Chapter 4

Metacognitive Skill Development and Applied Systems Science: A Framework of Metacognitive Skills, Self-Regulatory Functions and Real-World Applications

Michael J. Hogan[1], Christopher P. Dwyer[2], Owen M. Harney[3], Chris Noone[4], Ronan J. Conway[5]

School of Psychology, National University of Ireland, Galway Co. Galway, Republic Of Ireland
[1]michael.hogan@nuigalway.ie, [2]cdwyer@nuigalway.ie,
[3]o.harney2@nuigalway.ie, [4]noonec@gmail.com, [5]rojconway@gmail.com

Abstract. Metacognition, or thinking about thinking [1], refers to the application and regulation of cognitive processes. According to Boekaerts and Simons [2], Brown [3] and Ku and Ho [4], individuals think metacognitively in two ways: first, individuals must be aware of their own cognitive processes (e.g. through self-monitoring or self-regulation); second, individuals must be able to apply available cognitive processes for purposes of learning or devising solutions to problems (e.g. using critical thinking or reflective judgment [5]). Though a topic of research interest for almost forty years, debate continues as to how best to conceptualise metacognition and cultivate metacognitive ability. However, due to what can be considered an exponential increase in the creation of new information every year [6,7], higher-order, metacognitive skills are needed more than ever in order to aid individuals and groups in becoming more adaptable, flexible and better able to cope in the context of a rapidly evolving information society. In order to help guide the facilitation of metacognitive understanding in educational and applied settings, this chapter draws upon recent research in the learning sciences to propose a new framework of metacognition. Specifically, we outline a model of metacognition that integrates processes associated with self-other representations, executive function, emotion regulation, mindfulness, motivation, thinking dispositions, critical thinking, reflective judgment and collaborative systems thinking skills, which can be fostered in the context of individual and team-based tool use. Two cases studies are presented, which provide evidence for the value of both argument mapping and collective intelligence tools in facilitating the development of higher-order critical, reflective and collaborative metacognitive thinking skills. The chapter concludes with a number of recommendations for future research on applied systems science and metacognitive skills development.

Keywords: Critical thinking, Reflective judgment, Mindfulness, Executive Functioning, Self-Regulation, Argument Mapping, Collective Intelligence.

Abbreviations

AM	Argument mapping
CACS	Conversational argument coding scheme
CSCL	Computer-supported collaborative learning
CT	Critical thinking
IM	Interactive management
RJ	Reflective judgment
RJM	Reflective judgment model

4.1 Introduction

One of the defining features of human evolution is the emergent capacity of human beings to think about thinking. Cultural evolution is itself a metacognitive process, as each new generation thinks about the thinking of previous generations - the contents of thinking, the process of thinking, the products of thinking - and modifies the culture of thinking in multifarious ways. However, the ontogenesis of metacognitive skills is a gradual and uncertain process that is contingent upon the quality of education and training children and adults receive. Like other artefacts of culture, systems of education and educational practices are products of our cultural evolution that are open to metacognitive reflection. Nevertheless, for those of us who have received a science education, or who are immersed in acts of inquiry as part of our work, we may take for granted the curious nature of metacognitive acts and not seek to modify educational practices. We may assume that metacognitive action is a cultural given – a commonplace and everyday activity.

Congruent with Jean Piaget's theory of cognitive development, we may assume that the development of critical, reflective and collaborative metacognitive thinking skills in adolescence and adulthood is an inevitable product of an orderly, cumulative, directional sequence of change – a movement from reflexes, simple representations and intuitive logic toward increasingly logical and adaptive representations of reality. Not only is this view fundamentally false, culturally bounded, and idealistic, it distracts us, with its wonderful simplicity, from the complexity of metacognitive skill development and the educational challenges associated with cultivating these skills. The continuous development and cultural evolution of metacognitive skills is always a hard earned path – the skill and determination of each generation is needed to foster the skill and determination of the next generation. Understanding and influencing metacognitive skill development is essential for further cultural evolution, and ultimately, our survival, adaptation and flourishing as a species.

Due to what can be considered an exponential increase in the creation of new information every year [6,7], higher-order, metacognitive skills are needed more than ever in order to aid individuals and groups in becoming more adaptable, flexible and better able to cope in the context of a rapidly evolving information society. Thus, it is widely recognized that the challenge of education implies more than a focus on developing domain-specific knowledge - also needed is metacognitive knowledge and skill, and approaches to enquiry that allow children and adults to think about their thinking and approach problems, solutions, experiments, explanations, and simulated actions with a mindful, reflective, collaborative sensibility that facilitates adaptive action at individual and group levels.

In this chapter, we outline a model of metacognition that integrates processes associated with self-other representations, executive function, emotion regulation, mindfulness, motivation, thinking dispositions, critical thinking, reflective judgment and collaborative systems thinking skills. Building upon research highlighting the importance of self-regulation skills as basic building blocks of higher-order thinking skills, we also highlight the value of mindfulness as an intra-personal and inter-personal asset that facilitates enhanced executive functioning and emotion regulation skill in both individual and group learning contexts.

Our framework proposes an integration of organismic and pragmatic models of skill development. Consistent with organismic models [8], we assume that skills can unfold at greater levels of integration and complexity; however, skilled action is a function of training, support and the collaborative dynamics of social groups. Consistent with pragmatism and functional contextualism, we also propose a pragmatic systems science framework [9] that highlights the value of specific tools and processes to support the training and collaborative dynamics of metacognitive skill development [10]. Ultimately, we argue that metacognitive skills can be seen as part of a collection of potentially synergistic talents that can be fostered in the context of individual and team-based tool use. We present two cases studies that provide evidence for the value of both argument mapping tools and collective intelligence tools in facilitating the development of higher-order critical, reflective, and collaborative metacognitive thinking skills. We close the chapter with a number of recommendations for future research on applied systems science and metacognitive skills development.

4.2 Metacognition: Foundational Definitions and Perspectives

Although the term metacognition is relatively novel, first described by Flavell [1] as "knowledge concerning one's own cognitive processes and products or anything related to them; and the active monitoring, consequent regulation and orchestration of these processes", the construct has been the focus of attention in recent years. Though a large body of research and theory on metacognition exists [e.g. 11, 12, 13, 14, 15, 16, 17, 18], the majority of scholars envisage a two-component framework. For example, according to Boekaerts and Simons [2], Brown [3] and Ku and Ho [4], individuals think metacognitively in two ways: first, individuals must be aware of their own cognitive processes (e.g. through self-monitoring or self-regulation); second, individuals must be able to apply available cognitive processes appropriately for purposes of learning or devising solutions to problems (e.g. using critical thinking or reflective judgment [5, 19, 20]).

According to Schraw and Dennison [18], the two ways in which individuals think metacognitively can be described as the regulation of cognition and knowledge about cognition, respectively. Though Schraw and Dennison [18] suggested the existence of eight sub-components of these two types of metacognition (e.g. planning, information management strategies, comprehension monitoring, debugging strategies, evaluation, declarative knowledge, procedural knowledge and conditional knowledge), the results of factor analyses revealed little evidence to support the eight component model; however, the two-factor model proposed was confirmed.

From a developmental and educational perspective, Kuhn [13, 21] defines metacognition by reference to three types of knowing, which differ in terms of their declarative, procedural, and epistemological focus. First, *metacognitive knowing* is a type of declarative knowledge – the knowledge a person may possess in relation to cognition. For example, Kuhn describes *Theory of Mind* as a form of metacognitive knowing, specifically, knowledge that mental states exist - with personal metacognitive knowing referring to knowledge about one's own mental states, and impersonal metacognitive knowing referring to knowledge about others' mental states. Theory of Mind is therefore seen as a fundamental building block of higher-order critical, reflective and collaborative metacognitive thinking, as having knowledge of mental states is a prerequisite for the ability to think about mental states and thus think about thinking.

The second form of metacognition, *metastrategic knowing*, involves procedural knowledge - a person's knowledge about cognitive processes and of their impact on performance. Metastrategic knowledge comes in two forms, according to Kuhn, metatask knowledge about task goals and metastrategic knowledge about the strategies one has available to address these goals. Metastrategic knowledge is seen as a fundamental driver of cognitive development in Kuhn's scheme, as thinking skills cannot develop in the absence of awareness and control over goals and strategies. Finally, the third form of metacognition, *epistemological knowing*, refers to an individual's understanding of what knowledge and knowing are in general, and how one comes to know. As argued below, the development of epistemological knowing is fundamental to high-level critical, reflective, and collaborative thinking skills.

Rather than constituting a single transition from one way of being to another, development, according to Kuhn, entails a shifting distribution in the frequencies with which more or less adequate strategies are applied, with inferior strategies increasingly inhibited as more superior strategies are acquired [21]. This is a view consistent with the tenets of Dynamic Skill Theory [8, 22], which characterizes skill structures that vary in terms of how key principles, abstractions, representations, and actions are coordinated in context, with the context itself having a significant influence on the level of coordination achieved. Transfer and generalization of skill from one context to another also depends in part on whether or not key transferable principles and abstractions that may serve to metacognitively regulate action are available as part of coordinated action sequences across contexts [22]. According to Kuhn, this developmental 'shifting' in strategy and skill involves meta-level actions that dictate which strategies are selected for use and applied on a given occasion. Increasing meta-level awareness and control has been identified as an important target for interventions focused on promoting cognitive development [13]; and thus, we argue below that tools that facilitate meta-level awareness and control (e.g. awareness of argument structures and control over critical and reflective thinking processes) may provide a tool-mediated context in which skills can be transferred from one thinking context to another. Furthermore, dispositions, principles and practices associated with self-regulation of individual or collaborative action may support the transfer and generalization of key processes (e.g. mindful observation and non-reactivity) that facilitate awareness and control across different thinking contexts.

4.3 The Synergy of Teams, Tools and Talents in Metacognition

There are many ways to conceptualise meta-level awareness and control; and an applied systems science perspective highlights the active and applied nature of these acts in context. Consistent with Skill Theory [22], there are a variety of principles and abstractions that may be coordinated with action in context and that may be critical for understanding meta-level awareness and control. These include *epistemological principles and abstractions* associated with critical thinking and reflective judgment, and *dispositional principles and abstractions* associated with key motivations and values that frame critical, reflective, and collaborative action in context. Furthermore, at a lower level in the skill hierarchy, there are a number of fundamental self-regulation skills that influence the development of meta-level awareness and control, including self-other representation, executive control, and emotion regulation.

The emergence of higher-order skills or talents in an educational context often occurs in a social context and in the context of tool use. Social and tool affordances serve to accelerate the development of skills or talents, including lower-order and higher-order metacognitive skills or talents. But, effective tool design needs to be coupled with effective instructional design and management of teams in order for individual talents to be cultivated and coordinated in a group learning setting [10, 23].

While the learning sciences have provided a great deal of insight into the cultivation of key talents at the individual level, including the cultivation of critical thinking skills using argument mapping training programs [24], more work is needed to understand the optimal conditions needed to coordinate talents in a group learning level ([25]; see below). Moreover, while tools and teams provide a supportive context for the cultivation of skills or talents (Fig. 4.1), a broader understanding of developmental trajectories of child and adult development is needed to optimize the fit between individuals, teams, and the tools they are using to facilitate skill development. Notably, tools and teams provide a supportive context that facilitates intentional self-regulation and metacognitive control of key learning processes. Researchers have highlighted both the conscious and non-conscious aspects of intentional self-regulation that can be conceptualised in a *dual process* model of decision-making [e.g., 26, 27]. The common feature of these dual process models is that decision-making is subject to two systems: a reflexive, *intuitive* route of decision-making and a reasoned, *reflective* route of decision-making [26, 28, 29, 30].

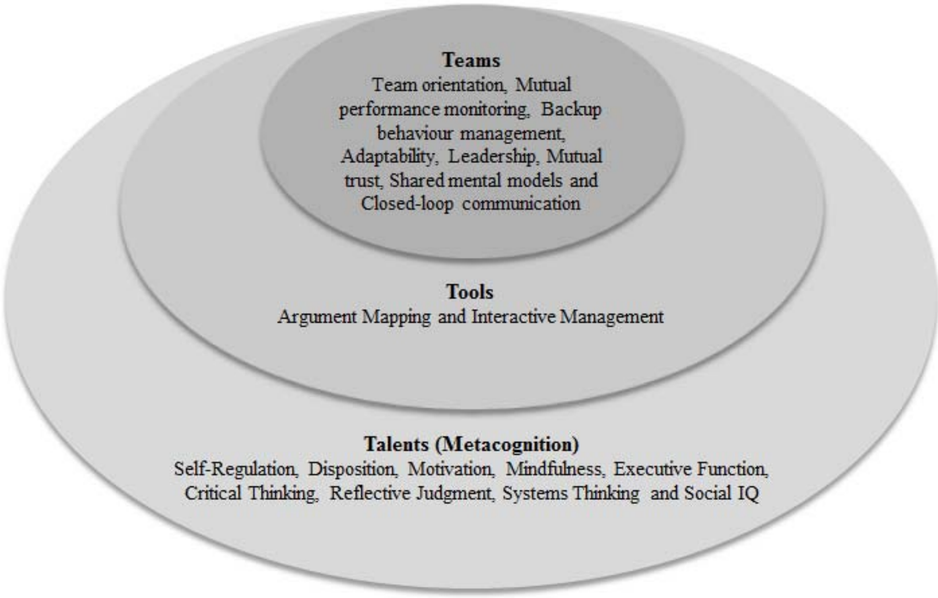

Fig. 4.1 The synergy of teams, tools and talents in metacognition

Intuitive judgment has been described as automatic cognitive processing, which generally lacks effort, intention, awareness or voluntary control - usually experienced as perceptions or feelings [26, 28]. This mode of decision-making has low consistency and is moderately accurate [30]. On the other hand, reflective judgment has been described as slow, conscious and consistent [31] and associated with high levels of cognitive control and conscious awareness and slow data processing [31, 32] and is generally quite accurate [30]. Essentially, reflective judgment allocates attention to the effortful mental activities that demand it (e.g. complex computation; [26]). Notably, the types of thinking necessary to make reflective and intuitive judgments are often considered as working in parallel, and are therefore capable of reaching different decisions [31, 32].

Given that intuitive judgment operates automatically and cannot be voluntarily ‘turned off’, associated errors and unsupported biases are difficult to prevent. Even when errors appear obvious, in hindsight, they can only be prevented through the careful, self-regulated monitoring and control afforded by reflective judgment. Thus, a key developmental challenge involves the cultivation of self-regulation skills that support metacognitive awareness and control and the slow, effortful, and intentional processes that are often needed for high-level reflective judgment, as well as critical and collaborative thinking.

In the next section, we outline some of the key developmental milestones relevant for understanding the emergence of higher-order, metacognitive thinking skills. We focus in particular on aspects of self-regulation, including self-other representation and executive control skills. We also describe how *mindfulness* (i.e. observation and non-judgmental awareness of ongoing thought processes) may support aspects of self-and emotion-regulation and thus support higher-order thinking skills. We propose that mindfulness is a skill or talent that can operate at both an individual and group level to facilitate adaptive action in context. Following on from this, we examine how specific team and tool affordances can serve to accelerate the development of lower-order and higher-order metacognitive skills or talents.

4.4 Milestones in the Development of Metacognition: An Integrated Framework

A key underlying feature of metacognitive skill is the development of self-regulation. During childhood, changes in self-regulation primarily encompass changes in controlling emotions, attention, and behaviour, including self-monitoring and response inhibition [33]. Two inter-related aspects of self-regulation facilitate the development of metacognitive abilities underlying skills such as reflective judgment: the development of self-representations and the development of executive functioning. A central aspect of self-regulation is the development of self-representation [12] and the differentiation of self from others [34]. Mental representations are necessary for self-regulation as they facilitate goal selection, monitoring of progress, and the development of problem-solving strategies.

In order to think metacognitively, individuals must be aware of their own cognitive processes and have a basic concept of the self as an active agent [2]. Throughout infancy and childhood, individuals develop increasingly higher-order representational systems, which by middle-late childhood, integrates self-evaluations and self-representations [35]. This functions as a general self-monitoring and self-evaluation agent that influences goal pursuit and increased meta-level awareness and control [12]. The abilities to self-monitor and self-correct are central to self-regulation as individuals must first obtain awareness of their current state in relation to a desired goal in order to identify potential conflicts and discrepancies, which may precede subsequent goal-correcting behaviour [22]. This is central to reflective judgment as it facilitates an individual's understanding of the nature, limits and certainty of knowing. By middle adolescence, simple abstractions are organised into higher order abstract mapping in relation to both self and others ([8]; e.g. "I am intelligent because I am smart and creative; and Dad is ignorant because he relies on prior learning and lacks creativity"). Furthermore, some aspects of the developing self-concept may include epistemological principles and abstractions associated with critical and reflective thinking and problem solving, or dispositional principles and abstractions associated with key motivations and values that frame critical, reflective, and collaborative action in context (e.g., "Personality shapes learning in context: I'm an ambivert who is extroverted when with friends, introverted when with a group of strangers initially, but I transition from introverted to extroverted in collaborative learning environments over time and this change dynamically influences my learning in context").

The executive functioning is essential for the metacognitive processes involved in self-regulatory functioning, strategic planning and application of higher-order thinking. Although many models of executive functioning have been developed [36, 37, 38, 39, 40, 41], there is a consensus that executive functioning involves three basic processes: updating, inhibition and shifting. Updating refers to the active revision and maintenance of working memory representations. Shifting refers to switching between tasks or mental sets; and inhibition refers to the active, deliberate suppression of thoughts or responses and the maintenance of attention on goal-relevant information [39]. These processes have been shown to interact differentially to control higher-order problem-solving [42], and decision-making [43]. Del Missier [43] found that, in a task where the application of decision strategies became increasingly complex, inhibition was the most crucial process observed, as attention must be directed away from no longer relevant information; while in a separate task, where subjects were asked to assess the probability of risky events, shifting was identified as a process observed, as attention must be switched between varying judgment contexts.

Executive functioning skills are particularly important in situations or tasks which are novel, where automatic, intuitive or learned automatic responses are not adaptive or where a conflict between goals and the situation has been detected; and therefore, additional control is required [44]. Hofmann, Schmeichel and Baddeley [44] have outlined how integral executive functioning is to self-regulation. They argue that executive functions allow us to organise our thoughts in a goal-directed manner and are essential for success in education, work and everyday living. The updating and maintenance of working memory is vital for the accurate active representation of goals and goal-related information in situations where self-regulatory routines have not been automatized [44]. Furthermore, greater working memory capacity protects goal representations from thought intrusions and decreases mind-wandering. This is often referred to as goal shielding [45]. The importance of inhibition is clear here, with greater inhibitory control linked to more successful self-regulation in behaviours ranging from eating behaviour to sexual fidelity [46, 47, 48].

Though certain aspects of executive control are slow to develop throughout childhood [49], such as inhibiting learned responses, consistent with Fischer's Skill theory, children aged nine years and older become increasingly effective at monitoring (e.g., "I'm good at this") and regulating their actions (e.g. "I need to slow down here"), thereby moving toward increasingly complex representational and abstract control skills that build upon less complex skill structures [8, 49, 50]. A consequence of these aspects of skill development is improved goal setting skills in children. For example, although children younger than 4-years old struggle to plan and organize actions in advance, simple planning skills, such as planning moves in the Tower of Hanoi task, are exhibited by older children [51]. Further development of executive function skills emerges as young children utilize increasingly complex strategies for planning and organisation. For example, when asked to copy a drawing of a complex figure (i.e. the Rey-Osterrieth Complex Figure Test), children younger than 7-years old may use simple strategies that are inefficient, inflexible, or haphazard, whereas children aged 7 to 11 years of age use strategies that are more organized, efficient, and flexible [52]. Improved organization and decision-making skills continues into adolescence [52] and correlates with ongoing biological changes within the adolescent brain, including continued myelination of nerve fibres, increased connectivity between frontal brain regions and other brain regions, and significant and localized synaptic pruning, especially in frontal areas, all of which are crucial for executive functioning [e.g. 53] and the coordination of affect and cognition [54].

Overall, the concurrent development of self-representations and executive functioning are fundamental for the emergence of meta-level awareness and control and the development of higher-order thinking skills. However, high-order reflective judgment, critical thinking and collaborative thinking do not automatically emerge, but rather, develop alongside effortful self-regulation. Such effortful self-regulation of thought and behaviour can be developed through mindfulness which involves deployment of the executive functions to ensure attention is fully focused on current experience in a non-judgmental and non-reactive manner. As such, mindfulness acts as a form of intentional self-regulation that can facilitate executive control, reflective judgment, critical thinking and self-regulation in collaborative learning contexts.

4.4.1 Mindfulness and Metacognition

In considering the development of metacognition, mindfulness is a functionally relevant construct [55, 56]. Much like critical and reflective thinking skills and dispositions, there is no guarantee that mindfulness will emerge as a result of development. Though conceptualisations of mindfulness vary, all highlight the role of mindfulness in enhanced self-regulation of thought, behaviour and emotional and physiological reactivity and all contrast mindful information processing with automatic, habitual or heuristic information processing, often referred to as mindlessness [57, 58].

Specifically, mindfulness is often operationalised as a two-component process. The first component involves the deployment of attention to both internal and external experience in the present moment [55]. This component has been associated with greater sensitivity to perceptual cues and facilitates conflict monitoring [59, 60, 61] and executive control skills, particularly switching between and updating the contents of working memory [55,62]. The second component of mindfulness is characterised by non-judgmental acceptance of emotions and thoughts. This involves executive control to inhibit elaboration and/or suppression of affective cues and allows for the early engagement of emotion regulation before intense emotional reactivity to the attended thoughts, feelings and sensations can occur [61]. Notably, these skills of attention and non-judgment follow distinct developmental trajectories which may vary across individuals [63]. This operationalisation of mindfulness implies both monitoring and control skills which are inherently metacognitive [55]. Often, studies investigating the mechanisms and outcomes of mindfulness either involve brief meditation inductions or more long-term meditation interventions. However, it is also possible to take a dispositional approach where measures of trait mindfulness are associated with specific outcome variables [64].

Evidence for improved self-regulation of behaviour as a result of mindfulness comes from studies on procrastination [65], smoking cessation [66], persistence [67], and alcohol intake [68], while evidence for improved self-regulation of thoughts and emotions comes from the extensive literature on the clinical benefits of mindfulness (See review by Hofmann, Sawyer, Wit & Oh [69]). Both components of mindfulness involve executive control [55, 60]. The sustained attention to current experience developed through mindfulness practice requires the ability to switch attention between stimuli in current experience and back to current experience when the mind wanders, updating the contents of working memory and inhibiting elaborative processing [56]. Notably, research on mindfulness and inhibition has found better performance on the Stroop task in experienced meditators [70], following a 6-week mindfulness training [71], after a brief mindfulness induction [72], and in association with dispositional mindfulness [73]. Studies focusing on the ability to shift between mental sets have shown improvements following mindfulness interventions [74]. Studies also show the benefits of mindfulness for working memory capacity as well as the updating of working memory [74, 75].

Evidence also suggests that it is through the enhancement of executive functioning that mindfulness facilitates successful self-regulation and that these effects may extend to higher-order thinking skills, including problem-solving, decision-making and both divergent and convergent thinking, and social cognitive skills [64, 76]. Mindfulness training is also beneficial for higher-order thinking skills, and has been found to be related to performance improvements on insight problem-solving tasks (r = .30, $p < .01$; [77]), moral reasoning and ethical decision-making ($r = 0.43$, $p < .01$, [78]; $p < .05$, $\eta^2 = .20$ [79]) and creative thinking (i.e. creative thinking flexibility: $p < .001$, $\eta^2 = .37$; creative thinking fluency: $p < .001$, $\eta^2 = .33$; and creative thinking originality: $p < .001$, $\eta^2 = 0.32$ [80]). Each of these studies highlighted the non-automatic, reflective processing of information associated with mindfulness practice as the key to improved thinking outcomes. Hart, Ivtzan and Hart [58] suggested Kahneman's description of dual-process theory as a framework for explaining the cognitive benefits of mindfulness interventions. They suggested that mindfulness prompts the self-regulation of attention which activates system 2 or reflective thinking. Default-interventionist dual process theories of higher-order cognition offer a more refined view [81], arguing that intuitive processing is always engaged and generates automatic responses by default.

Further reflective processing allows for higher-order thinking skills to be used but requires the engagement of executive functions which may or may not intervene depending on the individual and context. So, enhancement of executive functions may be the primary mechanism through which mindfulness facilitates higher-order thinking skills. Metacognitive monitoring of others thinking and representations of others' thinking strategies are key in interpersonal relationships and especially in social situations where higher-order thinking skills are applied interactively such as in group problem-solving [82]. Research into mindful leadership, mindfulness in the workplace, mindfulness in relationships and social mindfulness suggests mindfulness could enhance self-regulation and metacognitive monitoring in social interactions [83].

In addition to factors such as enhanced positive affect, decreased stress and increased acceptance, constructs of a metacognitive nature such as perspective-taking, theory of mind and empathy are key in explaining how mindfulness can enhance social interaction [76, 84]. In delineating social mindfulness, Van Doesum et al. [84] explain how perspective-taking and theory of mind involve the mental representation of others' beliefs, needs, intentions, desire and knowledge and that people who are socially mindful maintain these representations accurately, consider them and act in a manner which maximises other people's autonomy in cases of interdependence.

Studies on the use of mindfulness in close relationships have also shown that trait mindfulness is positively related to relationship satisfaction and quality of communication [85] as well as successful identification of and communication regarding emotional states [86]. Research on mindfulness in the workplace and mindful leadership is in its infancy but initial empirical work suggests that where leaders have higher levels of mindfulness, employees have higher levels of psychological need satisfaction, job satisfaction and successful job performance [83]. It was argued that the broadened attention cultivated by mindfulness attuned leaders to employee needs which allowed them to support their employees more. This suggests a degree of skill in perspective-taking and empathy. Thus, mindfulness may extend from the metacognitive monitoring of one's own thinking to the metacognitive monitoring of representations of other's thinking and social, collaborative dynamics.

It is for this reason that mindfulness is central to our framework on metacognition and applied systems science in an educational context and we will return to this issue below. However, before returning to this issue, we describe the meta-cognitive nature of higher-order critical and reflective thinking skills and their central role in collaborative systems thinking, and we present two case studies describing how we have used tools to foster these high-levels skills.

4.4.2 Higher-Order Thinking Skills: Critical Thinking & Reflective Judgment

Critical thinking (CT) is a metacognitive process, consisting of a number of sub-skills: analysis, evaluation and inference; that, through purposeful, reflective judgment, increase the chances of producing a logical conclusion to an argument or solution to a problem [19, 87, 88, 89, 90]. Analysis is used in the context of argumentation to identify: the role statements play in an argument (e.g. central claim, reason, objection or rebuttal); the inferential relationships among statements (e.g. between or among the central claim, reasons, objections and/or rebuttals); the source(s) of information presented in an argument; and the balance, or imbalance, of contrasting information presented [87, 88, 90]. Evaluation is a CT skill that is used in the assessment of the strengths and/or weaknesses of information resulting from: the credibility of information, with respect to its sources(s); the relevance of information to another presented in the same context; the logical strength of inferential relationships among propositions within an argument; and the potential for bias, for example, purposefully pitting weak arguments that lack credibility and relevance, against strong stronger arguments [19, 87, 91].

The final CT skill, *inference,* refers to the "gathering" of credible, relevant and logical evidence based on the previous analysis and evaluation of available evidence, for the purposes of "drawing a reasonable conclusion" [87, p. 9]. This may imply accepting a conclusion pointed to by an author in light of the evidence they present, or "conjecturing an alternative", equally logical, conclusion or argument based on the available evidence [87]. Notably, though CT may be best cultivated, initially, in an educational environment, the importance of CT utilisation is not restricted to such settings [4, 19, 91, 92]. Rather, CT is required for use in many every day, real-world situations, for example, when problem-solving, hypothesis testing, analysing arguments, and assessing risks and probabilities [19, 89, 91, 92, 93].

Though one may possess the cognitive skills necessary to conduct CT, the willingness to conduct these skills ultimately dictates how well they are performed [92, 94, 95, 96]. Along with the ability to perform CT skills, “a critical thinker must also have a strong intention to recognise the importance of good thinking and have the initiative to seek better judgment” [97, p. 71]. This willingness to self-regulate can be described in terms of executive function, key dispositions towards thinking, the motivation to think and learn, and the perceived need to use specific cognitive processes when solving problems [19].

Possessing this willingness, or disposition towards thinking, refers to the extent to which an individual is inclined to perform a given thinking skill [98]. Specific dispositions have also been described, including dispositions toward clarity, systematisation, truth-seeking, open-mindedness, scepticism, reflection, perseverance and confidence in reason [92, 99, 100, 101]. Notably, a large body of research has demonstrated significant correlations between CT dispositions and CT ability [91, 102, 103, 104, 105, 106].

The ability to metacognitively think about thinking [1, 20] and the ability to apply critical thinking skills to a particular problem also implies a reflective sensibility and the capacity for reflective judgment [107]. Reflective judgment (RJ) is a fundamental aspect of metacognition that is used in the context of critical thinking (see Fig. 4.2) to judge and make decisions in a reflective manner [5, 14]. Like critical thinking, RJ is an important skill for students to acquire and practice, because it may facilitate their ongoing acquisition and application of knowledge both inside and outside of school and university [108, 109].

According to King and Kitchener [107], reflective judgment is an individuals' understanding of the nature, limits, and certainty of knowing and how this can affect how they defend their judgments and reasoning in context. Moreover, reflective judgment involves the ability of an individual to acknowledge that their views might be falsified by additional evidence obtained at a later time [107]. The ability to acknowledge levels of certainty and uncertainty when engaging in critical thinking is important because sometimes the information a person is presented with (along with that person’s pre-existing knowledge) provides only a limited source of information from which to draw a conclusion. This is often the case when a person is presented with an ill-structured problem [110], that is, a problem that cannot be solved with absolute certainty [111]. In the context of uncertainty, a combination of critical thinking skills (i.e. analysis, evaluation and inference) and reflective judgment is often necessary in situations where one seeks to arrive at a reasonable conclusion or decide upon a reasonable course of action [111, 112, 113].

Research suggests that child and adult development may see a progressive development of RJ ability toward greater levels of complexity and skill. Kitchener and King [114] created the Reflective Judgment Model (RJM) in order to characterise the development of people’s RJ ability. The RJM describes changes in the thinker’s recognition of limited knowledge (i.e. uncertainty) and how these changes influence other thinking skills, such as analysis, evaluation and inference. Specifically, the RJM is a seven stage model that is broken down into three periods of development (i.e. pre-reflective thought, quasi-reflective thought and reflective thought; see [114]). Progress on the RJM (from one stage to another; and from one period to another) is a type of evolution of RJ, in which each progression marks the increasing complexity of the thinking required to justify a belief. The more developed one's RJ, the better able one is to present "a more complex and effective form of justification, providing more inclusive and better integrated assumptions for evaluating a view" [107, p. 13].

Within the RJM, a series of developmental changes occur in the way people come to understand the process of knowing and reasoning. More importantly, research supports a developmental trajectory of RJ along the lines described by King and Kitchener [107]. However, RJ development is not a simple function of age or time, but more so a function of the amount of interaction, or active engagement an individual has in working on ill-structured problems [5, 23, 115], such that the development of higher levels of reasoning and RJ ability can emerge, see Fig. 4.2.

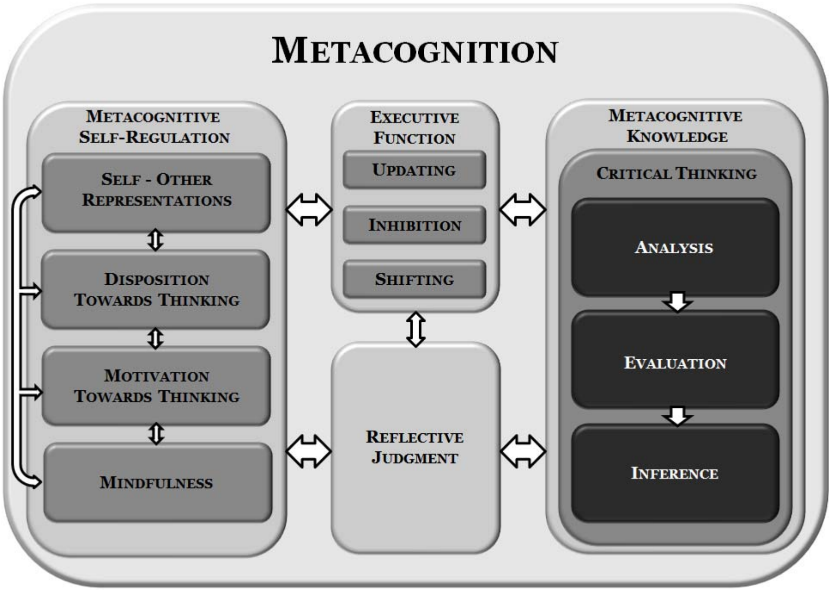

Fig. 4.2 An integrated model of metacognition

Notably, a large body of research suggests that RJ and CT are inter-related [5, 107, 110, 115] and RJ may be a component of CT [110, 116, 117]. Furthermore, positive dispositions towards thinking are positively correlated with CT-related abilities [91, 102, 103, 104, 105, 106]; and both CT abilities and possessing the disposition to apply CT skills together determine a person's actual thinking performance [4, 92, 94, 95, 96, 118]. It is widely accepted that CT and RJ skills require special training and support if they are to emerge during development [5, 91]. Below we describe how we have used argument mapping tools to enhance higher-order thinking skills in students. We also describe how one collaborative thinking tool and process, Interactive Management, can be used to cultivate higher-order, metacognitive thinking skills and effective team dynamics at the group level.

Case Study 1 – Argument Mapping for Critical Thinking. Argument mapping (AM) is a method of visually representing a text-based argument via 'boxes-and-arrows', wherein the boxes are used to highlight propositions and the arrows are used to highlight the inferential relationships that link the propositions together [19, 14, 89, 90, 119]. Specifically, an arrow between two propositions is used to indicate that one is evidence for or against another. Similarly, colour can be used in AM to distinguish evidence for a claim from evidence against a claim (i.e. green represents a support and red represents an objection). AM is designed in such a way that if one proposition is evidence for another, the two will be appropriately juxtaposed [120]; and the link explained via a relational cue, such as *because*, *but* and *however* (see Fig. 4.3).

These AM features have been hypothesized to facilitate metacognitive acts of critical thinking, both by making the structure of the argument open to deliberation and assessment; and by revealing strengths and weaknesses in the credibility, relevance and logical soundness of arguments in the argument structure. Recent research by Dwyer, Hogan and Stewart [89, 90] indicates that argument mapping may have beneficial effects on CT ability. Two separate studies examined the effects of a six-week argument mapping-infused CT training intervention on CT performance. Specifically, research by Dwyer, Hogan and Stewart [89] examined the effects of a six-week Argument Mapping-infused CT training course, compared with a traditional (Hierarchical Outlining) CT training course and a no-CT training control condition on CT ability, as assessed by the California Critical Thinking Skills Test [121]. Results revealed that though the CT course taught through AM did not facilitate overall CT performance over and above the traditional HO CT course or the control condition (i.e. no-CT course), participants in the AM training group performed significantly better on inductive reasoning than those in the control group (p = .038, d = .67). However, given that the HO group also scored significantly higher than the control group on inductive reasoning (p = .037, d = .55), findings suggested that teaching CT through AM was no better than teaching CT through HO. Furthermore, when analysed together, the CT course attendees (i.e. both AM and HO groups combined) outperformed the control condition on analysis, evaluation and inductive reasoning (p < .05 for all three), suggesting that exposure to CT training infused with some hierarchical organisation strategy may have beneficial effects on CT performance.

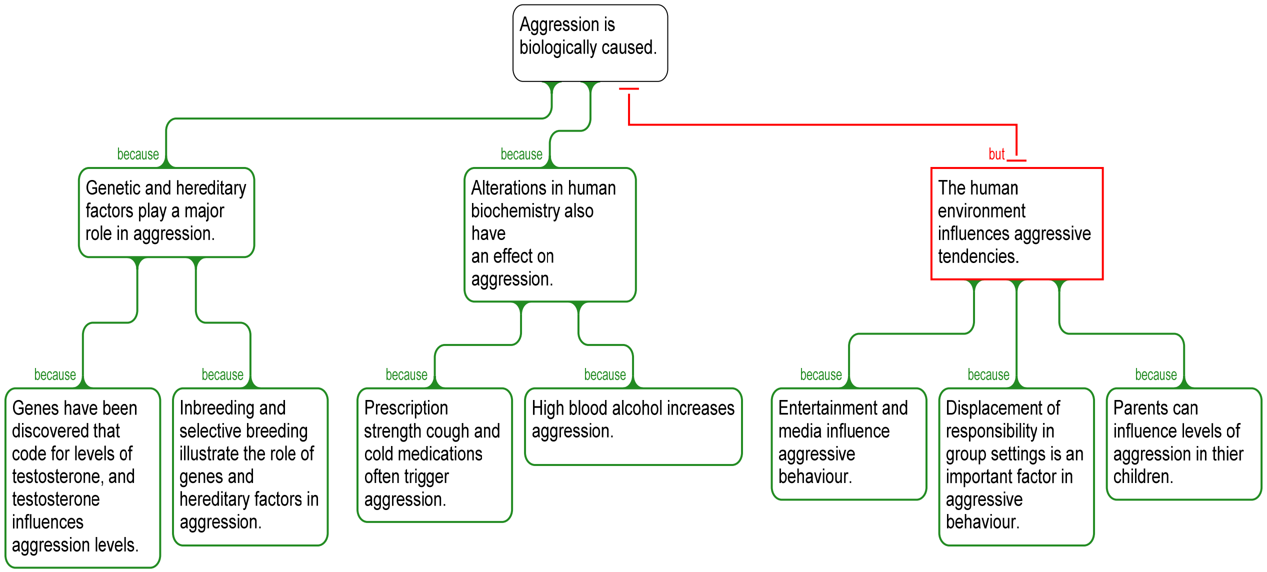

Fig. 4.3 Example of an argument map (Dwyer [89]) using Rationale™ (van Gelder [119])

Overall, these findings indicate that though the use of colour and spatial organisation of propositions within AMs may provide beneficial visual cues to both the reader and constructor of AMs, the hierarchical organisation of propositions within AMs and HOs may be the critical feature associated with the beneficial effects observed for CT learning outcomes. Further research by Dwyer, Hogan and Stewart [122] examined the effects of an AM-infused CT e-learning course on CT performance, as assessed by the Halpern CT Assessment [93], by comparing the effects of an AM-infused CT e-learning course with a no-CT course control group on measures of CT ability. The relationship between student engagement in the AM-infused CT course and CT performance changes over time was also evaluated. Results revealed that those who participated in the AM-infused CT group outperformed those in the control group on overall CT (p =. 018, d = .60) and argument analysis (p = .025, d =.54).

Results also revealed that performance on overall CT and all CT sub-scales (i.e. hypothesis testing, argument analysis, verbal reasoning, assessing likelihood and uncertainty, and problem-solving; $p < .05$ for all three) of those in the AM-infused CT group were enhanced from pre-to-post-testing. Results further revealed a time x engagement interaction effect for the CT sub-skill of problem-solving, with those in the high-engagement group showing a greater gain in problem-solving ability than those in the low-engagement group ($p = .004$, partial $\eta^2 = .19$). The positive effect of engagement on problem-solving performance in the AM group is promising, as it is broadly consistent with the suggestion that more intensive levels of engagement may be crucial for the development of higher-level thinking skills.

Recently, we have begun to examine collaborative critical and system thinking and we have developed a new tool that integrates argument mapping software with a system thinking tool, Interactive Management. Below we consider the issue of collaborative metacognition and we describe a second series of studies that highlight the value of our collaborative systems thinking tools and key processes associated with successful team dynamics.

4.4.3 Collaborative Metacognition

Collaborative learning is becoming increasingly prevalent within education. In educational settings, where foundational skills in collaborative learning may be developed for application in work settings, various forms of collaborative learning methodologies, centred on peer interaction and pooling of resources have been implemented and evaluated [123]. Many of these methodologies, especially those which facilitate collaborative problem-solving, are metacognitive in nature. Metacognitive collaboration refers to the process of team or group members thinking about, and reflecting on, how their team processes information, works on problems, and feels about the collaborative process [124, 125]. Effective metacognitive collaboration requires the coordination of a number of factors; effective facilitation, feedback and instruction regarding the collaborative process and goals; cultivation of enhanced team functioning in the collaborative context, including the promotion of cooperative, exploratory discourse; and the use of tools and methodologies which facilitate group coherence, the management of complexity and group problem-solving.

Dynamics of metacognitive team functioning. Metacognition in teams can promote effective teamwork [126]. McIntyre and Salas [127] identified four essential principles of effective teamwork which reflect metacognitive principles: Mutual performance monitoring, feedback, closed-loop communication and back up behaviours. Mutual performance monitoring refers to the ability of group members to monitor the work of their peers while simultaneously carrying out their own work [128]. This aspect of team functioning is closely related to the second aspect of effective teamwork, which involves the process of feedback. Notably, research has shown that although individuals are often unaware of their performance deficiencies [e.g. 129], peer feedback can result in individuals becoming more aware of their performance.

The third aspect of effective teamwork, closed-loop communication, has been suggested as an effective method for reducing inefficient information sharing, and ensuring that communications are adequately delivered, received and understood. Closed-loop communication involves (a) the sender initiating a message, (b) the receiver receiving the message, interpreting it, and acknowledging its receipt, and (c) the sender following up to insure the intended message was received [127]. Research conducted by Siegel and Federman [130] found that teams who received training in this type of communication outperformed teams who did not receive such training. Finally, back-up behaviour refers to the provision of resources and effort by team members upon recognition of inadequate workload distribution in their team [131]. Mutual performance monitoring allows team-members to recognise if and when the workload of others in their team has exceeded their capacity [128]. On recognition of such overload, team-members can provide three means of back-up behaviour: provision of performance-related feedback; assistance in completing the task, or complete the task for the team member [129]. Various research programs have highlighted the importance of these metacognitive processes in successful team performance. While these processes occur naturally in some teams, this is not always the case, and conscious effort must be made to promote them [126]. So an important role of the metacognitive facilitator, involves the cultivation and coordination of these processes.

Feedback and facilitation in metacognitive teams. Fruitful metacognitive collaboration does not occur spontaneously; it is not enough to provide learners with a method or tool. Much like in the development of critical thinking skills, it is necessary to guide learners through the process of metacognitive collaboration by means of effective feedback and facilitation. Feedback is considered to be a vital instructional tool in education. The beneficial effects of receiving feedback in a learning context are widely reported, including positive effects on learning, performance, and satisfaction [132]. Feedback can be administered for a number of purposes. For example, task-level feedback aims to provide declarative knowledge or information about the correctness of a learner's response. Such feedback provides the learner with the correct answer; however, it does not provide the learner with prompts or strategies to guide future efforts. As such, simple, basic, forms of feedback may fail to help learner's to monitor, be aware of, or adjust, their learning strategies according to how effective their current learning strategy is [e.g. 133, 134]. Lee et al [135] suggest that one potential solution here is to provide metacognitive feedback about cognitive strategies.

Metacognitive feedback is designed to make the learner conscious of the learning strategies being used and their degree of success. Such feedback reminds the learner to consider and evaluate the suitability of strategies employed. As noted by Kuhn [21], this type of meta-strategic awareness is a critical driver of cognitive development. Process-level feedback and self-regulation feedback are two types of metacognitive feedback. Through the use of such feedback strategies, learners can be guided through skills associated with critical thinking, including: analysis, evaluation, inference, and reflective judgment. Process-level feedback provides prompts or strategies that learners can use for error search, information search, or review and revision of work done. Examples include prompting students to consider other questions that could be asked in relation to a problematic situation or asking what other strategies could be used to complete a task or solve a problem. Feedback at the self-regulation level provides conditional knowledge, generally in the form of probing questions. The probes or prompts are designed to guide the learner on when, where are why they should select a certain strategy. It seeks to help the learner to identify the demands of the task at hand, and prompt them towards appropriate strategies. Examples may include questions asking students to compare the current problem to previous problems they have worked on or reflective questions such as “What am I doing here?”, or “What is the purpose of what I am doing here?”

Tool use in team contexts. Effective collaboration is rarely achieved in the absence of guidance [136]. Just as instruction and feedback from a facilitator can enhance the efficacy of collaboration, various forms of support or instruction tools have been developed to promote metacognitive collaboration [137]. One such methodology is Interactive Management (IM). IM is a computer facilitated thought and action mapping technique that enhances group creativity, group problem solving, group design, and collective action in the context of complexity. There are a series of steps in the IM process. First, a group of key stakeholders with an interest in resolving a problematic situation come together in a situation room and are asked to generate a set of ‘raw’ ideas (commonly 50 – 200) about what might potentially have a bearing on the problem they all agree exists. Next, under the guidance of a trained facilitator, group discussion and voting helps the group to clarify the sub-set of ideas that bear upon the most critical problem issues.

Throughout the course of this discussion, the facilitator cultivates a sense of critical engagement and reflective judgment in relation to the ideas suggested. Once a set of critical problem issues has been agreed upon, the idea structuring phase begins. Using IM software, each of the critical issues is compared systematically in pairs and the same question is asked of each in turn: “Does A influence B?” Again, the facilitator uses process-level and self-regulatory feedback and instruction to guide the group through this process, while also encouraging the use of strategies including: mutual performance monitoring, backup behaviours, and closed-loop communication. The facilitator encourages learners to reflect upon, and critically evaluate each relational statement presented by the IM, and cultivates a sense of cooperative and exploratory collaboration and collective mindfulness and awareness of ongoing thought and action in the room. Unless there is majority consensus within the group that one issue impacts upon another, the relation does not appear in the final analysis.

After all the critical issues have been compared in this way, IM software generates a problem structure (or problematique) showing how the issues are interrelated. The problematique can be viewed and printed for discussion. The problematique becomes the launch pad for planning solutions to problems within the problem field. The logical structure of problems is visible in the problematique and when generating solutions, action plans are aimed at resolving problems in a logical and orderly manner. When the group is happy that they have modelled both the problem field and the best possible set of solutions, the IM session closes and each member leaves with a detailed action plan, a specific set of goals to work on, and the roadmap and logic describing how all the various plans and goals of each member will work together to resolve the original problem.

As it is currently used, IM is a deeply engaging and cooperative process. However, when it is further merged with cooperative argument mapping (AM) work, the cooperative enquiry process is transformed into a process that explicitly links the metacognitive processes of critical thinking with ongoing metacognitive collaboration. More specifically, students who are mapping out a problematic situation are called upon to source and evaluate scientific evidence to support their beliefs as to the nature of discrete paths of influence in a problematique. Also, for problematic situations that draw upon multiple sciences of description, it is evident that students working in multidisciplinary teams will be exposed to arguments from multiple scientific domains and will have to learn to analyse and evaluate these arguments in cooperation with others. While it might be assumed that only those with specialized knowledge of domain-specific science content will be able to analyse domain-specific arguments and evidence, we believe that the knowledge and perspective of students from multiple scientific backgrounds can help to enhance the creativity and the overall quality of evaluation and inference work [23].

By way of example of an application of IM, presented below is the outcome of a session conducted in a *Thinking, Modelling and Writing in Psychology* module in NUI Galway, in response to the trigger question, *What are the most important skills and dispositions of good critical thinkers?*. Students used the IM software to structure the interdependencies among the highest ranked skills and dispositions (see Fig. 4.4).The problematique is to be read from left to right, with paths in the model interpreted as ‘significantly enhances’. Once the problematique had been designed, students used cooperative AM to explore and evaluate the paths of influence in the IM problematique.

Case Study 2 – Interactive Management and Collaborative Enquiry. We have conducted a series of studies to evaluate key aspects of our collaborative systems thinking tool and learning process. In the first study, Harney, Hogan & Broome [25] investigated the effect of open versus closed IM voting and dispositional trust on perceived consensus, objective consensus and perceived efficacy of IM technology. Two groups of 15 undergraduate students came together to structure the interdependencies between positive and negative aspects of social media. Participants high and low on dispositional trust were identified and were randomly assigned to either an open or closed voting condition. Those in the closed voting group were not permitted to discuss the problem relations, but consensus votes were recorded by the group design facilitator.

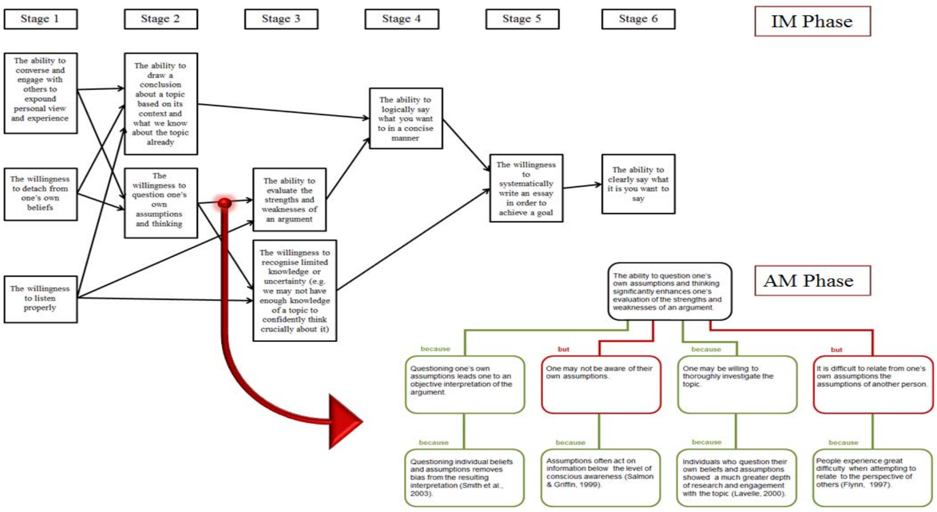

Fig 4.4. Sample enhancement structure of skills and dispositions required for critical thinking (top panel; paths in the model are to be interpreted as 'significantly enhances'); (bottom panel) linked argument map exploring how the ability to question one's assumptions and thinking enhances evaluation skills.

This scenario simulated an online voting system where participants converged upon a decision without direct contact or open dialogue in advance of voting. The open group was allowed to discuss the relations before voting. Notably, the results of this study indicated that participants with higher dispositional trust, and those in more open working groups, reported higher levels of perceived consensus (p = .007, partial η^2 = .25; p =.011, partial η^2 = .22, respectively) and higher levels of perceived efficacy of the IM technology (p= .047, partial η^2 = .14; p = .02, partial η^2 = .19, respectively).

These results, combined with results from studies showing increased learning gains in more open and interactive groups [e.g. 138], suggest that open discussion and dialogue are critical factors in the success of collaboration using tools such as IM. These results have implications for the design of computer-supported collaborative learning (CSCL) tools and how they are used. Peterson [139] highlighted the effect that a facilitator's directiveness has on the results of collaborative working sessions. Peterson found that process-directive leaders, who aimed to foster the decision-making process by encouraging discussion and by remaining open regarding their position, facilitated more positive group processes and outcomes than outcome-directive leaders who did not encourage discussion in the group and who focused solely on reaching a decision.

In the context of CSCL, it is imperative that the facilitator of any group session provide ample opportunities for open dialogue and discussion in the group. In the absence of open dialogue and discussion, metacognitive collaboration will not emerge. Harney, Hogan & Broome [140] investigated the effects of generic versus metacognitive feedback on levels of perceived and objective consensus and argumentation of subjects high and low in dispositional trust, in the context of an IM. Four groups of undergraduate psychology students (N = 75) came together to discuss the negative consequences of online social media usage. After screening for trust scores, participants high and low on dispositional trust were randomly assigned to either a generic or metacognitive feedback condition. In each feedback condition, an independent facilitator was given a specific set of prompts or instructions which could be used as part of the feedback process.

A second facilitator was present to oversee the feedback process, and assist with the input of ideas into the IM. In both conditions, participants were asked to silently generate ideas which they felt had a significant impact on the problem at hand. This is referred to as the *Idea Generation* phase of IM. Once this phase was complete, and each participant had their own list of ideas to offer, the facilitator went around the room, to each participant asking them to present their idea to the rest of the group. If necessary, they explained their idea clearly and succinctly to the rest of the group.

The facilitator would then open the discussion up to the group, by asking “Does anyone else have an opinion on this idea?” While these guidelines were also followed by the facilitator in the metacognitive feedback group, there was also the addition of further process-level and self-regulatory feedback prompts. Through the use of such feedback, the facilitator aimed to enhance the critical thinking of the group in relation to the suggested ideas. Specifically, the facilitator used these prompts to cultivate a higher level of analysis and evaluation as the group generated a set of problem issues. The facilitator could, where necessary, request further clarification, suggest that some ideas offered may be similar in nature and require further examination, suggest merging of ideas or breaking down of ideas which appear to have multiple components. The facilitator could also suggest considering the relevance of the idea offered in the problem context, and suggest considering the generalizability of the idea offered. Next, in the *Idea Structuring* phase, as each relation “Does issue A significantly influence issue B?” was presented on the screen, the facilitator would open the discussion to the room, and ask if anyone has a yes or no preference and this stage.

As participants indicated their preference, the facilitator would ask for some insight into their reasoning for this preference, and then request other opinions from the group. The facilitator would then request a show of hands from the group, and a vote would be taken. Again, these guidelines were also followed by the facilitator in the metacognitive feedback condition, but with the addition of some further prompts and instructions, designed to enhance the critical thinking and reflective judgment of the group as they discuss, and decide upon, the relational statements. In the metacognitive feedback condition, the facilitator could, where necessary, ask for contrary opinions, ask for further analysis and evaluation, suggest considering the relevance of arguments and suggest considering the generalizability of the opinions offered.

Levels of perceived consensus, objective consensus and perceived efficacy of the collaborative learning methodology were measured before and after the IM session. Results indicated that those in the metacognitive feedback condition, and those with higher levels of dispositional trust, reported higher levels of perceived consensus (p <.001, partial η^2 = .18; p = .035, partial η^2= 0.61, respectively) in response to the group design problem. Furthermore, those in the metacognitive feedback condition also reported significantly higher levels of perceived efficacy of the ISM process (p = .009, partial η^2 = .093) compared to those in the generic feedback condition. Finally, analysis of the dialogue from the IM sessions revealed that those in the information feedback condition exhibited higher levels of sophistication in their arguments, as revealed by the Conversational Argument Coding Scheme (CACS) [141].

Notably, of the 16 CACS possible argument codes, which comprise the five argument categories, 13 were observed in the metacognition feedback condition at least once; eight were observed in the generic feedback condition at least once; and three were not observed in any condition. Significant differences were reported across conditions for three argument codes, showing higher levels of incidence in the information feedback condition in each case, specifically, for amplifications (p =.002, V =.123), challenges (p = .006, V = .118) and propositions (p = .012, V = .108). In each of the remaining codes, higher incidence was also reported in the metacognitive feedback condition than in the generic feedback condition; however, these differences were not significant.

These results show that the metacognitive feedback group were engaging at a higher-level with the information at hand, and made more effective moves towards reaching a level of understanding and consensus within the group. For example, while elaborations – statements that support other statements by providing evidence, reasons or other support – were high in both groups, amplifications – statements that explain or expound upon other statements to establish the relevance of an argument through inference, were observed more frequently in the metacognitive feedback group. In this way, those in the metacognitive feedback group were moving beyond accumulation of evidence and support, and establishing how this reasoning relates to the problem at hand, that is, how relevant it is. Similarly, while levels of objections – statements that deny the truth or accuracy of an arguable - were almost identical across the two groups, challenges – statements that offer problems or questions that must be solved if agreement is to be secured on an arguable – occurred significantly more often in the metacognitive feedback condition.

This again shows that those in the information feedback condition engaging more critically with the information at hand, and thereby engaging in more productive argumentation. Finally, of the 16 types of argument codes with comprise the CACS, 13 were observed at least once in the metacognitive feedback condition, whereas only 8 were observed at least once in the generic feedback condition. This highlights the fact that those in the metacognitive feedback condition were engaging in more complex and varied argumentation, relative to the generic feedback group.

Our third study examined the effects of feedback on the emergence of cooperative conversational dynamics in groups high and low in dispositional trust. Specifically, we used Mercer’s Categories of Classroom Talk [142] and Multiple Episode Protocol

Analysis [143] in the context of a 2 (Generic Feedback versus Peer Feedback) x 2 (High Trust versus Low Trust) design to examine the individual and combined effects of feedback and trust on the emergence of exploratory, cumulative, and disputational talk within teams, and the replicability of these effects across multiple applied systems science project domains.

Generic feedback was operationalised in the same manner as in the previous study. Peer feedback, however, represented an extension of the metacognitive feedback strategy used in the previous study. In this case, the facilitator first administered metacognitive feedback to the group, thereby familiarising them with the metacognitive prompts and strategies. The facilitator then handed over the tasks of feedback and performance monitoring to the group, thereby empowering them to engage in peer-centred metacognitive feedback. Preliminary results indicate that process and self-regulatory feedback, provided by the facilitator, and subsequently by peers themselves, resulted in enhanced cooperative conversational dynamics, increased argumentation duration, intensity, and complexity, and significantly more episodes of exploratory talk than in the generic feedback condition [144].

4.5 Conclusions

Human evolution has resulted in the emergence of our capacity to think about thinking. However, the development of metacognitive skills and talents is contingent upon the availability of quality educational supports. Promoting the development of individual and collaborative metacognitive skills and talents during child and adult development is essential for survival, adaptation and flourishing. Higher-order, metacognitive skills are needed now more than ever in order to aid individuals and groups in becoming more adaptable in the context of a rapidly evolving information society. Promoting successful team dynamics and effective tool use can help children and adults to think about their thinking and approach problems with a mindful, reflective, collaborative sensibility that facilitates adaptive action at individual and group levels.

In this chapter, we highlight the importance of basic building blocks of self-regulation, including self-other representation, executive functions, and goal setting in supporting both lower-order and higher-order metacognitive regulation of ongoing action and problem-solving. We also highlighted the important role of mindfulness and thinking dispositions, both for executive functioning and for higher order critical thinking and reflective judgment. We presented evidence to suggest that teaching critical thinking skills using argument mapping tools can facilitate the development of critical thinking skills, particularly when students engage with and use the tool regularly.

We further highlighted the importance of metacognitive feedback in the context of collaborative tool use and we provided evidence to suggest that metacognitive feedback promotes trust and consensus along with increased complexity of collaborative argumentation and increased tendency to move beyond disputational and cumulative styles of talk to exploratory modes of talk. Central to our view on metacognition is the idea that mindfulness can emerge as a development asset that supports intra-personal and inter-personal meta-strategic awareness and control in both individual and group learning contexts. Given that mindfulness along with critical thinking, reflective judgment and collaborative enquiry may require explicit training to develop, we propose an integration of organismic and pragmatic models.

Consistent with neo-Piagetian organismic models [8], we assume that skills can unfold at greater levels of integration and complexity; however, skilled action is a function of training, support and the collaborative dynamics of social groups. Consistent with pragmatism and a pragmatic systems science framework [9] we have argued that specific tools and group-mediated processes can be used to support metacognitive skill development [10, 23]. However, we also believe that specific higher-order principles and practices, including those associated with mindfulness, can transfer from one context to another in the support of skilled action. Ongoing research in our lab is examining the relationship between mindfulness dispositions, executive functioning and higher-order critical thinking processes.

Furthermore, consistent with the idea that mindfulness can be trained, future work in our lab will examine if training in mindfulness enhances executive functioning and critical thinking abilities and if there are key underlying brain processes associated with the transferable benefits of mindfulness from one problem solving context to another. Ultimately, we believe that metacognitive skills display complex interdependencies in the context of lower-order and higher-order skill structures. In this way, metacognitive skills can be viewed as part of a collection of potentially synergistic talents that can be fostered in the context of individual and team-based tool use and problem solving.

Future research adopting an organismic and applied systems science perspective may seek to examine the efficacy of other environmental affordances and supports designed to enhance individual and collaborative metacognition, including training programmes focused on emotional intelligence and social intelligence. For example, while mindfulness training may enhance critical and collaborative thinking via improvements in executive functioning and emotion regulation, emotional intelligence and social intelligence programmes may be effective in transmitting key principles and practices that support perspective taking, empathy, listening skills, team orientation, and other processes that also enhance individual and collaborative metacognition.

One principle of organismic and systems models of development is relevant here, that is, the principle of *equifinality*. Simply stated, the principle of equifinality implies that there are many different ways in which the same developmental outcomes can be arrived at. As such, there may be many different ways to develop metacognitive skills and talents that support adaptive functioning and effective problem solving in context. We have focused here on the developmental affordances associated with a focus on teams and tools. However, within and outside of this broad focus there are many ways to develop metacognitive skills other than those addressed in this chapter.

As noted in the introduction, we believe that cultural evolution is itself a metacognitive process. It is the task of each new generation to think about the thinking of previous generations and modify the culture of thinking in ways that foster adaptive development. Like other artefacts of culture, educational practices are products of our cultural evolution that are open to metacognitive reflection. This offers us hope but also highlights the need for mindful skill and creativity, and determination such that we can continue to improve the education system for the benefit of the current and the next generation.

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