evolution. Recent research has provided empirical evidence that the meta-cognitive system: (a) reconfigures the brain as it prepares to execute existing routines; and, (b) monitors cognition during the acquisition of new learning strategies. Although there is a lack of clarity about the manner in which different aspects of the PFC interact internally and with other distal substrates there is consensus that "the region most clearly implicated as a component of the metacognitive system is ... the anterior pre-frontal cortex" (Chein & Schneider, 2012, p. 82).

"A fundamental goal of education is to equip students with the self-regulatory capabilities that enable them to educate themselves" (Bandura, 1997, p. 174). This is a goal of particular importance in a world characterized by rapid technological change, cultural fragmentation and ecological responsibility. Learners therefore encounter novel situations that entail the recruitment of the meta-cognitive architecture in order to support: (a) the acquisition and integration of new learning strategies; and, (b) the accurate selection and use of strategies. Consequently, empirical studies find high levels of PFC activity during the acquisition of new knowledge, which then recedes to baseline after these new rules have been acquired and integrated (Cole et al., 2010).

The notion that accurate autonoetic (self) knowledge has value, and something to master has pre-occupied thinkers since the time of Socrates. Yet, that quality of self-knowledge required for learners to plan, monitor and reflectively evaluate task performance accurately is often absent. Even in learners with healthy brains, self-assessments are consistently poorer than assessments applied to others leading to what Pronin (2007) termed the 'introspection illusion'. A recent study has shown that this illusion may be manipulated to create higher levels of self-efficacy that support task performance in real and measurable terms (Zacharopoulos et al., 2014). This again supports a common call for learning environments in which students feel confident, supported and respected by their peers and school staff.

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