Metacognitive skill; how it is acquired

Brendan Conway-Smith (brendan.conwaysmith@carleton.ca)
Robert L. West (robert.west@carleton.ca)
Myrto Mylopoulos (myrto.mylopoulos@carleton.ca)
Department of Cognitive Science, Carleton University
Ottawa, ON K1S5B6 Canada

Abstract

Metacognition can improve with practice, yet the mechanisms underlying metacognitive skill learning remain unclear, and lack a robust theoretical framework. We propose that metacognitive skill learning can be largely explained by the skill acquisition model advanced by Fitts (1964) and Anderson (2013). While this model has been successful in the domains of motor skill and cognitive skill, it has not yet been applied to metacognitive skill. This novel framework can help to explain metacognitive skill learning, its cognitive underpinnings, and shed light on otherwise unexplainable empirical data.

Keywords: Metacognition; metacognitive skill; skill; learning proceduralization

Introduction

Metacognition is the monitoring and control of cognitive processes and has received much attention in recent years across numerous fields. Metacognitive abilities are positively correlated with a variety of cognitive factors, such as reasoning, attention, emotional control, and they are the most important predictors of successful learning (Kramarski & Mevarech, 2003; Slagter et al., 2011; Keith & Frese, 2005; Veenman, 2015). While metacognition has been shown to be a learnable skill, the mechanisms that give rise to metacognitive skill remain unclear. This theoretical gap poses a significant barrier to research in metacognition and potentially impedes its application. It is sometimes said that metacognition, as a theoretical domain, "lacks coherence" and that more work needs to be done to understand the mechanisms according to which it operates (Veenman et al., 2006; Dunlosky and Rawson, 2019). Persisting issues in metacognition include: whether metacognition is domain-general or domain-specific, the distinction between implicit and explicit metacognition, as well as the largely unexplored realms of metacognitive instruction and metacognitive skill learning.

We propose that a coherent and parsimonious framework for understanding metacognition can be derived by viewing metacognition within the classic skill acquisition framework of Fitts (1964), as computationally interpreted by Anderson (1982; 2013). This article intends to bridge the research on metacognition with research on skill to help reveal the mechanisms underlying metacognitive skill learning.

First, we offer a brief review of the relevant literature on both metacognition and skill acquisition. Second, we explain how the classic skill acquisition models of Fitts and Anderson can be applied to the domain of metacognition. Third, we will discuss how the proposed framework sheds light on the nature of metacognition, and how this helps to explain otherwise unexplainable data.

The skill acquisition theories relied on here largely involve a process of increasing automaticity, where deliberate actions are practiced to become faster, less error prone, and more automatic. It is important to note that explanations of metacognitive skills (and skills in general) are not exhausted by theories of automaticity. Other factors such as cognitive control, flexibility, and metacontrol, are also important (Christensen et al. 2016; Pacherie & Mylopoulos, 2020). However, automaticity does play an important role in the development of skill and, considering the lack of competing theories, a model that examines the automatic aspects of metacognitive skill is a reasonable place to focus on.

This paper addresses outstanding questions such as: Does metacognitive skill result from dedicated cognitive mechanisms or from operations that are more domain-general? Can we gain insight into metacognitive skill by examining other successful models of skill? Is there a single parsimoniously framework that explains all skill learning; motor, cognitive, and metacognitive?

Metacognitive skill

Metacognition is increasingly being referred to as a domain of skill, one that belongs to a larger category that includes both sensorimotor and cognitive skill. Skilled action within any domain entails the high level of control that one possesses over their activity (Mylopoulos & Pacherie, 2021). Metacognitive skill refers to the extent to which one is able to monitor and control their own cognitive processes (Van der Stel & Veenman, 2010).

Research on metacognitive skill learning, and its neural and computational underpinnings, has largely focused on bottom-up models — where low level, implicit processes learn by way of stored feedback and reinforcement learning (Proust, 2013; Krueger, Lieder & Griffiths, 2017). While empirical studies have investigated top-down metacognitive learning by way of instructions, such as students being taught to self-monitor and self-regulate their own learning (Zimmerman & Schunk, 2011), these studies have largely focused on the effectiveness of pedagogical strategies. Overall, accounts of explicit metacognitive skill learning have remained largely descriptive.

Monitoring and control

Metacognitive skill presupposes that the components of metacognition, monitoring and control, can improve with practice and training. *Metacognitive monitoring* refers to the capacity to recognize and identify cognitive states. Monitoring involves the perception of some internal mental states, such as feelings or thoughts, for the purposes of regulating those states or directing behavior. *Metacognitive control* refers to the active regulation of cognitive states or processes (Flavell, 1979; Wells, 2019). It is the part of the system that performs mental actions (in contrast to world-oriented actions). Mental actions aim to make cognitive states available that would not otherwise be. The monitoring and control of cognitive activity can involve attention, emotion, planning, reasoning, memory, and various other processes (Slagter et al., 2011; Efklides, Schwartz, & Brown, 2017; Schraw et al., 2006; Fletcher, & Carruthers, 2012; Pearman et al., 2020).

Metrics

Quantifying metacognitive ability can be achieved by various metrics including neural data, behavioral observation (e.g.: task performance), and self-report such as confidence ratings (Fleming, & Lau, 2014). Scales for assessing metacognition include The Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994), The Metacognition Self-Assessment Scale (MSAS) (Pedone et al., 2017), The Metacognition Thinking Skills Scale (Tuncer and Kaysi, 2013), and The Metacognitive Skills Inventory (MSI) (Hameed & Cheruvalath, 2021).

Metacognitive training

Decades of empirical studies testify to the efficacy of metacognitive training. Research into metacognitive skill learning has a rich history in domains such as reading, mathematics, and general problem solving (Cross & Paris, 1988; Garofalo & Lester, 1985; Davidson & Sternberg, 1998). Metacognitive training has shown to result in improvements in self-regulation, monitoring, and self-evaluation (Azevedo, 2005; McCabe, 2011).

Education research indicates that metacognition can be taught to students to improve their learning outcomes. Students with better metacognition have been shown to be more likely to solve problems correctly, compared with students with weaker metacognitive abilities (Güner & Erbay, 2021). Metacognition in students has shown to correlate with improved academic performance across a variety of subjects (Girash, 2014). Within the education literature, metacognitive skills have been considered a foundation of critical thinking (Kuhn & Dean, 2004).

Metacognitive training plays a significant role in the success rates of Cognitive Behavior Therapy (CBT) and Metacognitive Therapy (MCT). Within both fields, patients are instructed in metacognitive strategies for monitoring and regulating their own thoughts and emotions (Dobson, 2013; Normann & Morina, 2018). Research indicates that individuals with metacognitive skills are better able to identify and govern their own harmful thoughts and emotions (Flavell, 1999; Wells, 2019). Conversely, a lack of metacognitive skill can contribute to the preservation of harmful thinking patterns, and unhelpful coping behavior patterns that contribute to anxiety and depression (Hagen et al., 2017; Cooney et al., 2010).

Knowledge and instruction

Metacognitive knowledge, or meta-knowledge, is considered a form of declarative knowledge (Schraw & Moshman, 1995; McCormick, 2003). Explicit meta-knowledge takes the form of metarepresentation that is propositionally formatted and refers to some cognitive property or process (Shea et al., 2014; Proust, 2013).

Metacognitive knowledge is considered to be distinct from metacognitive skill (Veenman & Elshout, 1999). Meta-knowledge does not automatically lead to the deployment of metacognitive processes. Meta-knowledge can simply refer to facts about one's own cognition, such as one's proficiency as a learner, or whether one's attention is distracted.

Meta-knowledge can also be distinguished from an instruction (Flavell, 1979; Shea et al., 2014). While meta-knowledge refers to facts about oneself as a cognitive agent, metacognitive instructions specify mental actions to be performed. A metacognitive instruction, or *meta-instruction*, prescribes a mental action directed toward controlling some cognitive process, such as regulating some emotion or focusing one's attention. While decades of research have investigated how instructions can direct external actions to develop skill, the process by which meta-instructions direct internal, mental actions to become skillful has defied systematic theoretical analysis.

Skill acquisition

Skill acquisition has been described in psychology and philosophy as a progression from deliberate conscious and declarative rule-following to a nonconscious procedural stage where aspects of performance become more automatic, fast, and accurate (Fitts, 1964; Dreyfus & Dreyfus, 1986; Anderson, 1982; 2013; Kim & Ritter, 2015). This framework has been used to help explain skill acquisition within both the cognitive and motor domain. Here we submit that it can also be used to understand metacognitive skill acquisition.

Fitts (1964) proposed that the acquisition of motor skill proceeds through three phases (Figure 1): the cognitive phase, the associative phase, and the autonomous phase. In the *cognitive phase*, the learner encodes the skill into a form that allows them to perform it crudely. In the *associative phase*, the performance of the skill is refined by identifying and eliminating errors in the initial understanding of the skill. The *autonomous phase* is characterized by skilled actions becoming largely automatic, as well as the ongoing improvement in the skill's performance.

Anderson (1982; 2013) expanded on Fitts's (1964) framework with a three-stage model of cognitive skill acquisition, and a computational explanation of its underlying processes. The *first* stage is referred to as the declarative stage (corresponding to Fitts's cognitive stage), where the learner receives instructions about the skill. The *second* stage, referred to as the knowledge compilation stage (corresponding to Fitts's associative stage), is the gradual process of converting declarative knowledge into procedural knowledge. The *final* stage, referred to as the procedural stage (corresponding to Fitts's autonomous stage) involves a further refining of the knowledge and a gradual speedup of performance.

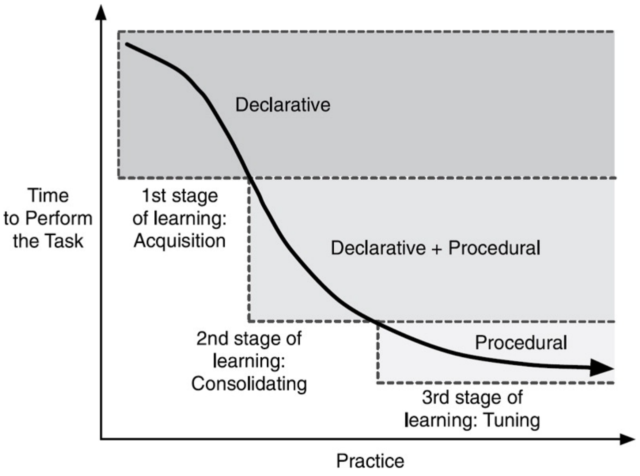

Figure 1: Performance changes during three stages of skill acquisition (Kim & Ritter, 2015).

Production rules

Anderson's theory is based on the computational cognitive architecture ACT-R, which distinguishes between procedural and declarative knowledge to explain the underlying mechanisms of cognitive skill. This accords with the present accounts of skill, which are grounded in the literature on declarative and procedural memory (Squire, 1992; Christensen, Sutton & McIlwain, 2016). Declarative knowledge is propositionally-formatted and structured within semantic networks. Procedural knowledge is commonly referred to by researchers as containing "procedural representations" (Anderson, 1982; Pavese, 2019). In Anderson's model, procedural representations are computationally specified as "production rules" which are a dominant form of representation within accounts of skill (Newell, 1990; Taatgen, 2013). Production rules, or "productions", transform information and change the state of the system to resolve a problem or complete a task. A production rule is modeled after a computer program instruction in the form of a "condition-action" pairing, which is essentially a "pattern-directed invocation of action" (Stocco et al., 2021). It specifies a condition that, when met, performs a prescribed action. A production is also thought of as an "if-then" rule. *If* the condition it specifies is satisfied, *then* it fires an action. Production rules (procedural knowledge) are considered to be central to human intelligence, and fundamental to the realization of cognitive skills (Anderson, 1993).

Proceduralization

The process of converting declarative knowledge to procedural knowledge in the domains of motor skill and cognitive skill is referred to as "proceduralization" (Ford, Hodges & Williams, 2005; Anderson, 2013). This notion has been useful in explaining the acquisition of physical skills in sporting expertise (Beilock et al., 2001) and cognitive skills such as mathematics (Taatgen, 2013). A key attribute of proceduralization is that as declarative knowledge is retrieved and repeatedly practiced, the inefficient knowledge retrieval can be skipped. Procedural knowledge becomes associated with the cue itself, and relies less on the slow retrieval of declarative knowledge. As a result, performance time speeds up and working memory load decreases. Performance can be further refined by mechanisms such as time delayed learning, where faster productions are rewarded.

The building and refining of procedural knowledge (production rules) marks a significant point of convergence among models of skill learning. Veenman et al. (2005) maintain that metacognitive skills can be understood as domains of procedural knowledge. Researchers have speculated that the improvement of metacognition involves the refining of procedural knowledge that people use to monitor and control their own cognitive processes (Flavell, 1992; Brown, 1978; Schraw & Moshman, 1995; Veenman, 2006).

Dual-system metacognition

According to dual-process theories, metacognition consists of two types of processes: conceptual metacognition and procedural metacognition (Koriat & Levy-Sadot, 1999; Shea et al., 2014; Proust, 2019). System-2 "conceptual" metacognition involves the use of metarepresentations with semantic content that directs monitoring and control processes. System-1 "procedural" metacognition is non-conceptual, and allows the monitoring and control of cognitive activity implicitly, without representing it conceptually.

These two types of metacognition exhibit characteristics of dual-system processes more generally. System-2 metacognition is considered to be slow, knowledge-driven, effortful and requiring working memory. System-1 metacognition is considered fast, implicit, affect-driven, and automatic. Within this framework, skill acquisition is partly considered to be a process where System-2 processes "migrate" to become System-1 operations (Kahneman & Frederick, 2004; Dayan, 2009). Metacognitive skill learning can likewise be understood as a process by which System-2 metacognition compiles or "migrates" to System-1 metacognition to become faster, more automatic, and requiring little working memory (Conway-Smith & West, 2022).

Metacognitive proceduralization

The research discussed so far has provided the background for our proposal that metacognitive skill learning develops by way of proceduralization, intended as an extension of the skill learning models by Fitts (1964) and Anderson (2013).

As in the cases of motor skill and cognitive skill, we propose that metacognitive skill progresses from an early declarative stage of instruction-following to an expert procedural stage (Figure 2). In the later stages of proceduralization, metacognition exhibits many of the signature properties of expert performance while becoming faster, more automatic, requiring less working memory, and operating largely outside of conscious awareness.

1. Declarative stage

The metacognitive novice begins with meta-instructions to monitor or control a cognitive state (e.g.: emotion, attention). The meta-instructions are inputted by way of verbal or written communication. Initially, a stimulus will cue the novice to monitor or control a cognitive state, which prompts the retrieval of meta-instructions into working memory. The execution of these meta-instructions triggers the activation of procedural knowledge (production rules) to act them out. Initial metacognitive performance exhibits the characteristics outlined by Fitts and Anderson in the declarative stage: slow, effortful, error-prone, and requiring a large degree of working memory.

2. Associative stage

The metacognitive intermediate has gained a modest degree of experience practicing meta-instructions. As a result, they have built up a significant amount of procedural knowledge to act out the instructions. Repeated practice has resulted in robust associations between procedural knowledge and task conditions, or task-relevant stimuli, leading to procedural knowledge beginning to bypass declarative memory. Because it is faster, this procedural knowledge is rewarded and is more likely to bypass the retrieval of meta-instructions in the future. Intermediate metacognitive performance displays the characteristics of the associative stage: both monitoring and control are achieved more quickly, with less effort, and more automatically.

3. Automatic stage

The metacognitive expert is able to act out monitoring or control processes quickly and effectively. The presence of the initial stimulus now causes metacognitive procedural knowledge to be deployed automatically. Procedural knowledge bypasses the retrieval of declarative knowledge almost entirely as meta-instructions have become embedded within procedural memory — they have proceduralized. Metacognitive expertise demonstrates the characteristics outlined by Fitts and Anderson in their final stages: fast, effective, automatic, and requiring minimal working memory.

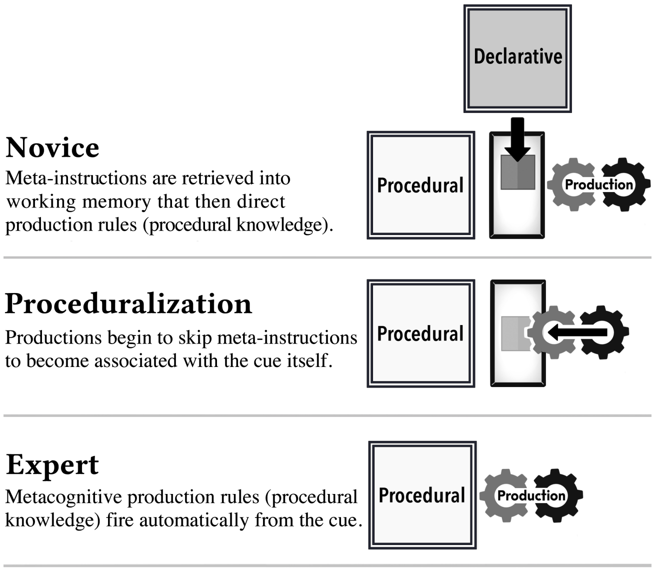

Figure 2: The three stages of metacognitive skill learning through proceduralization.

Elusive mechanisms

It is worth considering why proceduralized metacognition has so long remained unidentified. Our reasoning for this is that proceduralized metacognition has lain hidden behind two barriers. First, metacognition is invisible to outside observers, and its effects are less apparent when compared to overt motor skill (e.g.: tennis) and cognitive skill (e.g.: math). Second, automatized skill is generally less perceivable to the performers themselves. They run largely outside of working memory and operate under reduced levels of conscious access (Beilock & Carr, 2004; Ford et al., 2005).

While declarative knowledge can be directly accessed, procedural knowledge is typically not cognitively accessible (Squire & Zola, 1996), as evidenced by findings that procedural representations are largely unavailable for verbal report (Beilock & Carr, 2001). This is one reason why the development of expert skill in some cases causes performers to report becoming “unaware of them or unable to describe them” as they have become an “unconscious habit” (Ellis, 1994; Oxford, 2011). This helps explain why proceduralized metacognition has remained elusive. Motor skill and cognitive skill, when proceduralized, are still observable. For instance, researchers can watch as a tennis player or math student improves to become faster, more automatic, and less error-prone. Conversely, researchers cannot directly observe an individual practicing metacognition, nor can they watch them improve. Performers themselves have less access to their own advanced skills as proceduralization places the processes underlying them outside of working memory. Even though most skills do not fully automate and can continue to require declarative knowledge, their conscious accessibility is significantly reduced. Hence, we suggest that metacognitive proceduralization has remained obscured due to it being concealed behind twin blindfolds — that of the researcher and that of the participant.

Proceduralized emotional control

While proceduralized metacognition has not been identified explicitly, its presence has been tacitly detected within the literature. Evidence for its existence has appeared implicitly, often as confounding data. The term "implicit" here refers to something being apparent without being explicitly defined or explained. For instance, there has been significant research into a phenomenon wherein an athlete's performance becomes impaired under pressure, also known as "choking." In pressure situations, an athlete can have their skills disrupted by emotional anxiety and inappropriate attentional monitoring (Baumeister, 1984; Masters, 1992; Beilock & Carr, 2005). Here, a paradox can seemingly emerge. Studies indicate that people who tend to be more self-conscious are less likely to have their performance decrease under pressure. In other words, those who routinely feel *more* self-conscious anxiety are *less* likely to choke. What explains these counterintuitive data? This phenomena has been observed in repeated laboratory experiments by Baumeister (1984) and has since been supported (Lewis & Linder, 1997; Beilock & Carr, 2001). Mixed results are associated with variables such as skill level and task complexity (Wang et al., 2004).

To explain this paradox, Baumeister proposed that those who routinely experience more self-conscious anxiety have greater practice at self-regulation. This practice, he asserts, is what aids performance while under pressure (p. 611). While Baumeister's explanation terminates here, we can see within it the signature of proceduralized metacognition. It is described as an improvable skill that when sufficiently practiced operates automatically and outside of working memory. By routinely engaging in emotional regulation, emotional control processes can become learned to the point of automaticity, becoming more efficient and requiring minimal attention (Richards & Gross, 2000; Vohs & Baumeister, 2004). As a result they can assist motor tasks within working memory, mitigating the effects of pressure by self-regulating emotion and attention to improve performance. While initially confounding, Baumeister's paradoxical data can be made sense of in the light of proceduralized metacognition.

Proceduralized attentional control

Attentional control involves subjects concentrating on an object of focus while ignoring irrelevant stimuli (Lutz et al., 2008). Learning attentional selection (identifying targets for processing resources) has been studied from both bottom-up and top-down perspectives (Corbetta & Shulman, 2002; Theeuwes, 2010). Some consider this to be a "failed dichotomy" and call for a more integrated model (Awh, Belopolsky & Theeuwes, 2012). A previously unrecognized mechanism of learning has suggested a limitation in prevailing theories. Recently, researchers have investigated a unique way that attention can be automated to become an attentional "habit" (Anderson, 2016; Salovich, Remington, & Jiang, 2018). Studies have indicated a form of learned attention that can direct attentional resources without cognitive supervision. Whether this occurs through processes that are bottom-up, top-down, or some combination is a matter of controversy. Insight into this problem can be gained by viewing attentional control, when directed at internal states, as a form of metacognition susceptible to proceduralization.

Experiments by Ramamurthy and Blaser (2017) demonstrate what they call "procedural attention". In their experiments, subjects were engaged in visual tasks while being explicitly instructed how to direct their attention. Following training, the subjects performed a task in which both bottom-up cues and top-down selection were prevented. In their absence, the practiced attention allocation still occurred and went where it was trained to go. Because attention was directed toward the rehearsed locations, this was considered evidence for an attentional selection mode that was "offline," i.e.: cognitively unsupervised and automatic. The authors stated that it was "analogous to the procedural memory that guides skilled motor behavior, one can acquire new selection rules that are flexible and context-dependent, yet also implemented automatically and without supervision—a kind of procedural attention." (p. 1).

The researcher's data strongly indicates that subjects' attentional control was proceduralized in stages that correlate to those described by Fitts and Anderson. The authors describe the process as one of initial rule-following that, when practiced, became ingrained into procedural memory. Initially, subjects were given declarative instructions on how to control their attention. These meta-level instructions were then practiced repeatedly. Through rehearsal, the meta-instructions eventually became embedded in procedural knowledge and ran automatically. Given that metacognitive monitoring must also harness internally-directed attentional processes, an analogous account could be developed for the case of metacognitive skill learning.

Discussion

We have proposed that metacognitive skill learning and its underlying cognitive mechanisms can be largely explained through a model of *metacognitive proceduralization*. The motivation for this claim is to address the theoretical gap that has impeded metacognitive research and its application. Our explanation relies on a prominent framework employed within models of physical skill and cognitive skill, that of proceduralization, where declarative knowledge is converted into procedural knowledge and further refined. Hence, we propose that a single learning mechanism contributes to the acquisition of motor, cognitive, and metacognitive skill. This paper has set forth a variety of theoretical and experimental evidence to support this broader view of skill acquisition, where both external and internal actions rely on the same cognitive mechanisms. This explanation supports the viewpoint that metacognitive skill does not belong to an exclusive category of cognitive phenomena.

A goal of science is to unify an array of phenomena within a single theory (Newell, 1990). To this end, we have brought together several different threads of evidence and explained them by recourse to a single parsimonious framework. We have attempted to address what Vohs and Baumeister (2004) called a yet unanswered question, “where do these nonconscious self-regulation capabilities come from? How do they develop?” In response we have focused on two paradigmatic cases: emotional control and attentional control. Our framework helps to reveal these confounding and seemingly separate cases of skill learning as two instances of the same phenomena — metacognitive proceduralization. The process of converting meta-instructions into procedural knowledge allows metacognitive expertise to become an automatic skill as well as an ingrained habit of mind.

Further, this helps to resolve a question posed by researchers Charlton & Starkey (2013), “what effect does proceduralization of attention have on performance?” We submit that proceduralized attention (and metacognition more generally) can operate ‘offline’ and largely outside working memory to automatically assist task performance within working memory.

Likely there are many more instances of metacognitive proceduralization that have been overlooked within the literature, with its signature properties waiting to be identified. The proposed theoretical framework has the potential to inform metacognitive research and to broaden its impact within pedagogical practices, wherever applicable.

A limitation of this theory is that it does not consist of a full account of metacognitive skill as it exists in advanced experts. A more complete account would include the role of implicit learning, cognitive control, and meta-control. Instead, this paper highlights a particular unrecognized aspect of the process of top-down metacognitive skill development. A bottom-up account of metacognitive skill acquisition could involve implicit learning by way of procedural knowledge that is rewarded during direct experience. For example, this could be modeled in the Clarion cognitive architecture (Sun, Merrill & Peterson, 2001).

This model of metacognitive proceduralization is intended to provide testable hypotheses for follow-up work. One avenue for future research would be to test whether the proposed model and its hypothesized stages align with the empirical data that results from metacognitive training. Another route would be to investigate whether the neural correlates of metacognitive skill learning correspond to the same patterns of activation found within similar studies of motor skill and cognitive skill learning.

An abundance of research testifies to the value and efficacy of metacognitive training while lacking a thorough explanatory theory. We intend our proposed framework to provide a path forward in conceptualizing and testing the mechanisms of metacognitive skill and how they interact with other cognitive processes, to help advance a unified theory of metacognition.

Decades of research have investigated how human cognition develops skill at the outward, physical level, however similar research remains to be done at the internal, meta-level. A crucial question remains: How can human cognition learn to skillfully interact with its own processes?

References

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological review*, 89(4), 369.

Anderson, J. R. (1993). Knowledge representation. Rules of the mind.

Anderson, J. R. (2013). Cognitive skills and their acquisition. *Psychology Press*.

Anderson, B. A. (2016). The attention habit: How reward learning shapes attentional selection. *Annals of the new York Academy of Sciences*.

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in cognitive sciences*.

Baker L., & Brown, A. L. (1984). Metacognitive skills and reading. In *P. D. Pearson, The handbook of reading research.* New York: Longman.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology.*

Beilock, S.L., Afremow, J.A., Rabe, A.L., & Carr, T.H. (2001). “Don’t miss!” The debilitating effects of suppressive imagery on golf putting performance. *Journal of Sport & Exercise Psychology*.

Beilock, S. L., & Carr, T. H. (2004). From novice to expert performance: Memory, attention and the control of complex sensori-motor skills. In *Skill Acquisition in Sport.* Routledge.

Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: Working memory and “choking under pressure” in math. *Psychological science.*

Brick, N., Campbell, M., Sheehan, R., Fitzpatrick, B., & MacIntyre, T.(2020). Metacognitive processes and attentional focus in recreational endurance runners. *International Journal of Sport and Exercise Psychology.*

Brown, A. L. (1978). Knowing when, where, and how to remember; a problem of metacognition. *Advances in instructional psychology.*

Charlton, S. & Starkey, N. (2013). Driving on familiar roads: Automaticity and inattention blindness. *Transportation research.*

Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics.*

Christensen, W., Sutton, J., & McIlwain, D. J. (2016). Cognition in skilled action: Meshed control and the varieties of skill experience. Mind & Language.

Conway-Smith, B., & West, R. L. (2022). System-1 and System-2 realized within the Common Model of Cognition. In *AAAI Fall symposium.*

Cooney, R. E., Joorman, J., Eugene, F., Dennis, E. L., & Gotlib, I. H. (2010). Neural correlates of rumination in depression. *Cognitive, Affective & Behavioral Neuroscience*.

Cross, D. R. & Paris, S. G. (1988). Developmental and instructional analyses of children's metacognition. *Journal of Educational Psychology.*

Davidson, J. E., & Sternberg, R. J. (1998). Smart problem solving: How metacognition helps. In *Metacognition in educational theory and practice.* Routledge.

Dayan, P. (2009). Goal-directed control and its antipodes. *Neural Networks*.

Dobson, K. S. (2013). The science of CBT: toward a metacognitive model of change?. *Behavior therapy.*

Dreyfus, H. L., & Dreyfus, S. E. (1986). Mind over machine: The power of human intuition and expertise in the era of the computer. New York: Free Press.

Dunlosky, J., & Rawson, K. A. (2019). How cognitive psychology can inform evidence-based education reform. *The Cambridge handbook of cognition and education*.

Efklides, A., Schwartz, B. L., & Brown, V. (2017). Motivation and affect in self-regulated learning: does metacognition play a role?. *In Handbook of self-regulation of learning and performance.* Routledge.

Ellis, R. 1994. The Study of Second Language Acquisition. Oxford, UK: Oxford University Press.

Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.). *Categories of human*. New York: Academic Press.

Fitts, P. M., & Posner, M. I. (1967). Human performance. Oxford, England: Brooks/Cole.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American psychologist*.

Flavell, J. H. (1992). Perspectives on perspective taking. *Piaget's theory: Prospects and possibilities*.

Fleming, S. M., & Lau, H. C. (2014). How to measure metacognition. *Frontiers in human neuroscience*.

Fletcher, L., & Carruthers, P. (2012). Metacognition and reasoning. *Philosophical Transactions of the Royal Society B: Biological Sciences.*

Ford, P., Hodges, N. J., & Williams, A. M. (2005). Online attentional-focus manipulations in a soccer-dribbling task: Implications for the proceduralization of motor skills. *Journal of motor behavior.*

Garofalo, J., & Lester, F. K. (1985). Metacognition, cognitive monitoring, and mathematical performance. *Journal for research in mathematics education*.

Hagen, R., Hjemdal, O., Solem, S., Kennair, L. E. O., Nordah, H. M., Fisher, P., & Wells, A. (2017). Metacognitive therapy for depression in adults: A waiting list randomized controlled trial with six months follow-up. *Frontiers in Psychology*,

Haith, A. M., & Krakauer, J. W. (2018). The multiple effects of practice: skill, habit and reduced cognitive load. *Current Opinion in Behavioral Sciences.*

Hameed, H. A., & Cheruvalath, R. (2021). Metacognitive skills inventory (MSI): development and validation. *International Journal of Testing.*

Kahneman D, & Frederick (2004) Attribute substitution in intuitive judgment. Models of a man: Essays in memory of Herbert A. Simon.

Keith, N., & Frese, M. (2005). Self-regulation in error management training: emotion control and metacognition as mediators of performance effects. *Journal of Applied Psychology*.

Kuhn, D., & Dean, Jr, D. (2004). Metacognition: A bridge between cognitive psychology and educational practice. *Theory into practice*.

Kim, J. W., & Ritter, F. E. (2015). Learning, forgetting, and relearning for keystroke-and mouse-driven tasks: Relearning is important. *Human–Computer Interaction*.

Koriat, A., & Levy-Sadot, R. (1999). Information-based and experience-based monitoring of one's own knowledge. *Dual-process theories in social psychology*.

Kramarski, B., & Mevarech, Z. R. (2003). Enhancing mathematical reasoning in the classroom: The effects of cooperative learning and metacognitive training. *American educational research journal*.

Krueger, P. M., Lieder, F., & Griffiths, T. (2017). Enhancing metacognitive reinforcement learning using reward structures and feedback. In *CogSci.*

Lewis, B. and Linder, D. (1997). Thinking about choking? attentional processes and paradoxical performance. *Personality and Social Psych. Bulletin.*

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Attention regulation and monitoring in meditation. Trends in cognitive sciences.

Masters, R. S. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British journal of psychology*.

McCabe, J. (2011). Metacognitive awareness of learning strategies in undergraduates. *Memory & Cognition.*

McCormick, C. B. (2003). Metacognition and learning.

Mylopoulos, M., & Pacherie, E. (2020). Self-control as hybrid skill. Surrounding self-control.

Mylopoulos, M., & Pacherie, E. (2021). "Skilled Action Control". *Review of Philosophy and Psychology.*

Newell, A. (1990). Unified theories of cognition. Harvard University Press.

Normann, N., & Morina, N. (2018). The efficacy of metacognitive therapy: a systematic review and meta-analysis. *Frontiers in psychology.*

Oxford, R. L. (2011). Strategies for learning a second or foreign language. *Language teaching.*

Papies, E. K., & Aarts, H. (2016). Automatic self-regulation: From habit to goal pursuit. *Handbook of self regulation: Research, theory, and applications.*

Pavese, C. (2019). The psychological reality of practical representation. *Philosophical Psychology.*

Pearman, A., Lustig, E., Hughes, M. L., & Hertzog, C. (2020). Initial evidence for the efficacy of an everyday memory and metacognitive intervention. *Innovation in Aging*.

Pedone, R., Semerari, A., Riccardi, I., Procacci, M., & Carcione, A. (2017). Development of a self-report measure of metacognition: The Metacognition Self-Assessment Scale (MSAS). *Clinical Neuropsychiatry.*

Proust, J. (2013). The philosophy of metacognition: Mental agency and self-awareness. *Oxford.*

Proust, J. (2019). From comparative studies to interdisciplinary research on metacognition. Animal *Behavior and Cognition*.

Salovich, N. A., Remington, R. W., & Jiang, Y. V. (2018). Acquisition of habitual visual attention and transfer to related tasks. *Psychonomic Bulletin & Review*.

Schaeffner, S., Chevalier, N., Kubota, M., & Karbach, J. (2021). Metacognitive training. *Cognitive Training: An Overview of Features and Applications*.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*.

Schraw, G., & Dennison, R. S. (1994). Metacognitive Awareness Inventory. *Contemporary Educational Psychology.*

Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational psychology review*.

Shea, N., Boldt, A., Bang, D., Yeung, N., Heyes, C., & Frith, C. D. (2014). Supra-personal cognitive control and metacognition. Trends in Cognitive Sciences.

Slagter, H. A., Davidson, R. J., & Lutz, A. (2011). Mental training as a tool in the neuroscientific study of brain and cognitive plasticity. Frontiers in human neuroscience.

Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of cognitive neuroscience*.

Squire, L. R., & Zola, S. M. (1996). Structure and function of declarative and nondeclarative memory systems. *Proceedings of the National Academy of Sciences*.

Stocco, A., Sibert, C., Steine-Hanson, Z., Koh, N., Laird, J. E., Lebiere, C. J., & Rosenbloom, P. (2021). Analysis of the human connectome data supports the notion of a "Common Model of Cognition" for human and human-like intelligence across domains. *NeuroImage.*

Sun, R., Merrill, E., & Peterson, T. (2001). From implicit skills to explicit knowledge: a bottom-up model of skill learning. *Cognitive science*.

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. *Psychological review*.

Ramamurthy, M., & Blaser, E. (2017). New rules for visual selection: Isolating procedural attention. Journal of vision.

Richards, J. M., & Gross, J. J. (2000). Emotion regulation and memory: the cognitive costs of keeping one's cool. Journal of personality and social psychology.

Taatgen, N. A. (2013). The nature and transfer of cognitive skills. Psychological review.

Tuncer, M., & Kaysi, F. (2013). The development of the metacognitive thinking skills scale. *Development*.

Van der Stel, M., & Veenman, M. V. (2010). Development of metacognitive skillfulness: A longitudinal study. Learning and individual differences.

Veenman, M. V. (2015). Metacognition. In *Handbook of individual differences in reading.* Routledge.

Veenman, M., & Elshout, J. J. (1999). Changes in the relation between cognitive and metacognitive skills during the acquisition of expertise. *European journal of psychology of education*.

Veenman, M. V., Van Hout-Wolters, B. H., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and learning*.

Veenman, M. V., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and individual differences.*

Vohs, K. D., & Baumeister, R. F. (2016). Handbook of self-regulation: Research, theory, and applications. Guilford Publications.

Wang, J., Marchant, D., Morris, T., & Gibbs, P. (2004). Self-consciousness and trait anxiety as predictors of choking in sport. *Journal of science and medicine in sport.*

Wells, A. (2019). Breaking the cybernetic code: Understanding and treating the human metacognitive control system to enhance mental health. *Frontiers in Psychology*.

Zimmerman, B. J., & Schunk, D. H. (2011). Self-regulated performance: An introduction and overview. *Handbook of Self-Regulation of Learning and Performance*. New York, NY: Routledge.