Unlocking the Power of Metacognition: The Role of Metacognitive Skills in Decision-Making using Type I/II Thinking

Sylvanna Pavão

A thesis submitted to the University of Ottawa in partial fulfilment of the requirements for the Master's degree in Chemistry

Department of Chemistry and Biomolecular Sciences

Faculty of Science

University of Ottawa

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Abstract

Strong reasoning skills are vital in a variety of academic and everyday contexts, requiring strong metacognitive awareness to be strategic and efficient. However, relatively little is known about how metacognitive abilities and skill-building relate to making purposeful choices about reasoning. We investigated the role of metacognition in Dual Process theory, including learners' awareness and self-description of their cognitive engagement. Dual-process theory describes that most reasoning results from the interaction of two cognitive processes: Type I (fast/intuitive thinking) and Type II (slow/analytical thinking). The purposeful use of reasoning types is complex, including metacognitive awareness of the Type being used, identifying the optimal type, deciding if there is a need or benefit to switching, desire/motivation to switch, and the ability to do so (e.g., cognitive resources). This mixed-methods study examined how a metacognition intervention influenced awareness of and engagement with Type I/II thinking, and the impacts of training in discipline agnostic and discipline specific contexts (organic chemistry). Using an experimental design that included pre- and post-tests, participants completed a worksheet targeting Type I/II reasoning three times over two weeks. Participants in the treatment/intervention group completed a metacognition learning module, while the control group completed an unrelated activity. In the worksheets, participants identified the thinking type they engaged with for questions and explained their thought process. We found that having an organic chemistry background and/or belonging to a particular group (intervention/control) were correlated with differences in analytical engagement. Participants in the treatment group demonstrated more deliberate monitoring and regulation of their reasoning, whereas participants in the control group relied on rigid, superficial distinctions between thinking types. Metacognitive accuracy and regulation varied across groups.

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Acknowledgments

This work was funded by the Social Science and Humanities Research Council (SSHRC) through a Canada Graduate Research Scholarship – Master's Program (CGS-M).

Thank you, Alison for your support and wisdom throughout this journey. You have been a wonderful mentor, I have gained so much from graduate studies, both academically and personally. Your support has meant so much to me, and I am forever grateful for the opportunity you have given me.

I would also like to thank my Thesis Advisory Committee, Dr. Charles Collin and Dr. Joseph Moran for your support and guidance.

The opportunity to continue pursuing my education has been a privilege for which I am eternally grateful. Not only am I thankful for the opportunity to learn, but for all the friendship and people I have connected with. I want to thank every member of the Flynn Research Group. I am so thankful to have had such a supportive work environment, thank you all for your guidance and for all the laughs. Specifically, I'd like to thank Kathryn (could not emphasize enough how much your support means to me), Meredith (I have learned so much from you in such a short time), Silvi (thank you for all of your insight and amazing questions), and Priyanka (became a pro-coder overnight!). Thank you to Uche, Sarwa, Lilli, Wilton, Britney, Olivia, Malaika, and Dash for being such wonderful colleagues and friends!

To the friends outside of research who supported me on my journey. Makenna, I will forever be grateful for supporting me through my hardest days and believing in me when I did not. I will forever cherish the friendship we built, our late-night talks, and cooking with you. I learned so much from you and I would not be here without you. Amélie, I could not have asked for a more amazing and kinder human to live with these last two years. Your kindness is truly infectious, and I cannot wait for more adventures together. Alex and Gus, I am so happy we met, you both bring so much energy and laughter, thank you for all the memories. Thank you to Camille, Lily, and Jemimah for being there for me, listening, and for staying connected beyond our time at McMaster.

David, you have supported me through everything, no matter how difficult. Your encouragement and constant support means more to me than I am able to express. I look forward to our next chapter and for all the movies we will be watching!

To everyone, and others, I am so grateful that I crossed paths with all of you in Ottawa. This thesis came to be because of your positivity and support. And finally, to all the movies I watched over the last two years! I just really like movies.

Chapter 1. Introduction

Assessing whether learners gain the intended benefits of education is inherently complex. Although education is regarded as a powerful tool for empowerment, in providing opportunities to develop new skills, confidence, and knowledge to shape decision-making, these outcomes are not guaranteed (Azevedo et al., 2015; Zimmerman, 2000). Education benefit is often assumed to ideally enhance personal growth and builds critical thinking skills that extend beyond the classroom. Simply gaining access to information, however, does not mean that a learner is gaining skills that are effective and transferable. In particular, learners do not always develop the metacognitive knowledge and regulatory strategies needed to effectively guide their thinking. Nor do learners consistently engage in appropriate forms of reasoning, as a result, they may rely on inefficient or inappropriate cognitive strategies to use in their learning processes (Stanton et al., 2021). Meaningful learning therefore depends not only on what learners know, but on how effectively they can monitor, regulate, and adapt their thinking in context (Flavell, 1979; Tanner, 2012; Stanton et al., 2021). In a chemistry context, these challenges are often reflected in students' difficulties with coordinating conceptual knowledge and approaching tasks (Talanquer, 2025). Understanding the long-term impacts of pedagogical innovation as a whole requires systematic, evidence-driven research.

Chemistry is fundamental to our engagements in scientific inquiry, discovery, and innovation (Mahaffy et al., 2019). As a discipline, chemistry is characterized by complex connections and interactions across scientific fields and global issues, demanding more than the acquisition of isolated chemistry knowledge (Balaban & Klein, 2006; Pazicni & Flynn, 2019). Expert chemists routinely navigate and integrate various chemical perspectives into their work depending on their goals (Talanquer, 2025). This work involves the integration of multiple theoretical principles including representational models, causal mechanisms, and practical goals (Talanquer, 2025). Each principle offers a distinct perspective that chemists can use to construct meaning, generate explanations, and make predictions (Ruthenberg & Mets, 2020; Talanquer, 2025). The pluralistic nature of chemical knowledge, however, complicates how such understanding is developed and applied (Ruthenberg and Mets, 2020). In contrast, chemistry learners can see these ideas as disconnected, or confined to a course, topic, or textbook chapter. As a result, learners often struggle to think about chemistry in the same integrated and flexible ways as experts, relying instead on fragmented or surface-level understandings. Addressing this gap requires pedagogical approaches that support learners in recognizing multiple conceptual perspectives, articulating their reasoning, and transferring their understanding across contexts (Talanquer, 2025).

Education research plays a central role in addressing the challenge of understanding how learners can effectively build knowledge and skills. The field seeks to gather, interpret, and apply evidence on student learning and teaching methods aimed at improving learning experiences (American Educational Research Association, 2021; Creswell, 2012). Building on philosophical perspectives that position learning as a process of inquiry, discovery, and reflection (Dewey, 1938; Schön, 2009), educational research examines how students reason when engaging with problems. In STEM fields, learners must not only to acquire conceptual knowledge, but also apply reasoning skills that support analysis, explanation, and problem-solving (Schraw et al., 2006). Consequently, there has been growing attention to investigating how students develop and apply reasoning skills in scientific contexts. Discipline-Based Research (DBER), which focuses on a specific domain, such as Chemistry Education Research (CER) is grounded in the "priorities, worldview, knowledge, and practices" of the discipline being studied (Henderson et al., 2017). CER provides evidence-based practices towards improving teaching and learning of chemistry (National Research Council, 2015). Within this growing body of work, there has been increasing attention to understanding how learners regulate their thinking and engage in reasoning during problem-solving.

Despite growing attention to metacognition and reasoning in STEM education, these areas have largely been studied in parallel, with metacognitive instruction and reasoning research rarely being integrated within Dual Process Theory of Reasoning (DPTOR) frameworks. Although metacognitive instruction supports learners' awareness and regulation of thinking and reasoning has been widely studied in STEM through frameworks such as Dual Process Theory, these bodies of work have rarely been integrated. Little research has explicitly investigated how metacognitive instruction relates to learners' engagement with, and transitions between, Type I and Type II thinking as conceptualized within DPTOR. This gap is present in chemistry education, where effective problem-solving depends on learners' ability to both identify and regulate their reasoning processes in context (Talanquer, 2025).

More specifically, what remains underexplored in the gap is how learners shift from more automatic, intuitive forms of reasoning toward more deliberate and strategic thinking during problem-solving, and the role that metacognitive processes play in supporting this transition. Explicit attention to metacognitive awareness and regulation of thinking types remains underdeveloped, although some studies have considered the role of metacognitive instruction in promoting analytical reasoning. Aspects that remain unclear include how learners monitor their cognitive processes, how they decide when a shift in thinking is warranted, and how instructional support might foster this flexibility. Taken together, these gaps point to a need for research that more explicitly connects metacognitive instruction with learners' use of Type I and Type II thinking during authentic problem-solving to better understand how students recognize, regulate, and shift their reasoning in disciplinary contexts such as chemistry.

1.1 What is Chemistry Education Research?

CER involves the investigation of teaching and learning that is grounded in educational and cognitive theories that explain how chemistry learners construct, apply, and refine their understanding of chemistry (Herron & Nurrenbern, 1999). CER's primary goal is the research of instructional approaches and learning environments that support meaningful learning, conceptual understanding, and the development of scientific reasoning. In this way, CER contributes to improving both learner performance and broader educational outcomes in chemistry.

To address these goals, CER draws on a combination of quantitative and qualitative research methods to capture both measurable learning and the underlying processes that shape learners' thinking (Henderson et al., 2017). CER represents a domain of Discipline-Based Education Research (DBER), which grounds investigations in the "priorities, worldview, knowledge, and practices" of the discipline being studied (Henderson et al., 2017). In a world with increasingly complex issues, including those of scientific nature, STEM education requires the development of core skills that extend beyond formal education.

CER research is typically based on a theoretical lens used to interpret and understand the data collected (Cooper & Stowe, 2018). CER studies can also examine aspects of student thinking and engagement, introducing complexities in research design that must be carefully considered. Complexities arise as learning is not strictly a cognitive process, but depends on factors such as motivation, prior knowledge, affect, social context, etc.(Mayer, 2009; National Research

Council, 2015; Zimmerman, 2000). CER extends beyond measuring how concepts are taught and how well students recall them; it considers how students are thinking, the factors shaping their reasoning, and how instructional approaches influence learning.

Understanding how learners think and regulate their reasoning has led CER to increasingly focus on metacognition as a means of improving learning outcomes. Metacognition is defined as the awareness and control of thinking for learning which includes the knowledge of how you think and the regulation of how you control your thinking and approaches (Flavell, 1979; Tanner, 2012). While cognitive skills involve carrying out a task or applying knowledge, metacognitive skills involve recognizing what one does and does not know, alongside the monitoring, evaluation, and regulation of cognitive processes (Schraw & Dennison, 1994; Veenman et al., 2006). In this thesis, I examine the effect of a metacognitive intervention tool on learners' decision-making and problem-solving skills, both within and beyond the chemistry discipline. In chemistry contexts, metacognitive skills play an important role in supporting learners as they navigate abstract concepts, integrate multiple representations and apply knowledge (Akyol et al., 2010). Research suggests that metacognition has a strong potential to improve learning by enabling students to become more effective and efficient in their approaches (Stanton et al., 2021; Tanner, 2012). Despite this potential, developing metacognitive skills in practice remains challenging. The inherently tacit nature of metacognition makes learners' thinking difficult to observe, measure, and assess (Stanton et al., 2021). As a result, research aimed at fostering metacognitive skills remains less developed than more theory-driven work. This study addresses this gap in fostering metacognitive skills by investigating how a metacognitive intervention influences learners' decision-making and problem-solving processes, with the goal of informing instructional approaches and contributing to CER literature on reasoning and learning in STEM contexts.

1.2 Current Literature

Reasoning skills, including argumentation and explanation, are acknowledged as essential learning objectives in mathematics, science, and engineering (English, 2016; Jensen et al., 2017; Yaki, 2022). Students are anticipated to integrate their acquired knowledge and reasoning skills developed throughout a course into their respective fields of study (Hasanah, 2020). In recent decades, STEM education researchers have identified various challenges students face with key concepts and have developed teaching strategies that substantially enhance student performance across different contexts (Gette et al., 2018; Kryjevskaia et al., 2014; Speirs et al., 2021). Amongst challenges, a lack of conceptual understanding has been identified as a key source of incorrect responses; however, refinements to instructional materials designed to address these conceptual difficulties have not led to significant improvements in performance (Gette et al., 2018). These findings suggest that improving conceptual instruction alone may be insufficient to meaningfully enhance learners reasoning skills without also addressing how learners engage in reasoning processes.

Despite evidence supporting lack of conceptual understanding leading to incorrect responses, some studies have revealed incorrect responses may more so be attributed to reasoning difficulties (Heckler, 2011; Krist et al., 2019; Kryjevskaia et al., 2014; Speirs et al., 2021). Reasoning difficulties, considered common to all human reasoning and not limited to STEM, influence the strategies learners use when solving problems (Krist et al., 2019). As a result, there has been a shift towards investigating the cognitive mechanisms behind human reasoning and their effect on learners reasoning in STEM contexts (Gette et al., 2018; Speirs et al., 2021). Researchers can work to identify the underlying mechanisms that may lead to observed patterns of student reasoning and develop tools to enhance student reasoning skills.

Competing perspectives within STEM education research offer different explanations for why students produce incorrect responses, challenging the assumption that such errors reflect a lack of conceptual understanding (Speirs et al., 2021). However, alternative perspectives shift attention from what students know to how their reasoning is constructed and applied in context. One perspective conceptualizes misconceptions as stable and robust knowledge structures that are consistently applied across situations (McCloskey & Kohl, 1983; Posner et al., 1982). In contrast, other approaches focus on identifying patterns in students' reasoning, emphasizing common incorrect reasoning pathways across learners rather than fixed knowledge deficits (Heron, 2017; McDermott & Redish, 1999). The Resources Framework offers a further alternative by proposing that learners construct responses dynamically from fragmented pieces of knowledge that are activated in the moment, leading to variability in reasoning across contexts (Brown et al., 2010). These perspectives differ in how they conceptualize the structure and stability of student knowledge but collectively suggest that incorrect responses may arise from multiple underlying mechanisms rather than a single deficit in understanding. This distinction motivates a closer examination of the cognitive processes that shape how learners construct and apply reasoning, which is central to the focus of this thesis.

The Resources Framework provides a dynamic account of student reasoning by conceptualizing knowledge as context-sensitive elements that are assembled during problem-solving (Brown et al., 2010). Within this perspective, learners draw on networks of "resources" that are activated and coordinated in response to task demands (Lesener et al., 2020; Young & Meredith, 2017). A central challenge, however, lies in explaining the mechanisms through which learners construct, evaluate, and revise these mental models, ultimately deciding which ideas to accept or reject. Researchers have therefore sought to develop a predictive account of why certain knowledge resources are activated when faced with a certain problem or decision while others are not (Elby, 2000). One proposed mechanism is epistemological framing, which describes how learners interpret the nature of a task and determine what kinds of knowledge or reasoning strategies are appropriate to apply (Louca et al., 2004). These interpretations influence which resources students activate during problem-solving. To further account for the cognitive processes underlying these decisions, researchers have increasingly drawn on frameworks from cognitive science that characterize reasoning and decision-making (Heron, 2017). In particular, Dual Process Theories of Reasoning (DPTOR) offer a framework for interpreting patterns in learner reasoning by describing how intuitive (Type I) and analytical (Type II) processes interact during problem-solving (Evans & Stanovich, 2013; Evans, 2006; Gette et al., 2018; Kahneman, 2011). Together, these perspectives shift attention toward identifying the cognitive mechanisms that govern how reasoning is activated and applied in context.

Dual Process Theory can be used to describe reasoning skill mechanisms through Type I and Type II thinking. Type I thinking is described as one's intuitive and automatic decision-making process based on one's prior knowledge or experiences (Kahneman, 2011; Osman, 2004; Sloman, 1996; Stanovich, 2009). In contrast, Type II thinking is a deliberate, analytical approach requiring conscious thought and effort; it is ideally used when approaching more complex decisions or problems. While the Type I/II distinction provides an objective framework for describing more of reasoning, the extent to which individuals engage in these processes is inherently subjective to individuals' differences in prior knowledge, skill level, task familiarity, etc. This variability is particularly evident in educational contexts, where students' intuitive Type I responses often manifest as persistent misconceptions during problem-solving.

Typically, the misconceptions students apply in decisions and problem-solving are deeply ingrained, intuitive ideas that are activated via Type I thinking (A. K. Wood et al., 2016). These intuitive ideas are typically deployed without conscious awareness, which highlights the role of metacognition in both recognizing when Type I responses are guiding one's thinking and regulating whether to engage in more deliberate Type II reasoning. From a Dual Process perspective, learners who can monitor their thinking and reflect on the adequacy of their initial responses are better positioned to override automatic intuitive responses, when necessary, thereby supporting more flexible reasoning (Wood et al., 2016).

One study investigated students' ability to suppress their initial, intuitive ideas to engage with more deliberate thinking (Wood et al., 2016). They assessed the student's ability to transition between thinking types by assessing student performance on using two different instruments: Cognitive Reflection Test and the Force Concept Inventory. The Cognitive Reflection Test is a three-item instrument composed of questions that cue an incorrect, Type I response via a series of "brain teasers" developed by (Frederick, 2005). The FCI is a 30-item multiple choice test which tests students' understanding of Newtonian mechanics designed by (Hestenes et al., 1992). Researchers compared students' scores between each assessment to understand mechanisms behind student reasoning. They found that students who can successfully override these intuitive responses and perform better on the CRT are more likely to activate the appropriate resources to correctly respond to a question. Due to a cognitive bias toward the less demanding nature of Type I thinking, it is often inadequate for daily tasks requiring higher-order reasoning. (Wood et al., 2016). However, they do not explicitly explore the specific mechanisms behind how some individuals are better able to transition between thinking types. Students' reasoning within the context of Dual Process Theories of Reasoning remains underexplored, despite the framework's potential to provide insights into mechanisms underlying reasoning.

Another study sought to develop and refine methodologies for disentangling student reasoning skills from conceptual understanding by Speirs et al. (2021). Students were asked to respond to two different physics questions intended to cue Type I as the incorrect cognitive pathway. Researchers provided students with reasoning chain tasks as a scaffold composed of a list of reasoning elements (all of which were true) to help students assemble a chain of reasoning intended to lead to a conclusion. One main finding was that providing increased access to information relevant to the correct line of reasoning did not produce large differences in student answering patterns. However, increasing access to information that challenged initial Type I conclusions impacted student answering patterns, but only for students who demonstrated relevant mindware (i.e., conceptual understanding). These findings were consistent with Dual Process Theory and demonstrate the applicability of such reasoning frameworks. Another study also investigated the disentanglement of student conceptual understanding and reasoning approaches using sequence related questions by Kryevskaia et al. (2014). They investigated how to use Dual Process Theory to analyze inconsistencies in student responses on physics questions. Findings showed that students could use correct ideas to justify an anticipated conclusion, yet often failed to engage in the reflective Type II reasoning needed to question an incorrect intuitive response.

Research in chemistry education has increasingly demonstrated that students often rely on heuristic-based reasoning when solving chemistry problems, specifically in the organic chemistry context (Talanquer, 2014). Heuristics are cognitive shortcuts or simplified rules that enable rapid judgments and decision-making, often with limited conscious deliberation (Evans, 2006; Krist et al., 2019). Talanquer (2014) highlights that chemistry learners frequently depend on intuitive patterns of reasoning that are productive in some contexts but can also lead to systematic misconceptions and errors that can impede on learners' understanding with further organic chemistry exposure. Talanquer identifies several "heuristics to tame" relating to common (and at times) incorrect reasoning tendencies in chemistry. For example, the "stability heuristic" where learners assume chemical systems naturally more toward the most stable arrangement (without considering kinetic control), and the "more is better" heuristic, where students assume that increasing a variable increases an outcome proportionally, although these assumptions are reaction dependent (Talanquer, 2014). Heuristics allow leaners to rapidly interpret chemical information but may limit full engagement in mechanistic or analytical reasoning.

Additional ways heuristics manifest in specific chemistry contexts include assumptions that stronger acids always react faster or produce more extensive reactions because of an intuitive association between "strength" and greater chemical effect. Similarly, student often interpret equilibrium systems through a balancing heuristic, assuming reactions process equally in both directions or that equilibrium implies equal concentrations rather than rates (Talanquer, 2014). These reasoning patterns demonstrate how cognitive shortcuts can shape students' interpretations of chemical phenomena while bypassing deeper conceptual evaluation. An example of chemistry learners applying a Type I reasoning heuristic can be seen in identifying E2 products via a stability-based assumption. Leaners are initially taught that E2 reactions preferentially yield the more substituted, thermodynamically stable alkene (i.e., Zaitsev product) (Figure 1). However, this heuristic does not always hold, as substrate structure, reaction conditions, and other factors can affect the outcome. When a bulky base (e.g., t-BUOK) is used, steric constraints shift the reaction pathway to favour the less substituted Hofmann product. This outcome requires consideration of mechanistic factors such as base sterics and anti-periplanar geometry. As a result, Figure 1 serves as an example where Type I reasoning can lead to incorrect intuitive judgments where more analytical Type II reasoning may be appropriate or necessary.

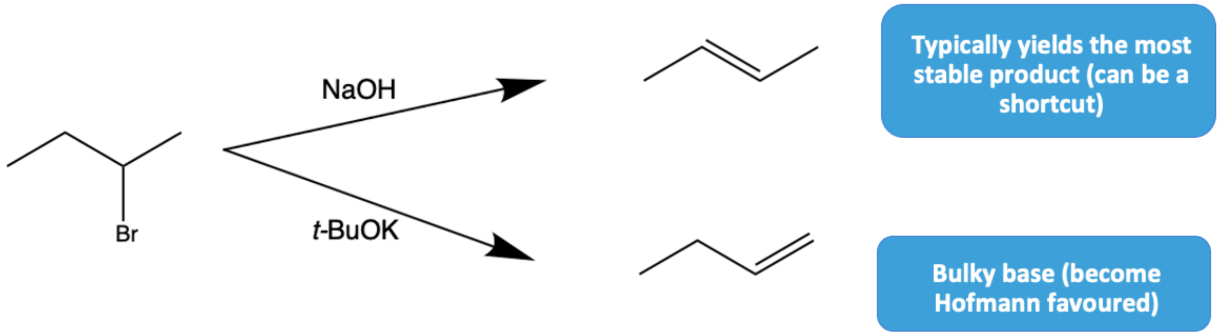
NaOH
Br
t-BuOK
Typically yields the most stable product (can be a shortcut)
Bulky base (become Hofmann favoured)

Figure 1. Representation of an E2 reaction with two possible outcomes depending on reaction conditions.

Within chemistry problem-solving and reasoning, heuristics can be understood as a manifestation of Type I processing. Learners often rely on familiar surface features or memorized associations to generate quick responses when under cognitive- or time-related pressures. This relationship between heuristics and Dual Process Theory is also evident in organic chemistry when learners are asked to coordinate symbolic representations, mechanistic reasoning, and electron movement simultaneously. For example, Grove et al. (2012) demonstrated that students may use curved arrows in a superficial or symbolic manner, relying on product-oriented reasoning rather than using electron flow to support causal mechanistic explanations. Additional research has also demonstrated that students are capable of engaging in productive mechanistic reasoning strategies when approaching unfamiliar reactions. For example, Flynn and Featherstone (2017) examined how students interpreted and applied the electron-pushing formalism in unfamiliar organic reactions and found that students are excellent at analyzing the symbolism generally, but there are specific situations (e.g., implicit atoms/electrons, cyclic structures, etc.) where they demonstrate difficulties when reasoning through mechanistic steps. Bhattacharyya (2013, 2014) found that students often used the electron-pushing formalism to track electron density, identify reactive sites, and iteratively test mechanistic possibilities, suggesting an emerging causal understanding of reactivity. Similarly, Caspari et al. (2018) showed that students frequently engaged in backward-oriented reasoning by working retrospectively from products to infer plausible mechanistic pathways. Webber and Flynn (2018) showed that students are also capable of productive mechanistic reasoning, often generating chemically plausible solutions by leveraging strategies such as expanding structures, identifying charges and reactivity patterns, and mapping atoms and electrons across transformations, even when their pathways differed from expected solutions. These findings align with broader research showing that students' mechanistic reasoning is sensitive to representational demands, such as implicit atoms, stereochemistry, and reaction complexity, which can constrain their ability to fully coordinate structure, electron flow, and reactivity (Bhattacharyya, 2013, 2014; Caspari et al., 2018; Flynn & Featherstone, 2017; Graulich, 2025; Talanquer, 2024).

Research on reasoning difficulties in chemistry has also shown that learners often struggle to consistently track atoms and electrons across multistep mechanisms (Bhattacharyya, 2013, 2014; Caspari et al., 2018; Flynn & Featherstone, 2017; Graulich, 2025; Talanquer, 2024). Learners often fail to track formation of bonds, omit lone pairs and formal charges, or incorrectly shifted atoms during a mechanism. In many cases, there is a "backward" reasoning approach where student identify the product of a reaction and construct the mechanism based on a memorized final product rather than a mechanistic analysis grounded in electron flow. As a result, learners are able to demonstrate knowledge of formal conventions of mechanisms without fully understanding their chemical meaning conveyed by the arrows and representations (Bhattacharyya, 2013; Flynn & Featherstone, 2017). These studies suggest that heuristic reasoning reflects adaptive cognitive processing under demanding learning conditions, particularly as organic chemistry require (oftentimes) novice learners to simultaneously coordinate information (e.g., symbolic representations, structure, stereochemistry, electron movement, etc.) while managing academic pressure and memory demands (Bhattacharyya, 2013, 2014; Caspari et al., 2018; Flynn & Featherstone, 2017; Graulich, 2025; Talanquer, 2024). Under these conditions, heuristic shortcuts are used to reduce cognitive load by allowing student to generate quick and plausible responses. From a Dual Process Theory perspective, these heuristic strategies represent efficient Type I processing but may also interfere with the deeper Type II analytical engagement when left unexamined.

Research examining reasoning challenges in STEM contexts has largely relied on task-based designs, in which learners are presented with controlled problem scenarios that manipulate features such as context, data, or cognitive conflict to examine how reasoning is applied (Amsel et al., 2008; Frederick, 2005; Hestenes et al., 1992; Janssen et al., 2021; Paulsen & Kolstø, 2022; Speirs et al., 2021; A. K. Wood et al., 2016; Zhou et al., 2016). In parallel, instrument-based approaches used standardized assessments to assess learners' tendencies toward Type I or Type II thinking and identify patterns in reasoning across contexts (Bhaw et al., 2023; Böckenholt, 2012; Frederick, 2005; Krell et al., 2022). Reasoning studies also incorporate structured scaffolds to examine how learners construct and apply reasoning when provided explicit support (Gette et al., 2018; Hardy et al., 2021; Hein & Prediger, 2024; Kranz et al., 2023; Renkl, 1997). Collectively, findings across the mentioned studies demonstrate that learners often rely on initial intuitive responses and struggled to evaluate or override them, even when relevant conceptual knowledge is available. This pattern highlights a critical challenge: supporting learning in recognizing when their initial reasoning is insufficient and in engaging in more deliberate, analytical processes when needed. This challenge has prompted growing attention toward instructional approaches that explicitly support the regulation of reasoning during problem-solving.

Within this emerging focus, recent research has examined the design and implementation of instructional intervention aimed at supporting learners' metacognitive awareness and regulation during problem-solving (Pulukuri & Abrams, 2021; Salekdeh et al., 2025; Udu & Mbamalu, 2025; Vo et al., 2025; Z. Muteti et al., 2021). Within CER and STEM research, explicit metacognitive instructions has been shown to enhance learners' ability to articulate, monitor, and regulate their thinking processes (Fono & Zohar, 2024; Wass et al., 2023). Studies integrating metacognitive prompts, structured reflection, and feedback engagement demonstrate some improvements in how students approach learning tasks, including the greater use of strategic thinking and deliberate evaluation of solutions (Blackford et al., 2023; Heidbrink & Weinrich, 2021; Mutambuki et al., 2020; Olop et al., 2024; O'Neill et al., 2025; Salekdeh et al., 2025; Vo et al., 2025; S. Y. Wood & Cross, 2024). In chemistry-specific contexts, research shows that learners who engage in metacognitive regulation are better able to evaluate problems and justify their reasoning, although such strategies are not consistently or spontaneously applied (Blackford et al., 2023; Z. Muteti et al., 2021).

Interventions such as structured metacognitive instruction embedded within active learning environments show that prompting students to evaluate their understanding and reasoning can improve both conceptual understanding and strategic performance (Blackford et al., 2023b; Heidbrink & Weinrich, 2021; Mutambuki et al., 2020; Olop et al., 2024; O'Neill et al., 2025; Salekdeh et al., 2025; Vo et al., 2025; S. Y. Wood & Cross, 2024). Similarly, studies using prediction-reflection-feedback cycles demonstrate that when students are repeatedly asked to assess their understanding before and after solving problems, they become more accurate in judging their own knowledge and more likely to adjust their problem-solving strategies over time (Casselman & Atwood, 2017; Mutambuki et al., 2020; King et al., 2022). CER specifically embeds metacognitive prompts into discipline specific tasks (e.g., reaction prediction, mechanistic reasoning, and explanation generation) can increase students' use of monitoring strategies such as checking for consistency of answers, evaluating alternative solutions, and justifying reasoning steps (Blackford et al., 2023; Richards-Babb et al., 2025; Halmo et al., 2024). However, these studies consistently report that metacognitive engagement is uneven: while some learners adopt more reflective and evaluative strategies when prompted, others continue to rely on intuitive or surface-level reasoning even when structured supports are present.

Building on intervention-focused work, complementary research has examined how metacognitive development, at the surface-level, relates to learners' ability to regulate reasoning and manage intuitive responses during problem-solving. Longitudinal research suggests that increases in metacognitive awareness co-occur with improvements in inhibitory control and reflective reasoning, indicating a strengthening of learners' capacity for cognitive regulation over time (Amsel et al., 2008; Symeonidou et al., 2025). These findings suggests that the ability to manage or override intuitive responses may develop alongside broader metacognitive and executive functions. Experimental and classroom-based studies further find that learners who engage in metacognitive monitoring are more likely to detect conflicts in their reasoning, reconsider initial responses, and adjust their problem-solving strategies accordingly (Bjork et al., 2013; Veenman et al., 2006).

Across the past decade, research on metacognition and reasoning has introduced metacognitive prompts, scaffolds, or instructional modules and evaluate their impact on student performance or self-reported strategy use (Olop et al., 2024; O'Neill et al., 2025; Symeonidou et al., 2025; S. Y. Wood & Cross, 2024). Other studies examine metacognition through self-report and survey-based studies, often revealing a misalignment between perceived and actual understanding (Cooper et al., 2008; Mutambuki et al., 2020; Z. Muteti et al., 2021). In parallel, some studies have also adopted process-oriented approaches, such as think-aloud protocols (students articulates their thought process when solving a problem to a researchers who records their ideas) or written reflections, to capture how learners monitor and evaluate their thinking during problem-solving (Blackford et al., 2023b; Heidbrink & Weinrich, 2021; Salekdeh et al., 2025; Vo et al., 2025). Within chemistry-specific contexts, this work has highlighted that while learners can articulate aspects of their thinking when prompted, metacognitive processes are not consistently or spontaneously applied during complex tasks (MacNeil et al., 2024; Tanner, 2012; Veenman et al., 2006).

The evidence base in metacognitive studies primarily demonstrates associations between metacognitive engagement and improved reasoning outcomes, rather than explaining how these processes unfold during problem-solving. Pre-existing work relies on performance comparisons, or aggregate outcome scores, which limits understanding of when learners recognize the need to adjust their reasoning or how transitions between intuitive and analytical processes occur in real time (Blackford et al., 2023; Olop et al., 2024; O'Neill et al., 2025; Symeonidou et al., 2025; S. Y. Wood & Cross, 2024). As a result, the mechanisms through which metacognitive processes support dynamic reasoning shifts are not thoroughly examined.

However, this focus on metacognitive regulation alone may still be insufficient to fully account for variability in reasoning processes during problem-solving. Engagement in analytical (Type II) reasoning is also influenced by motivational factors that shape whether individuals choose to invest cognitive effort, even when they are capable of doing so (Evans and Stanovich, 2013). Need for cognition (NFC) captures stable individual differences in the tendency to engage in and enjoy effortful cognitive activity (Cacioppo & Petty, 1982). Individuals higher in NFC are more likely to persist in analytical reasoning and engage in elaborative processing, whereas those lower in NFC are more likely to rely on cognitive shortcuts or intuitive responses when available. NFC reflects a motivational orientation towards thinking rather than cognitive capacity itself (Fleischhauer et al., 2010; von Stumm et al., 2011). As a result, variability in engagement with Type II reasoning may reflect not only differences in metacognitive regulation, but also differences in the willingness to exert cognitive effort during problem-solving.

1.3 Impetus for Research

This thesis brings together Dual Process Theory and metacognition to examine the underexplored mechanisms underlying learners' decision-making and problem-solving processes, with the aim of better understanding how metacognitive skills support transitions in reasoning. We investigate the impact of an intervention designed to improve how learners use metacognitive skills to understand and regulate how they engage with Type I and Type II thinking when problem-solving. An overreliance on either thinking type, however, could lead to either an oversimplification (Type I) or over-complication (Type II) of the decision-making process. Building an understanding of metacognition is important as individuals can struggle with transitioning from Type I to Type II thinking, leading to a tendency to default to familiar shortcuts (Evans & Stanovich, 2013a; Stanovich, 2009). Learners must understand and deliberately engage in the optimal thinking process, though they may lack the cognitive strategies to consciously apply the appropriate thinking types when faced with a problem (De Neys, 2012). It must be noted, however, that neither thinking type is more important than the other, as their utility is task dependent. Effective cognition plays a role in understanding when to rely on which type, and shift between them depending on the task.

Metacognition is an essential element of students' efforts to attain a deeper understanding of concepts in chemistry and become expert problem solvers (Bell & Volckmann, 2011; Cook et al., 2013; Mutambuki et al., 2020; Rickey & Stacy, 2000). As such, we chose metacognition to explore reasoning mechanisms as it was a project whose premise was mapped out by Dr. Alison Flynn in which I picked up the idea and saw the study through. Metacognition's influence on students' reasoning is poorly understood. Research studies are lacking that specifically investigate the impact of a metacognitive intervention in the context of student reasoning and decision-making skills despite its significant role in one's learning process (Kryjevskaia et al., 2014).

Adopting new thinking strategies is complex and demanding for novice learners, though the process can be facilitated by instructors who actively support the development of students' metacognitive skills (Kryjevskaia et al., 2014). Improvement of student metacognition could potentially address some gaps in their reasoning pathways as metacognition serves to regulate the interaction between Type I and Type II thinking and bridge the gap between these processes. Fostering students' ability to critically evaluate different ways of thinking and integrate insights from those evaluations into their ever-growing understanding could help them approach problems more consciously and intentionally (Schraw et al., 2006). Teaching and learning intentionally to encourage students to navigate between both systems when appropriate can better equip them to tackle the broad and complex challenges they will encounter after graduation (Amsel et al., 2008).

Currently, to our knowledge, there is no research that explicitly investigates the impact of teaching metacognition on students' understanding of intentional engagement with Type I and Type II thinking. This connection could provide valuable information behind students decision-making processes and mechanisms behind choices contributing to different reasoning pathways. Mental models play a crucial role in how individuals approach decision-making and reasoning (Bongers et al., 2019; Holtrop et al., 2021). Therefore, a deeper understanding is needed of how people apply these models in specific situations. By examining the variations in the level of detail within individuals' mental models, we can pinpoint where gaps emerge in their reasoning process. Identifying these gaps is key to helping students enhance their mental models and become more strategic problem solvers. This understanding can not only improve students' performance on assessments but also better prepare them to tackle challenges beyond academia, in their future careers. Therefore, using Dual Process Theory as the primary framework is crucial, as it is widely recognized as a universal process across humans, rather than being limited to a specific discipline. This makes interpreting reasoning through this framework highly applicable across various contexts. The goal of this research is to create a tool for understanding how individuals consciously engage with either Type I or Type II thinking processes, and to explore the role of metacognition in helping individuals engage more effectively with their existing mental models, as well as those they can develop or refine.

1.4 References

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Chapter 2. Theoretical Frameworks

2.1 What is a Theoretical Framework?

In qualitative research, theoretical frameworks guide theory-driven thinking and decision-making in selecting a research topic and developing research questions to inform study design and analysis. As a result, frameworks can be viewed as "blueprints" that help assist in structuring all aspects of the research process (Grant & Osanloo, 2014). This blueprint then serves as the foundation upon which all knowledge is constructed. A theoretical framework provides support for the rationale of the study, including the problem statement, the purpose, the significance, and the research questions. The theoretical framework serves as a foundation and anchor for the literature review, and above all, the methods and analysis. Lysaught (2011) highlights the necessity of identifying one's theoretical framework for a dissertation study:

"A researcher's choice of framework is not arbitrary but reflects important personal beliefs and understandings about the nature of knowledge, how it exists (in the metaphysical sense) in relation to the observer, and the possible roles to be adopted, and tools to be employed consequently, by the researcher in [their] work. (p. 572)"

Choosing a theoretical framework requires careful and deliberate consideration to ensure that the problem, purpose, significance, and research questions are closely aligned and seamlessly integrated with the framework. Researchers can choose to explore pre-existing frameworks that relate to the chosen research topic. Each aspect of the framework is assessed, including its strengths and weaknesses. Choosing a framework should provide a perspective that aligns with the research process and goals.

In this thesis, frameworks were carefully chosen as a guiding lens for research to inform assumptions, research methodology, and goals. These theoretical frameworks connect us back to pre-existing knowledge and how other education research have used these frameworks to guide their studies, situate their findings, and identify the limits of the finding interpretation. We identified the chosen frameworks after extensive literature review to identify gaps in the literature by which the frameworks could address. We then conducted a review of how these frameworks have originally been used to investigate education-related studies and how we can improve or change their methodologies. From identifying these gaps, we proposed addressing them by bringing forth the metacognitive theoretical framework as an additional guiding lens. These frameworks were then used to develop research questions in terms of what processes will be investigated in the study. The theoretical frameworks also informed the study design, including the variables and constructs examined, the development of instruments used to address the research questions, and the overall approach to data collection and experimental design. Finally, the framework plays a role serving as a guide for data analysis and interpretation to assist us in both describing results and explaining why they may occur.

2.2 Theoretical Frameworks in this Study

To guide this research, we use the following theoretical frameworks: Dual Process Theories of Thinking and Reasoning, Theory of Metacognition, Judgments of Learning, and Feelings of Rightness. Section 2.3-2.5 will detail how the framework was used to inform study design.

2.3 Dual Process Theories of Reasoning

In this study, Dual Process Theories of Reasoning (DPTOR) serves as the primary theoretical framework guiding the development of the research questions, study design, and interpretation of findings. The framework provides a basis for examining how individuals engage in Type I/II thinking during decision-making and problem-solving. Type I thinking involves a fast, automatic process, while Type II involves a slow, deliberate, and analytical process in terms of how individuals' reason and conduct decision-making (Kahneman, 2011; Osman, 2004; Evans, 2006). Dual Process Theory informs the design of the study in terms of being the foundation for instruments (e.g., questions for worksheets, etc.) as we were able to better understand how to prompt specific types of thinking or investigate specific mechanisms behind one's reasoning process.

2.4 Metacognition

In this study, metacognition provides a conceptual basis for understanding how learners monitor and regulate their reasoning during decision-making and problem-solving. Metacognition refers to the awareness and regulation of one's cognitive processes, especially in evaluating one's own knowledge, gaps in knowledge, and strategies to approach their learning (Schraw, 1998). In this study, the regulatory aspect of metacognition is used to examine how individuals engage with and manage their reasoning processes in relation to Dual Process Theory. Metacognitive regulation does not operate independently of cognitive ability; rather it interacts with underlying cognitive resources (e.g., working memory capacity, prior knowledge) and is also shaped by affective factors such as motivation, perceived stakes, and fear of failure (Efklides & Schwartz, 2024; Cushing et al., 2024). These affective factors shape metacognitive regulation by influencing learners' willingness to invest cognitive effort, the availability of working memory resources under pressure, and the calibration of confidence during problem-solving (Cushing et al., 2024). As a result, higher motivation and perceived stakes may increase engagement with analytical (Type II) reasoning by promoting monitoring and strategic control, whereas fear of failure or heightened cognitive load may inhibit metacognitive regulation and reinforce reliance on intuitive (Type I) heuristic responses (Pescetelli et al., 2016; Spada et al., 2008).

A portion of my work is directly reflected in my research group's work, which develops and studies open educational resources designed to support both conceptual understanding and learning skills development. Central to this program is the Growth & Goals Module, a metacognitive interactive module that explicitly targets students' development of goal setting, planning, monitoring, and evaluation of strategies within authentic course contexts (O'Connor et al., 2022). The module operationalizes metacognition as both metacognitive knowledge (awareness of one's understanding and knowledge gaps) and metacognitive regulation (the selection and adjustment of strategies). In addition, it incorporates principles from growth mindset and mindfulness research to support students in managing attention, responding adaptively to challenge, and interpreting setbacks as part of the learning process. By embedding these components within course contexts, the module explicitly connects metacognitive skill development with students' lived learning experiences rather than treating it as decontextualized instruction. The module has been implemented across multiple postsecondary courses and has been used by over 10,000 students, with evaluation findings indicating that it is well received by both students and instructors and supports students' development of learning skills, including metacognition awareness (O'Connor et al., 2023). Evidence from the module's implementation suggests that embedding structured metacognitive activities within courses can support students in actively engaging with and reflecting on their learning processes, while also demonstrating the feasibility of scaling such interventions across educational contexts (O'Connor et al., 2023).

Complementing the Growth & Goals research, tools such as the OrgChem101 Organic Reaction Mechanisms module were designed by our research group to scaffold how students interpret and apply the language of mechanisms, while simultaneously enabling the study of learners' reasoning strategies as they engage with core disciplinary tasks (Carle et al., 2020; Flynn & Ogilvie, 2015). Together, these initiatives reflect a broader program of research that not only designs metacognitive learning environments but also systematically investigates how learners regulate their thinking within them.

2.5 Judgments of Learning (JOLs) and Feelings of Rightness (FORs)

Judgements of Learning (JOLs) and Feelings of Rightness (FORs) fall within the metacognitive framework. JOLs are predictions connected to the likelihood of an individual recognizing/recalling information in future situations (Koriat, 1997). Feelings of Rightness (FORs) refer to an individual's subjective sense of the likelihood that their response is correct, typically arising rapidly and automatically (Wang and Thompson, 2019). Together, JOLs and FORs serve as a form of confidence judgment that follows the generation of an initial answer or solution (Thompson et al., 2011). As such, JOLs and FORs provide insight into how learners monitor their confidence in their responses and regulate whether their initial answers are accepted or reconsidered. In the context of this study, metacognitive judgments can demonstrate how learners evaluate their reasoning processes and determine whether further analytical thinking is required.

The frameworks discussed above (i.e., Dual Process Theory, Metacognition, Judgments of Learning, and Feelings of Rightness) will be expanded upon in term of theory and application in section 4.1 in the study's manuscript.

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Chapter 3. Data Collection and Instruments

3.1 Overview of Research Questions

In this study, we aimed to address three research questions:

RQ1: What is the accuracy of students' metacognitive ability to recognize the type of thinking they employ when solving a problem?

This research question aimed to investigate whether students are able to accurately recognize what thinking type they engage when solving different types of problems. Examining individuals' ability to accurately recognize their thinking processes provides insight into their problem-solving approaches and their awareness of reasoning strategies. Our goal when designing the research question was to help identify gaps in students' metacognitive monitoring and their ability to engage or transition between Type I/II thinking. We hoped for this analysis to inform instructional strategies aimed at supporting students in more accurately identifying the optimal thinking type to thereby promote more effective and efficient problem-solving.

RQ1 Hypothesis: We anticipated that the metacognitive intervention would positively influence learners' ability to accurately identify and control the type of thinking they used. We expected that the participants who explicitly learned about Type I/II and metacognition would more accurately distinguish between Type I (intuitive) and Type II (analytical) reasoning, demonstrating greater metacognitive accuracy than participants who did not possess this knowledge. We also predicted that Type II thinking would be more frequently reported among participants in the experimental condition, in addition to greater overall deliberate monitoring, regulation, and less reliance on intuitive processes.

RQ2: In what ways do students from different disciplines engage in Type I/II thinking when faced with a general/discipline-specific question?

This research question sought to explore whether disciplinary background influences how students approach reasoning tasks, including how they regulate their thinking processes. Investigating disciplinary differences in how individuals engage with Type I/II thinking may reveal how disciplinary experiences shape reasoning and decision-making processes. We hoped that findings could highlight how disciplinary training influences the development of reasoning strategies and metacognitive awareness and to inform instructional practices aimed at supporting effective reasoning across diverse learning contexts.

RQ2 Hypothesis: We considered the interaction between discipline and intervention group, such that we hypothesized that the participants both with a background in organic chemistry and exposure to the intervention will show the strongest identification skills and an increased likelihood to be more intentional in the strategies they use with thinking type engagement (Chi et al., 1981; Renkl, 1997).

RQ3: To what extent can an intervention of teaching metacognition influence students' intentional engagement with either Type I or Type II thinking when faced with a problem?

The research question aimed to investigate whether explicit instruction in metacognitive strategies can influence how students intentionally reflect on their metacognitive skills and their awareness of how they choose to engage with Type I/II thinking. We aimed to gather evidence regarding the role metacognition may play in supporting students' decision-making and problem-solving strategies. We hoped for findings to contribute to a better understanding of how metacognitive awareness can support intentional regulation and to equip students with strategies for self-evaluation to navigate different types of problem-solving tasks.

RQ3 Hypothesis: We predicted that the metacognitive intervention would encourage intentional engagement in metacognitive processes, including monitoring and deliberate use of strategies when approaching problem-solving. We anticipated that participants who participated in the intervention would show improved identification skills with thinking types, more flexibility with their thinking type engagement, and increased awareness of intentional shifting between thinking types.

3.2 Data Collection Instruments

Establishing validity in educational and behavioural research refers to the extent to which an instrument can accurately measures the construct it is intended to assess and support the interpretation of the results (Cronbach, 1949; Deng et al., 2021; Wynd et al., 2003). Without evidence supporting the validity of the data elicited using the study instruments, poorly designed instruments may lead to misinterpretation of participants' cognitive processes or effects of the intervention. For example, a chemistry assessment question that asks students to "select the strongest acid from a list of compounds" without providing structural representations or contextual information may unintentionally cue memorization-based responding rather than reasoning about acidity trends (if that is the goal). In such cases, student responses may reflect recall or pattern-matching rather than the intended construct of chemical reasoning, thereby limiting the interpretability of the results.

We focused primarily on content validity, which examined how well the items of an instrument represents all relevant aspects of a given construct (e.g., Type I/II Thinking) (Cronbach, 1949; Polit & Beck, 2006; Wynd et al., 2003; Zamanzadeh et al., 2015). Content validity also addresses how well the selected sample of items in an instrument represents the overall content (Zamanzadeh et al., 2015). We want to ensure that the instruments measure the cognitive/metacognitive processes of interest, not unrelated skills or knowledge. In this study, we wanted to ensure that the instruments we designed were able to measure and collect data so that it aligns with the theoretical frameworks and addresses the research questions.

Evidence supporting the content validity of each instrument was gathered through multiple steps. First, we reviewed existing instruments that measure Type I/II thinking, including the Cognitive Reflection Test (CRT), which aims to trigger Type I responses for Type II questions (Frederick, 2005a). We also included a CRT-style question from Böckenholt (2012) to further broaden construct coverage (Böckenholt, 2012). Questions specific to organic chemistry were developed with reference to the University of Ottawa's Organic Chemistry I curriculum (Ogilvie, 2017; Flynn, 2015) We also conducted interviews with course instructors to ensure the questions were appropriate and aligned with the curriculum (Deng et al., 2021; Polit & Beck, 2006).

Finally, before the study, we conducted response process validity interviews with individuals representative of the target population (n = 3) to determine if participants would interpret and respond to the instrument items as intended (Deng et al., 2021; Scheurs et al., 2024; Epstein et al., 2023). Within CER literature, sample sizes for response process interviews have varied from 2—58 participants, while methodological recommendations commonly suggest that approximately 5—15 participants is sufficient for reaching saturation of response processes and identifying major patterns in how participants interpret and engage with items (Peterson et al., 2017; Beatty & Wilis, 2007; Creswell, 2012). Evidence indicates that sample sizes for interview beyond can yield diminishing returns in identifying new response process issues (Blair &

Conrad, 2011). These interviews were used to gather evidence that their thought processes align with the intended construct being measured (Deng et al., 2021; Scheurs et al., 2024; Epstein et al., 2023). Participants in these interviews were eligible for the study but did not take part in the main data collection. We used their feedback to improve instruments as needed to ensure the items are interpreted in the intended way. Their feedback related to the reflection activity (e.g., Are participants interpreting prompts/questions as intended? Do participants understand the Dual Process Theories of Thinking and Reasoning and what the thinking types represent?). Without adequate response process validity, results may misrepresent participants' understanding or abilities, leading to flawed or biased conclusions. For example, participant feedback in our study indicated that some reflection prompts were overly similar, and interviewees noted that they could respond to them in the same way. This led to a review of the prompts and the removal or rewording of items that elicited redundant responses.

3.3 Data Analysis: Mixed-Methods Approach

We used a mixed-methods approach to analyze the data, focusing on both qualitative and quantitative components to provide a comprehensive understanding of participants' engagement in Type I and Type II thinking. Quantitative and qualitative analyses address research questions differently. Quantitative analysis is deductive and is suited to establishing cause-and-effect relationships and test hypotheses (Verhoef, 1997). In contrast, qualitative analysis relies on interpretative data, aiming to understand the deeper meaning of the data and proceeds in a non-linear fashion (Creswell, 2012; Neuman and Robson, 2014). In tandem, quantitative and qualitative analysis are complementary, allowing for both in-depth interpretation and examination of the research questions.

3.4 Qualitative: Thematic Analysis

Thematic analysis is a method for identifying and analyzing patterns within qualitative data. In thematic analysis, we examine an entire dataset to identify recurring patterns that are relevant to the research questions. At first, these patterns are labelled through codes, which are labels applied to a segment of data (e.g., sentence, phrase, or paragraph) that captures the perceived main idea or meaning expressed in a segment (Saldaña, 2009). Often, multiple iterations of coding are needed to capture the meaningful units within the data. Codes are then grouped into categories that represent broader, more clearly defined patterns within the data. Finally, together the codes and categories form themes, which reflect patterns of meaning within the data and often capture subtle or tacit processes underlying participants' responses (Saldaña, 2009). Themes do not need to represent the majority of responses within a dataset; they are identified based on their relevance and ability to meaningfully address research questions (Ryan & Bernard, 2002; Braun & Clarke, 2006).

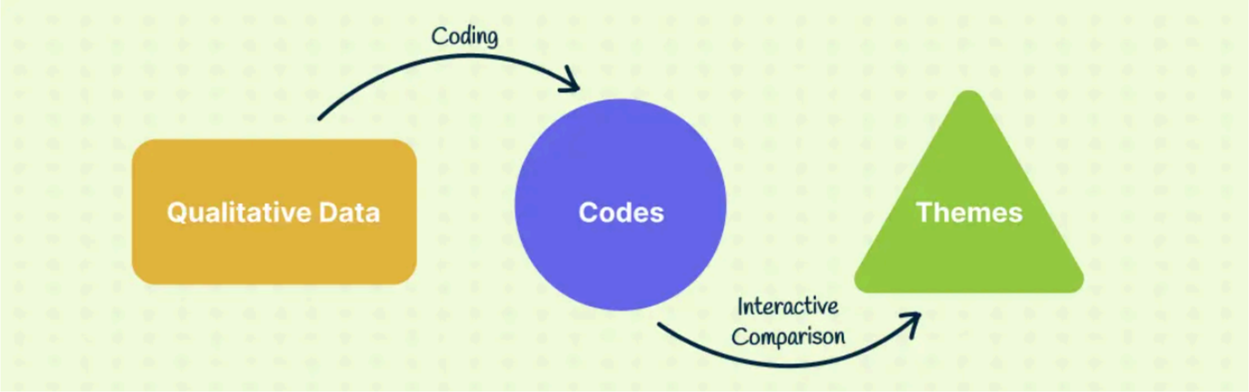

Figure 1. Visualization of Thematic Analysis Process (George, 2026).

Coding can be done as a deductive or inductive process (Creswell, 2012; Gibbs, 2018). Deductive coding involves applying codes that are established prior to analysis, often informed by theoretical frameworks or from other studies' "codebooks". Inductive coding on the other hand allows codes to emerge directly from the data as the researcher explores (Creswell, 2014; Saldaña & Omasta, 2016). In this project, our thematic analysis focused on coding participants' reflection activity responses to identify patterns in metacognitive engagement and reasoning processes.

We initially used an inductive thematic analysis approach to explore how participants engaged in Type I/II thinking across reflection activities as existing studies did not provide established codebooks aligned with our research goals. Participant responses from reflection activities were organized and analyzed using Miro, an online whiteboard platform that allowed for iterative organization and visual mapping of the coding process. Initial memoing for each participant's response captures initial interpretations and reflections on their reasoning processes. These initial memos aim to capture the main idea(s) from a response. Initial memos were followed by first-cycle coding, in which memos were grouped into smaller, similar categories and assigned descriptive codes. This inductive coding process uses the Dual Process Theories of Thinking and

Reasoning as a guiding framework given the exploratory nature of the study and absence of pre-existing codebooks. Themes were derived directly from participants' language guided by the framework.

Each successive cycle of coding involved iterative refinement and external review from another research to focus on the validity of the codes. Their role was to confirm code alignment with categories and to suggest clarifications. Subsequent second, third, and fourth cycles involved broadening and consolidating categories into higher-order themes, each round reviewed by the same additional researcher to ensure consistency and shared interpretation. Following the four cycles, the uncovered themes were presented to a group of researchers external to the project but within the field of education for feedback on their clarity and relevance to the research questions.

3.5 Validity in Qualitative Inquiry

As consistent with Creswell and Miller's (2000) criteria for establishing validity in qualitative inquiry, multiple verification strategies in this study were employed to ensure trustworthiness (Creswell and Miller, 2000). In this study, peer review and external feedback were used as forms of peer debriefing and triangulation. For peer debriefing, I asked a group member to serve as a second reviewer to critically review the coding process and interpretations, providing alternative perspectives and challenging potential researcher bias. In addition, once the coding process was complete, a final researcher who was not previously involved with the study reviewed the data in search of disconfirming evidence. Disconfirming evidence refers to the data that contradicts or does not align with the emerging patterns or interpretations, prompting further examination of initial assumptions (Creswell and Miller, 2000; Creswell, 2009). After identifying disconfirming evidence, the final co-researcher and I re-examined and re-wrote some themes to ensure they more accurately represented the data. The disconfirming evidence revealed substantial overlap between several themes, leading to the removal or consolidation of themes to improve clarity and conciseness. In one case, an entire theme was omitted because the disconfirming evidence outweighed the confirming evidence. I conducted triangulations by incorporating multiple reviewers at different stages of the analysis to allow us to compare interpretations and strengthen the credibility of the findings through discussion of perspectives. In addition, I maintained transparent records of the coding process and associated analytic decisions to provide an audit trail to support the credibility and dependability of the analysis. The practices I used in this study are intended to align with Creswell and Miller's framework for demonstrating validity through researcher perspectives, systematic verification, and transparent documentation.

3.6 Quantitative Analysis

Quantitative statistical analysis allows researchers to make inferences about a broader population based on observed patterns in a sample. As it is often impractical or not possible to measure an entire population, samples are used as a manageable subset that is assumed to be representative of that population (D. Creswell & Creswell, 2009). Statistical methods then estimate population parameters from sample data and quantify the uncertainty associated with these estimates. Estimate population parameters are necessary as samples are subject to random variation; any single sample will not perfectly reflect that population from which it is drawn. Rather than assuming observed effects are exact, statistics provide a framework for determining how likely it is that observed patterns reflect true underlying relationships rather than chance variation (D. Creswell & Creswell, 2009).

Building on this framework, an a priori power analysis was conducted to identify the minimum sample size required to detect the anticipated effects with adequate statistical power (Cohen, 2013). Power analysis estimates the probability that a statistical test will correctly reject a false null hypothesis given a specific effect size, alpha level, and sample structure (Cohen, 2013). Effect size refers to the magnitude of the expected relationship or difference between conditions (i.e., how large the effect is in practical or standardized terms). The alpha (set at 0.05) level represents the standard threshold for statistical significance, or the probability of incorrectly rejecting a true null hypothesis. Finally, sample structure refers to the design characteristics of the data, including the number of groups, sample sizes within each group, and whether the observations are independent or nested/repeated (as in longitudinal or within-subject designs) (Cohen, 2013). For this research, power was estimated using a binary logistic regression model and a linear mixed-effects modelling framework to reflect the repeated measures nature of the data, with tasks being completing across multiple days and there being four group conditions. Based on an anticipated large effect size ($f = 0.750$, an alpha level of 0.05 and the study's unbalanced structure, the analysis indicated that a minimum sample size of approximately N = 85 would be required to achieve adequate statistical power.

The final sample consisted of 67 participants, which fell below this initial target. However, the study retains sufficient sensitivity to detect effects of the magnitude predicted by the hypotheses, particularly for fixed effects of group and time due to increased efficiency of the within-subject repeated-measures design, which reduces error variance by allowing each participant to serve as their own control. This study can be considered to be adequately powered for large effects, although power to detect smaller effects may be more limited. As a result, non-significant findings were interpreted with caution, as they may reflect limited sensitivity rather than true absence of an effect.

The quantitative analysis for this research was conducted in R using statistical models, including linear mixed-effects models, to examine differences in Type II engagement across tasks, disciplines, and intervention conditions.

Quantitative data were examined to assess the accuracy of participants' ability to describe the thinking types they used throughout the study. Participants were assessed based on their response to the following prompt: *For a given question, how did you decide and/or recognize the type of thinking you were engaging with?* Initially, participants were scored on a binary scale of Yes or No of whether they could accurately describe their thinking types or not. Then, participants were scored on a 4-point scale of an accuracy rubric. The accuracy rubric was created and refined using literature rooted in the Type I/II and metacognition frameworks (Flavell, 1979; Kahneman, 2011; Efklides, 2006; Koriat, 2012). The grading basis of the rubric centres around the accuracy of thinking type description (e.g., correct description off thinking type as outlined by the framework) and quality of the metacognitive depth (e.g., awareness of cognitive strategies, self-monitoring, understanding interactions of the thinking types). Two researchers independently scored participant responses using the rubric and discrepancies were later resolved through consensus discussion. Inter-rater reliability for the rubric-based coding was strong, with Cohen's $\kappa = .81$, indicating substantial agreement between raters prior to discussing our scores (Landis & Koch, 1977). Cohen's kappa was used instead of simple percent agreement because it corrects for the level of agreement that would be expected by chance alone, providing a more conservative and interpretable estimate of reliability than raw agreement proportions. This value supports the reliability of the coding process used to evaluate participants metacognitive depth in articulating the thinking type they engaged with. Specific outcomes from this analysis are found in Results and Discussion.

3.7 Methodology Approach: Constructivist Grounded Theory

Though this thesis work does not employ grounded theory as a primary methodology, some of the analytic principles from grounded theory informed our qualitative analysis process. Grounded theory is a qualitative method used to build explanations or theories directly from the data be repeatedly comparing and refining ideas throughout the analysis (Glaser & Strauss, 2017). Constructivist grounded theory recognizes that researchers are not neutral observers and bring their own knowledge, perspectives, and experiences to the research process (Charmaz, 2016; Novak, 1993; Bodner and Domin, 2000). Researchers conduct their analysis with frequent referral to the research questions while drawing on their own disciplinary knowledge and experiences to guide interpretation of the data (Dahlberg, 2006).

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Chapter 4. The Role of Metacognitive Skills in Decision-Making using Type I/II Thinking

This chapter will present a manuscript that has been submitted to the European Journal of Psychology of Education (May 5th, 2026, submission number: EUPE-D-26-00626) and describes the main project I contributed during my graduate studies. This study was approved by the University of Ottawa's Research Ethics Board (File #: H-01-25-11095) and informed consent was obtained from all participants.

4.1 Manuscript

Title: The Role of Metacognitive Skills in Decision-Making using Type I/II Thinking

Abstract

Strong reasoning skills are vital in a variety of academic and everyday contexts, requiring strong metacognitive awareness to be strategic and efficient. However, relatively little is known about how metacognitive abilities and skill-building relate to making purposeful choices about reasoning. We investigated the role of metacognition in Dual Process theory, including learners' awareness and self-description of their cognitive engagement. Dual-process theory describes that most reasoning results from the interaction of two cognitive processes: Type I (fast/intuitive thinking) and Type II (slow/analytical thinking). The purposeful use of reasoning types is complex, including metacognitive awareness of the Type being used, identifying the optimal type, deciding if there is a need or benefit to switching, desire/motivation to switch, and the ability to do so (e.g., cognitive resources). This mixed-methods study examined how a metacognition intervention influenced awareness of and engagement with Type I/II thinking, and the impacts of training in discipline agnostic and discipline specific contexts (organic chemistry). Using an experimental design that included pre- and post-tests, participants completed a worksheet targeting Type I/II reasoning three times over two weeks. Participants in the treatment/intervention group completed a metacognition learning module, while the control group completed an unrelated activity. In the worksheets, participants identified the thinking type they engaged with for questions and explained their thought process. We found that having an organic chemistry background and/or belonging to a particular group (intervention/control) were correlated with differences in analytical engagement. Participants in the treatment group demonstrated more deliberate monitoring and regulation of their reasoning, whereas participants in the control group relied on rigid, superficial distinctions between thinking types. Metacognitive accuracy and regulation varied across groups.

Abstract graphic

TYPE1
TYPE2

Key words

Metacognition, Type I/II Thinking, Cognitive Regulation, Education, Dual-Process Theories of Reasoning

Introduction

Learning requires reasoning through complex problems, integrating prior knowledge, and making decisions. Successful problem-solving depends not exclusively on what learners know, but how they regulate and apply that knowledge while reasoning. Research suggests that learners often possess relevant conceptual understanding, but they struggle to apply it effectively, often lacking strategies or awareness of strategies to connect their knowledge to the reasoning the problem requires (Bago & De Neys, 2017; Speirs et al., 2021). Without consciously reflecting on what the question demands or one's problem-solving approach, a gap emerges between what a learner knows and how they reason through the problem (Speirs et al., 2021). This disconnect highlights the vital role of metacognitive skills in supporting effective reasoning and decision-making.

Our decisions are driven each day by Type I (intuitive) or Type II (analytical) thinking processes. Dual process theories of reasoning (DPTOR) describe Type I thinking as fast and automatic, whereas Type II thinking as slow and deliberate. We need both types of thinking in our daily lives, but how we interact with either thinking type is context-/task-dependent.

Studies have suggested that metacognitive instruction could serve to help develop learners' reasoning skills via problem-solving strategies (Amsel et al., 2008; Kryjevskaia et al., 2014; Stanton et al., 2015; Z. Muteti et al., 2021). Metacognition is the awareness and regulation of one's cognitive processes specifically in evaluating one's knowledge, gaps in knowledge, and strategies to approach their learning (Brown et al., 2010; Flavell, 1979; Schraw, 1998). Metacognition enables individuals to monitor their current knowledge and skills, allocate learning resources with optimal efficiency, and evaluate their current learning state (Stanton et al., 2015). Individuals' metacognitive abilities regulate their thinking processes and allow them to consciously use metacognition to support and guide their reasoning (Amsel et al., 2008; Schwabe et al., 2012). Recent studies have shown that some patterns of persistent, incorrect responses may be attributed to reasoning difficulties, rather than a lack of relevant conceptual understanding (Gette et al., 2018; Heckler, 2011; Heron, 2017; Kryjevskaia et al., 2014). These reasoning difficulties studies are not discipline specific; they are common to all human reasoning and influence how individuals approach questions (Heckler, 2011; Kryjevskaia et al., 2014; Speirs et al., 2021). As a result, there has been a shift towards investigating the cognitive mechanisms behind human reasoning and their effect on learners' reasoning in STEM education problems (Gette et al., 2018; Heckler, 2011; Speirs et al., 2021; A. K. Wood et al., 2016). Identifying the underlying mechanisms may lead to observed patterns of student reasoning and develop tools to enhance student reasoning skills.

Purposefully engaging with a given thinking type can be difficult, as it requires being able to identify what type is being used (metacognition), what type is needed (metacognition and task analysis), and takes more effort and time. Several studies have used Dual Process Theories of Reasoning as a framework to examine individuals' ability to suppress intuitive Type I thinking to engage in more analytical Type II thinking. For example, Wood et al. (2016) investigated physics learners' capacity to override intuitive answers and found that those who successfully suppressed Type I responses demonstrated stronger conceptual understanding. However, their analysis focused on performance outcomes rather than on the reasoning strategies or mechanisms by which learners transitioned between thinking types.

Similarly, Speirs et al. (2021) examined how learners respond to physics problems designed to cue incorrect Type I shortcuts by manipulating the information available during problem-solving.

They found that providing information that challenged learners' initial intuitive assumptions shifted response patterns, but only for learners with sufficient conceptual understanding. While this work demonstrates how intuitive reasoning can be disrupted through task design, it does not examine the specific cognitive strategies learners use to regulate or shift their thinking.

Related work by Kryjevskaia et al. (2014) further demonstrated that learners use correct ideas to justify incorrect intuitive conclusions, constructing arguments that support immediate Type I thinking rather than evaluating them. Through an investigation of patterns of inconsistent responses, the authors found that learners often construct an intuitive or pattern-based assumption and built their argument in support of that assumption. Collectively, these studies suggest that learners' difficulties often stem not from a lack of conceptual knowledge, but from challenges in recognizing and regulating the influence of intuitive reasoning.

Despite these insights, Type I/II thinking research has largely emphasized tasks that cue incorrect Type I responses and focused on identifying reasoning patterns rather than on investigating the cues, mechanisms, or conditions that lead learners to engage with one thinking type over another. Moreover, there has been limited attention to the role of explicit instruction in helping learners recognize and manage their use of different thinking types or to the importance of shifting flexibly between them as task demands change. One exception is Schwab et al. (2020), who examined how explicit instruction about intuitive and analytical reasoning influenced medical learners' reported decision making. Their findings suggest that supporting learners in recognizing when intuitive responses are insufficient may improve reasoning; however, their work remains focused on overriding incorrect intuition rather than on fostering metacognitive regulation of when and why different thinking types are engaged.

Recent research extended this perspective by emphasizing the role of metacognitive awareness and adaptive regulation in reasoning processes. For example, explicit metacognitive instruction supports learners' ability to articulate and regulate their thinking. Evidence connects explicit instruction to enhancing both metacognitive knowledge and strategic use of cognitive processes in learning contexts (Fono & Zohar, 2024; Wass et al., 2023). Complementary longitudinal work in children demonstrates that gains in metacognitive awareness are associated with the development of inhibitory control and reflective reasoning, suggesting that the ability to regulate thinking evolves alongside broader cognitive capacities (Symeonidou et al., 2025).

Research also suggests that structured supports such as explicit strategy instruction, feedback engagement, and scaffolded reflection can improve learners' ability to monitor their understanding and adjust their problem-solving approaches (Olop et al., 2024; O'Neill et al., 2025; S. Y. Wood & Cross, 2024). For example, engagement in metacognitive reflection on feedback can deepen conceptual understanding, while design frameworks with embedded metacognitive prompts can support sustained regulation of thinking over time (Olop et al., 2024; O'Neill et al., 2025; S. Y. Wood & Cross, 2024). Meta-analytic evidence further indicates that explicit instruction and enhanced learning processes are most often measured in performance gains than shifts in how learners regulate their thinking (Ren et al., 2024). Despite a growing emphasis on metacognitive support, research continues to focus on improving performance outcomes rather than explicitly examining mechanisms behind how learners develop the ability to shift between reasoning approaches in response to tasks.

Automatic to strategic: The need for metacognition

Explicit attention to metacognitive awareness and regulation of thinking types remains underdeveloped, although some studies have considered the role of metacognitive instruction in promoting analytical reasoning. Aspects that remain unclear include how: (i) learners monitor their cognitive processes, (ii) they decide when a shift in thinking is warranted, and (iii) instructional support might foster this flexibility. Strong metacognitive skills could allow for intentional engagement with the optimal thinking type and recognizing the need to switch between types. Type I/II thinking is rarely explicitly taught, and individuals are not given the opportunity to better understand the cognitive pathways behind their decisions and approaches to problems. Without this opportunity, individuals may miss out on learning to be more strategic in their handling of information. Research is needed to better understand the relationship between metacognition and Type I/II Thinking as there is no empirical evidence identifying the impact of teaching metacognitive skills on decision-making related to Type I/II thinking. This study aims to provide evidence on the role of metacognition in learners' intentional engagement with Type I/II and how individuals' ability to recognize and control the thinking types they use in their decision-making/problem-solving processes.

Research Questions

To investigate how individuals engage with Type I/II thinking and how metacognition can serve as an intervention tool to help postsecondary learners understand their reasoning processes, we asked the following research questions:

1. What is the accuracy of learners' metacognitive ability to recognize the type of thinking they employ when solving a problem?
2. In what ways do learners from different disciplines engage in Type I/II thinking when faced with a discipline general/specific question?
3. To what extent can an intervention of teaching metacognition influence learners' intentional engagement with either Type I or Type II thinking when faced with a problem, compared to a control group that does not receive the intervention?

Hypotheses

RQ1: We anticipated that the metacognitive intervention would positively influence learners' ability to accurately identify and control the type of thinking they used. We expected that the participants who explicitly learned about Type I/II and metacognition would more reliably distinguish between Type I (intuitive) and Type II (analytical) reasoning, demonstrating greater metacognitive accuracy than participants who did not possess this knowledge. We also predicted that Type II thinking would be more frequently reported among participants in the experimental condition, in addition to greater overall deliberate monitoring, regulation, and less reliance on intuitive processes.

RQ2: We considered the interaction between discipline and intervention group, such that we hypothesize that the participants both with a background in organic chemistry and exposure to the intervention will show the strongest identification skills and an increased likelihood to be more intentional in the strategies they use with thinking type engagement (Chi et al., 1981; Renkl, 1997).

RQ3: We predicted that the metacognitive intervention would encourage intentional engagement in metacognitive processes, including monitoring and deliberate use of strategies when approaching problem-solving. We anticipated that participants who participated in the intervention would show improved identification skills with thinking types, more flexibility with their thinking type engagement, and increased awareness of intentional shifting between thinking types.

Theoretical Frameworks

This research is guided by the integration of several frameworks: Dual Process Theories of Reasoning (Type I/II Thinking), Metacognition, and Judgments of Learning/Feelings of Rightness.

Dual Process Theories of Reasoning

Type I and Type II Thinking describe the cognitive pathways humans are bound by in reasoning and decision-making tasks (Kahneman, 2011; Osman, 2004; Sloman, 1996; Stanovich, 2009). The theory proposes that there is a distinction between the two pathways, often referred to as Type I and Type II. Type I describes a fast, intuitive, and automatic process, while Type II describes a slow, deliberate, and analytical process (Evans, 2006; Evans & Stanovich, 2013b; Kahneman, 2011). The application of cognitive processes, and theories such as Dual Process Theories of Reasoning in education, can inform practices to improve learning, reduce cognitive biases, and enhance critical thinking.

Type I thinking occurs when an individual generates a fast, automatic response, which typically operates unconsciously and based on one's prior knowledge or experiences (Evans & Stanovich, 2013b; Kahneman, 2011; Osman, 2004; Tay et al., 2016). As a result, Type I is often referred to as the default model for individuals as it requires the lowest amount of cognitive effort (Bago & De Neys, 2017). Type I is based on heuristics, which are mental shortcuts that allow for quick judgments with minimal effort. Type I is ideal for low-stakes situations in everyday life and learning situations where a "rule of thumb" can be applied but can lead to incorrect conclusions when tasks require deeper analysis or logical reasoning (Tay et al., 2016).

Type II thinking is a deliberate, analytical approach requiring conscious thought and effort; it is used when approaching more complex decisions or problems (Kahneman, 2011; Osman, 2004; Sloman, 1996; Stanovich, 2009). Type II processing is slower and more effortful, making it less frequently used in everyday reasoning (Evans & Stanovich, 2013b; Kahneman, 2011). Neither thinking type is more important than the other, as their utility is task dependent. Type I needs to be overridden by Type II to engage in slower, more deliberate and conscious effort. By engaging in Type II, individuals can override initial impulses and more critically evaluate information. The transition from Type I to Type II thinking requires increased conscious effort and time, leading to a tendency to default to familiar shortcuts or an inability to recognize when the other thinking type is needed (Evans & Stanovich, 2013b; Kahneman, 2011; Tay et al., 2016). An overemphasis on one thinking type may risk oversimplifying (Type I) or over-complicating decisions (Type II), and unnecessary shifts between thinking types may undermine decision-making processes (Ball et al., 2018; Hodgkinson & Healey, 2011). Effective cognition involves the ability to identify and use the appropriate thinking type and to shift between them depending on the task.

Metacognition

Metacognition is generally defined as "thinking about thinking" (Flavell, 1979). Metacognition is the awareness and regulation of one's cognitive processes, specifically in the evaluation of one's knowledge, gaps in knowledge, and strategies to approach their learning (Schraw, 1998). Metacognition plays a central role across cognitive domains, including problem-solving, memory, and attention, and raises the question of how cognitive monitoring supports effective thinking (Drigas et al., 2022; Halmo et al., 2022; Stanton et al., 2021; Z. Muteti et al., 2021).

Metacognition is conceptualized through two interrelated components: metacognitive knowledge and metacognitive regulation (Flavell, 1979; Ozturk, 2017). Metacognitive knowledge refers to what individuals know about their cognition and includes declarative (knowledge of self, tasks, and strategies), procedural (knowledge of how to apply strategies), and conditional knowledge (knowledge of when and why to use them (Flavell, 1979; Jacobs & Paris, 1987; Veenman et al., 2006). This knowledge enables learners to evaluate their understanding, identify strengths and limitations, and make informed decisions about strategy use. Recent work further highlights that students with well-developed metacognitive knowledge are able to accurately judge their learning and adjust their study approaches accordingly (Stanton et al., 2021).

Judgments of Learning (JOLs) and Feelings of Rightness (FORs)

Within the metacognitive framework are the concepts of Judgements of Learning (JOLs) and Feelings of Rightness (FORs). JOLs are predictions related to how likely one can recognize/recall information in future situations (Koriat, 1997). JOLs take place during the monitoring phase, after a learner engages with material, they gain access to knowledge cues that they use to gauge how likely they are to need the information in future, then make a prediction. Predictions take on the form of rating confidence, task performance ("I will score 80% on this exam"), ease-of-learning, and Feeling of Knowing (FOK) ("I can't remember, but if I saw it, I'd know it") (Townsend & Heit, 2011). JOLs are related to overconfidence, which occurs when a learner's JOLs are greater than that of their actual performance. In other words, they believe they know more than they do. Overconfidence tends to occur when there is a reliance on surface level cues, for example, ease of reading or familiarity rather than retrieval ability. Overconfidence connects to the frequent trust in an intuitive (Type I) answer rather than engaging in reflective (Type II) thinking where appropriate. These judgments guide study behaviours, which include determining what material to restudy, practice, or move on from.

Feelings of Rightness (FORs) are a part of JOLs that take on the form of a confidence judgment that occurs after generating an initial answer or solution (Thompson et al., 2011). FORs are related to an individual's perception of how likely their response is to be correct, often generated quickly and automatically. With high FORs, the likelihood to accept one's first response and move on is high, whereas low FORs prompt additional reasoning, checking, and revision (Wang & Thompson, 2019). FORs play a role in regulating problem-solving and ensuring that intuition is re-evaluated.

Integration of Frameworks

Together, the aforementioned frameworks form the basis of this research. Type I/I Thinking offers a foundational framework for understanding how individuals engage in their cognition and explore the dynamics of decision-making. Metacognition is then used to explore how individuals consciously engage in the thinking types and how they regulate their metacognition. JOLs and FORs are used specifically to investigate the direction in which individuals may engage with thinking types. Finally, JOLs/FORs provide a measurable construct of the monitoring phase of metacognition during which participants in this study describe their decision-making. A growing body of research has begun to explore the relationship between Dual Process Theories of Reasoning and metacognition, particularly how monitoring and awareness relate to Type I and Type II thinking. (Bago & De Neys, 2017; De Neys, 2012; Thompson et al., 2011). These studies have primarily examined the relationship at a general level, without explicitly investigating how learners intentionally engage with and regulate these thinking processes in context. These frameworks describe when and why individuals transition between thinking types and context behind how the intervention in this study aims to improve the cognitive processes to enhance monitoring accuracy and regulate overconfidence.

Methods

Context and Participants

We conducted this study at a large research-intensive institution located in Ontario, Canada during the 2024–2025 and 2025-2026 academic years. This study was approved by the university's Research Ethics Board (file: H-01-25-11095) and informed consent was obtained from all participants.

Recruitment: Recruitment focused on two groups. The first group included graduate or undergraduate learners who were either currently or previously enrolled in Organic Chemistry I (OC I) or II (OC II) at the university or course equivalents offered as a different postsecondary institution ("Organic sample", n = 38). The second group included any graduate or undergraduate student at any postsecondary institution who had not taken an OC I/II course ("General sample", n = 27). The recruitment period took place during the Winter 2025 and Fall 2025 terms. Physical copies of posters were displayed across the university campus during the recruitment period. We also recruited participants via course spaces hosted on the university's learning management system. We contacted various instructors asking them to post a recruitment advertisement and video announcement within their respective course spaces.

Compensation

Participants had the opportunity for one entry to a raffle to win a $20 gift card for completing the first component of the study (1 in 4 chance), as well as being entered in a baked good raffle. Those who completed the second component of the study received a second entry to the gift card raffle and a research participation certificate.

Study overview: experimental design

The study used an experimental design with a pre-test, post-test, and delayed post-test. Data were collected over two sessions within a two-week period (Fig. 1). Participants were randomly assigned to treatment and control groups and subdivided based on their disciplinary background (organic chemistry vs general). Participants in the organic chemistry groups came from a broad STEM background (e.g., biology, pharmaceutical science, chemical engineering, etc.). Participants in the general groups had backgrounds across political science and psychology.

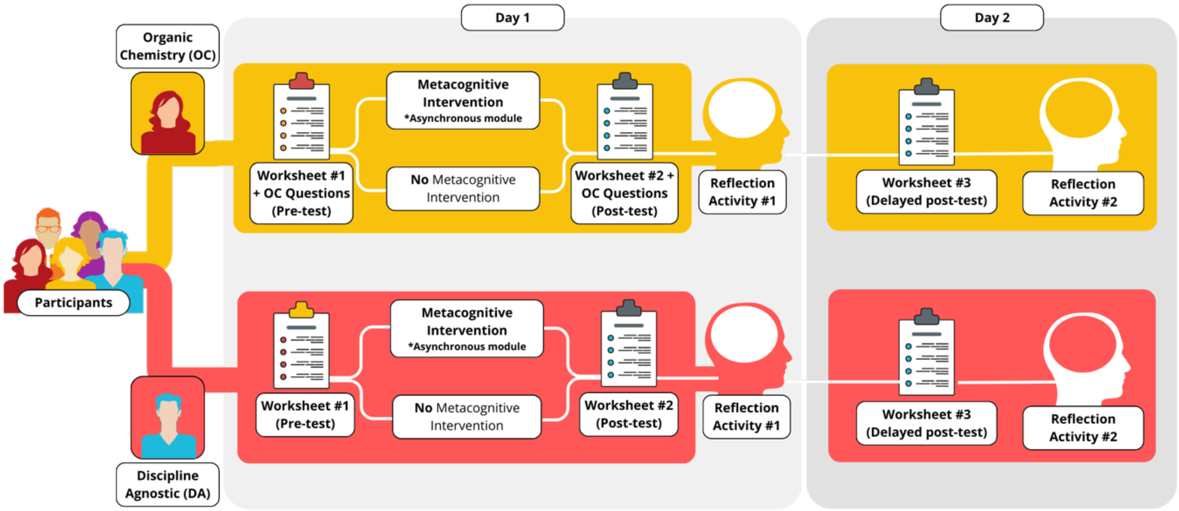

Day 1
Day 2
Organic Chemistry (OC)
Participants
Discipline Agnostic (DA)
Worksheet #1 + OC Questions (Pre-test)
Metacognitive Intervention *Asynchronous module
No Metacognitive Intervention
Worksheet #2 + OC Questions (Post-test)
Reflection Activity #1
Worksheet #3 (Delayed post-test)
Reflection Activity #2
Worksheet #1 (Pre-test)
Metacognitive Intervention *Asynchronous module
No Metacognitive Intervention
Worksheet #2 (Post-test)
Reflection Activity #1
Worksheet #3 (Delayed post-test)
Reflection Activity #2

Fig. 2 Overview of the experimental design

Participants first completed a demographic questionnaire, which was used to assign them to a disciplinary group (Organic or General). Participants were then randomly assigned into control and experimental groups, for a total of four groups, called: $P_{\text{Organic+Intervention}}$(n = 23), $P_{\text{Organic+Non-intervention}}$ (n =15), $P_{\text{General+Intervention}}$ (n = 15), and $P_{\text{General+Non-Intervention}}$ (n = 12).

On Day 1, participants completed four activities: Worksheet 1 (pre-test), an identification task, the intervention (treatment) or placeholder activity (control), and a reflection activity (RA1). The placeholder/control activity was designed to match the intervention activity in duration and general cognitive demand, while remaining unrelated in content to the metacognitive instruction. The General sample received a worksheet consisting of logic- and situation-based problems that were not specific to any academic discipline (discipline-agnostic), allowing for broad applicability across fields. The organic chemistry sample received the same worksheet with an additional four organic chemistry questions. Following the worksheet, all participants completed Identification Task 1. First, participants watched a video that described the differences between Type I and Type II thinking. Subsequently, participants completed an identification task asking them to determine which type of thinking they had used for each of the worksheet questions. Participants were not informed in advance that they would be completing this identification task, to minimize potential bias in their initial worksheet responses. Once completed, participants moved on to complete either the intervention (treatment) or placeholder (control) activity. All instruments are described in greater detail below and are available in the Supporting Information (SI).

Next, participants completed the same worksheet (Worksheet 2) and Identification Task 2 a second time, without receiving feedback on their responses from the first administration. Finally, all participants completed Reflection Activity 1 consisting of a series of prompts that asked them to explain their reasoning for identifying with one type of thinking over the other, as well as to describe the strategies they used to solve the worksheet problems. All the tasks are available in the SI.

Two weeks later, participants were emailed a link to complete a delayed post-test, which included completing the worksheet and identification task a third time, and the Reflection Activity a second time. Delayed post-tests are commonly distributed in educational studies to evaluate potential long-term effects of instructional interventions (Latimier et al., 2019; Ryan et al., 2024). In lieu of administering an immediate post-test, the delayed assessment can provide insight into the durability of learning and the extent of retention and application of knowledge over time (Ryan et al., 2024). Delayed post-tests are also intended to control for test-retest effects, wherein participants may recall specific questions or their previous answers that could bias results (Alexander et al., 2003; Bird et al., 2003; Weinstein & Roediger, 2012). Memory performance measured at a time interval of two or more weeks can provide more robust indication of longer-term retention and help observed performance reflect more than just memory (Emmerdinger & Kuhbandner, 2018; Khalafi et al., 2024). The delayed post-test may also mimic real-world education contexts where knowledge retrieval occurs post-instruction (Latimier et al., 2019; Ryan et al., 2024).

Data Analysis

A mixed-methods approach was used to analyze the data, focusing on both qualitative and quantitative components to provide a comprehensive understanding of participants' engagement in Type I and Type II thinking.

Quantitative Analysis

The quantitative analysis for this research was conducted in R using statistical models, including linear mixed-effects models, to examine differences in Type II engagement across tasks, disciplines, and intervention conditions.

RQ1: Quantitative data were examined to assess the accuracy of participants' ability to describe the thinking types they used throughout the study. Responses were evaluated at two different scales for the following prompt: *For a given question, how did you decide and/or recognize the type of thinking you were engaging with?* Initially, participants' responses were scored on a binary scale of whether they accurately described their thinking types (yes/no). Then, participants were scored on a 4-point scale to assess metacognitive depth of their understanding. The accuracy rubric was created and refined using literature anchored in the Type I/II and metacognition frameworks (Flavell, 1979; Kahneman, 2011; Efklides, 2006; Koriat, 20120). The rubric centres around the accuracy of thinking type description (e.g., correct description off thinking type as outlined by the framework) and quality of the metacognitive depth (e.g., awareness of cognitive strategies, self-monitoring, understanding interactions of the thinking types). Two researchers independently scored participants' responses using the rubric and discrepancies were later resolved through consensus discussion. Inter-rater reliability for the rubric-based coding was strong, with Cohen's $\kappa = .81$, prior to discussion resolving discrepancies and indicates substantial agreement between raters (Landis & Koch, 1977).

Participant scores for the surface level rubric (Yes/No) were assessed using a binomial logistic regression to examine if discipline, intervention status (control or experimental), and time influenced the likelihood that participants provided an accurate surface-level description and evaluated using a binary logistic regression (Hosmer et al., 2013).

Qualitative Analysis

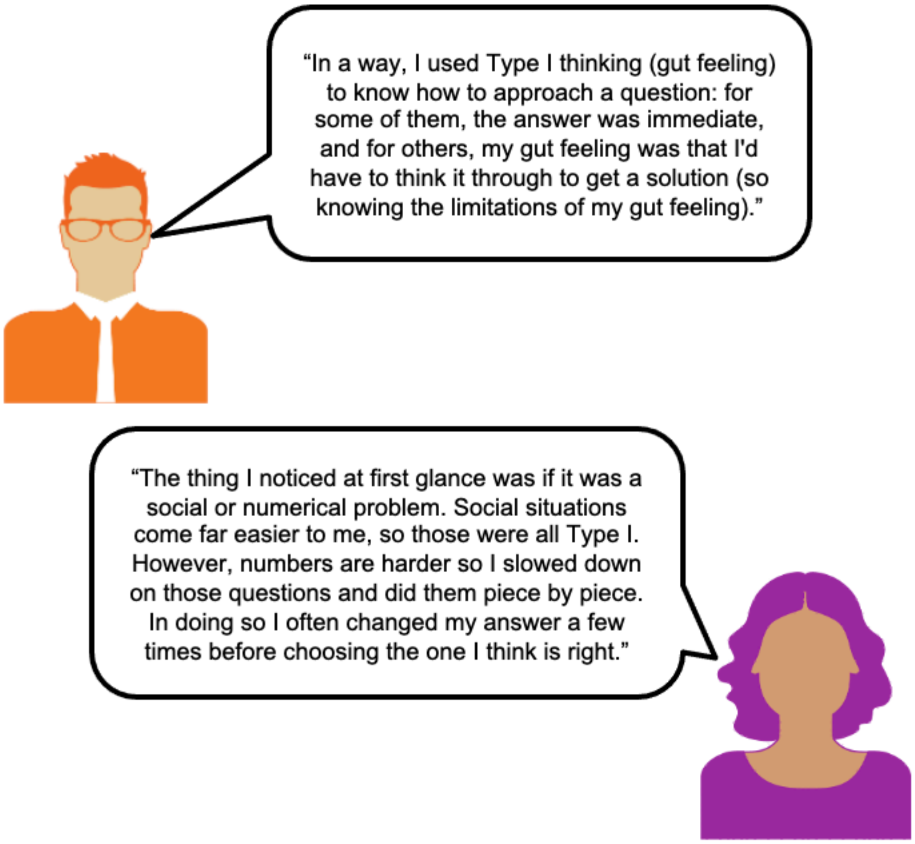
Qualitative data were analyzed using an inductive thematic analysis approach to examine patterns in participants' metacognitive engagement and reasoning based on responses from the reflection activities (Ahmed et al., 2025; Byrne, 2022). Responses were iteratively coded through multiple cycles, progressing from initial memoing and first-cycle descriptive coding to the development of themes, guided by Dual Process Theories of Reasoning. To support validity and reliability, coding decisions were independently reviewed throughout the process by an additional researcher to ensure consistency and alignment, and final themes were discussed with external researchers for feedback on clarity and relevance.

Results and Discussion

Theme 1: Participants described their thinking types relying on Type I/II criteria, but their metacognitive accuracy varied by their ability to integrate multiple cues. Some participants frequently relied on repetitive use of the same, singular cue.

Participants reported cues consistent with the Type I/II framework; however, the accuracy of these self-assessments varied depending on how effectively cues were integrated into their cognitive processes/approach. While some participants demonstrated nuanced awareness of how intuition and reflection guided their problem-solving, others relied on oversimplified, incomplete or misinterpreted indicators of their cognitive processes.

Some participants showing greater metacognitive accuracy were able to integrate multiple cues (e.g., speed of response, effort, confidence, task characteristics, and self-assessment of skills) to evaluate their thinking type. This integration of cues could connect to an awareness of their intuition/analytical skills and their boundaries aligning with metacognitive monitoring (Fig. 3) (Stanton et al., 2021).



“In a way, I used Type I thinking (gut feeling) to know how to approach a question: for some of them, the answer was immediate, and for others, my gut feeling was that I'd have to think it through to get a solution (so knowing the limitations of my gut feeling).”

“The thing I noticed at first glance was if it was a social or numerical problem. Social situations come far easier to me, so those were all Type I. However, numbers are harder so I slowed down on those questions and did them piece by piece. In doing so I often changed my answer a few times before choosing the one I think is right.”

Fig. 3 Selected quotations from participants' responses to reflection activity

These excerpts highlight explicit recognition of the dynamic and multi-faceted nature of thinking type engagement. These participants connected their intuitive and reflective tendencies to the Type I/II framework in how these elements interact with one another, not as separate entities. This integration represents greater metacognitive awareness and the participants’ ability to assess the appropriate application of intuitive judgement. In contrast, other participants demonstrated a limited metacognitive accuracy by oversimplifying their engaged thinking type exclusively with time taken to respond to a question. Such reflections show minimal engagement or awareness of the cognitive or contextual factors that inform the dynamic nature of Type I/II processes (Fig. 4).

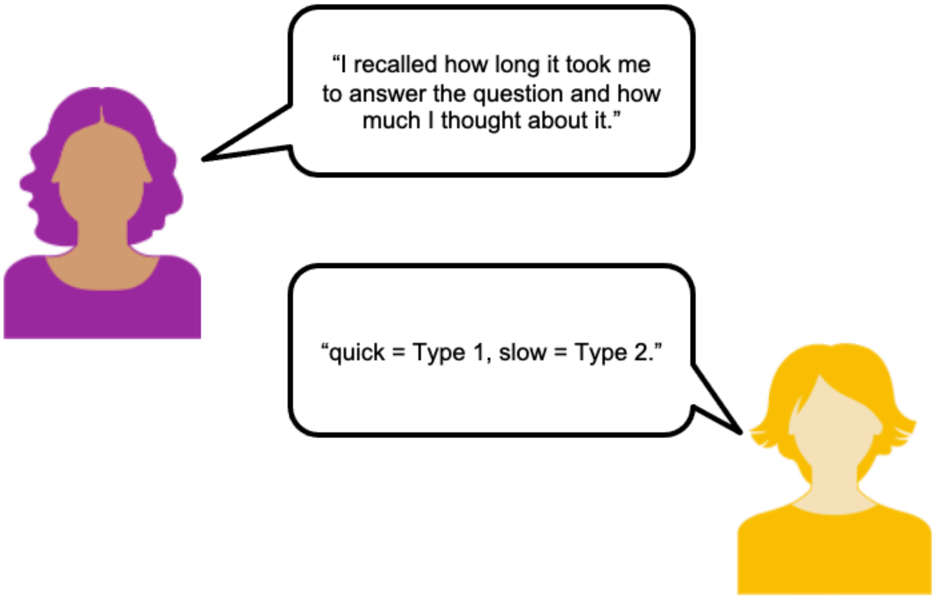

“I recalled how long it took me to answer the question and how much I thought about it.”
“quick = Type 1, slow = Type 2.”

Fig. 4 Selected quotations from participants’ responses to reflection activity

These excerpts provide an example on how participants apply superficial heuristics (e.g., response time) as a metacognitive cue to use Type I. This oversimplification aligns with literature on misattributed processing fluency, where cues that are more immediately noticeable or easier to process ca disproportionately influence responses—in this case, leading participants to define thinking type based primarily on speed or effort alone (Morewedge & Kahneman, 2010; Talanquer, 2014). Processing fluency typically relates to one’s subjective experience of the ease or difficulty one has with completing a cognitive task (Talanquer, 2014). Such that those, who are satisfied with the “path of least resistance” and lean more into process fluency may subjected to increased use in intuitive judgements or in this case oversimplification of how they perceive their cognitive processes (Morewedge & Kahneman, 2010).

This theme highlights a distinction between recognition and understanding; while participants succeed to identify feature(s) of their thought process, few demonstrated accurate integration of the interaction of these features. Thus, the alignment of participants’ perceived cognitive processes depended on how well participants understood the source and meaning of their cues.

Theme 2: Participants used cues of confidence and familiarity to regulate and label their thinking; however, participants' overreliance on these cues impaired their judgements for tasks with different expectations.

A large proportion of participants were able to accurately describe the thinking types at a surface level, suggesting that the ability to distinguish between Type I and Type II thinking is accessible even with minimal introduction. This finding indicates that participants generally understood the difference between the thinking types but does not indicate deeper metacognitive engagement.

Most participants frequently reported relying on internal cues to recognize or regulate their thinking type. These self-assessments demonstrate active metacognitive monitoring as participants use these cues to evaluate their thinking type engagement. However, the accuracy of judgements varied, which reveals some challenges associated with using subjective feelings as reliable indicators of cognitive engagement.

Those participants demonstrating greater metacognitive accuracy used confidence and familiarity cues as part of active reflection, continuously questioning whether judgements were grounded evidence such as conscious, analytical reasoning (e.g., recalling relevant concepts, step-by-step planning, or cross-checking outcomes) or intuition (Fig. 5).

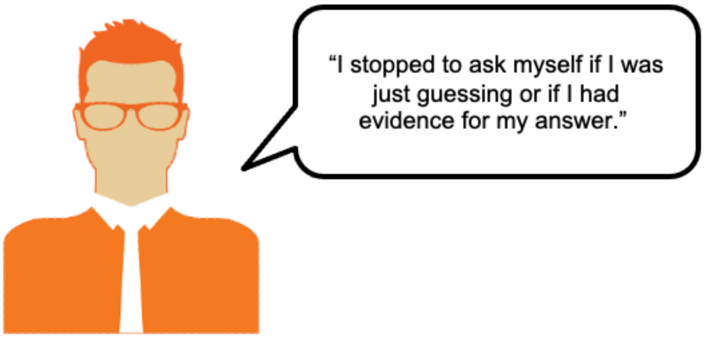

"I stopped to ask myself if I was just guessing or if I had evidence for my answer."

Fig. 5 Selected quotation from participants' responses to reflection activity

Participants with similar excerpts to Fig. 5 exhibited metacognitive control—to pause and evaluate where their reasoning originated (Efklides, 2009). Participants who engaged in similar interrogative processes demonstrated greater awareness of analyzing internal cues to transition between thinking types.

Other participants misinterpreted internal cues such as confidence as evidence of correct reasoning, equating a subjective feeling of certainty with the depth or quality of their cognitive reasoning (Fig. 6).

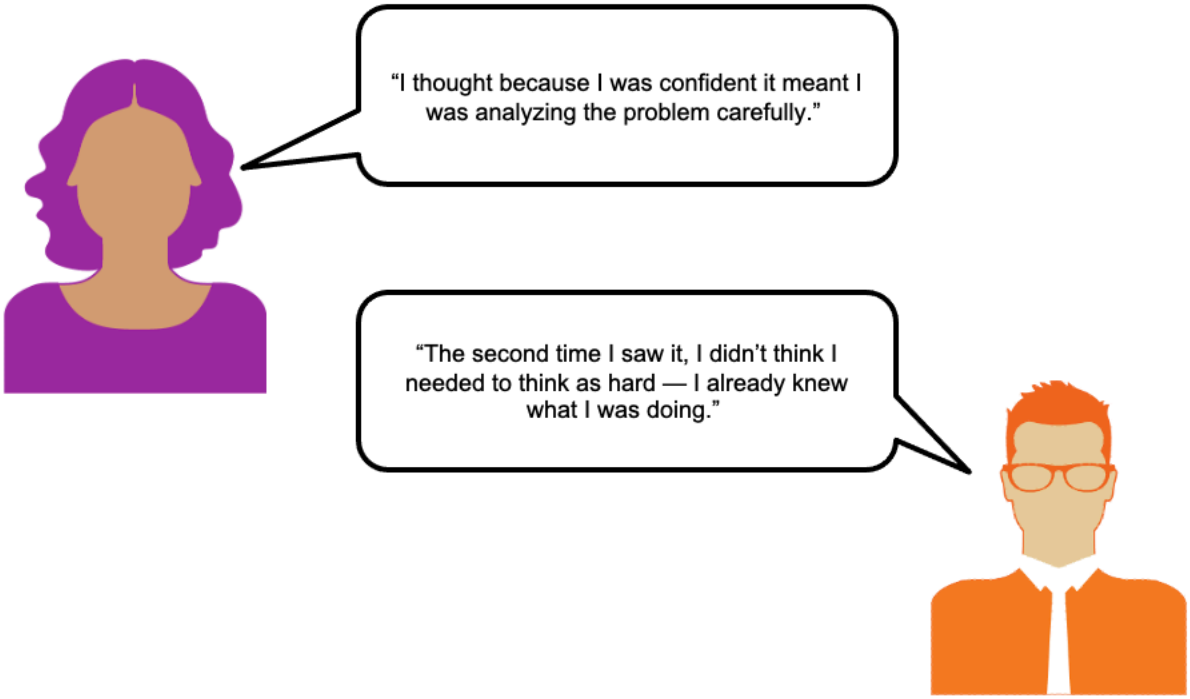

"I thought because I was confident it meant I was analyzing the problem carefully."
"The second time I saw it, I didn't think I needed to think as hard — I already knew what I was doing."

Fig. 6 Selected quotations from participants' responses to reflection activity

This excerpt was one of several responses in which participants demonstrated an overreliance on confidence. This overreliance reflected metacognitive illusions or fluency heuristics, where confidence acted as a false cue, allowing for intuitive judgements to "feel right" though they may not have been appropriate (Talanquer, 2012). This overconfidence bias was encountered frequently when participants were repeatedly exposed to similar questions (Bjork et al., 2013; De Neys, 2012; Koriat, 1997; Koriat et al., 1980). Participants assumed that prior exposure and/or familiarity with the task automatically translated to correct reasoning, so they could apply the same logic as before without reassessing whether their initial approach was correct.

Overconfidence also fostered complacency amongst participants where they confuse recognition for understanding. This overconfidence extended to more complex tasks, where a participant was able to default to previously used strategies as they were previously successful but led them to misinterpret the actual demands of the question. For example, participants overlooked key features of the question (e.g., changes in structure) if they felt they could apply a strategy they were familiar with and confident in. This pattern aligns with Koriat's (2012) idea of knowledge miscalibration and the Dunning-Kruger effect where learners struggle to accurately gauge or overestimate their own skill set of the validity of their cognitive process (Koriat, 2012a; Kruger

& Dunning, 1999). In this study's context, participants' confidence often posed a barrier for recognizing when Type II reasoning was needed, which brings forth evidence of the reinforcement of intuitive engagement. For example, some participants reported that they relied on an initial answer because it "felt right" or aligned with previous questions, and they infrequently recognized that they did not correctly evaluate the expectations of the task. In these cases, participants' confidence in an intuitive response prevented them from engaging in more deliberate analysis, even when the question might have required more thought.

Certain versus uncertain feelings also posed a barrier to identifying thinking types, as these feelings reflect an individual's subjective experience of processing fluency (which may or may not align with reasoning depth) (Koriat, 2012b). Several participants note initially trusting their instinctive response but double checking the logic upon a second encounter. They describe this "double-checking" as an intuitive process.

The findings associated with this theme centered around metacognitive calibration and how learners can distort or facilitate cues that lead them towards inaccurate self-assessments. To support the claims arising from the qualitative data, we measured participants' accuracy in recognizing/describing the type of thinking they engaged based on their responses in the reflection activity (Fig. 7).

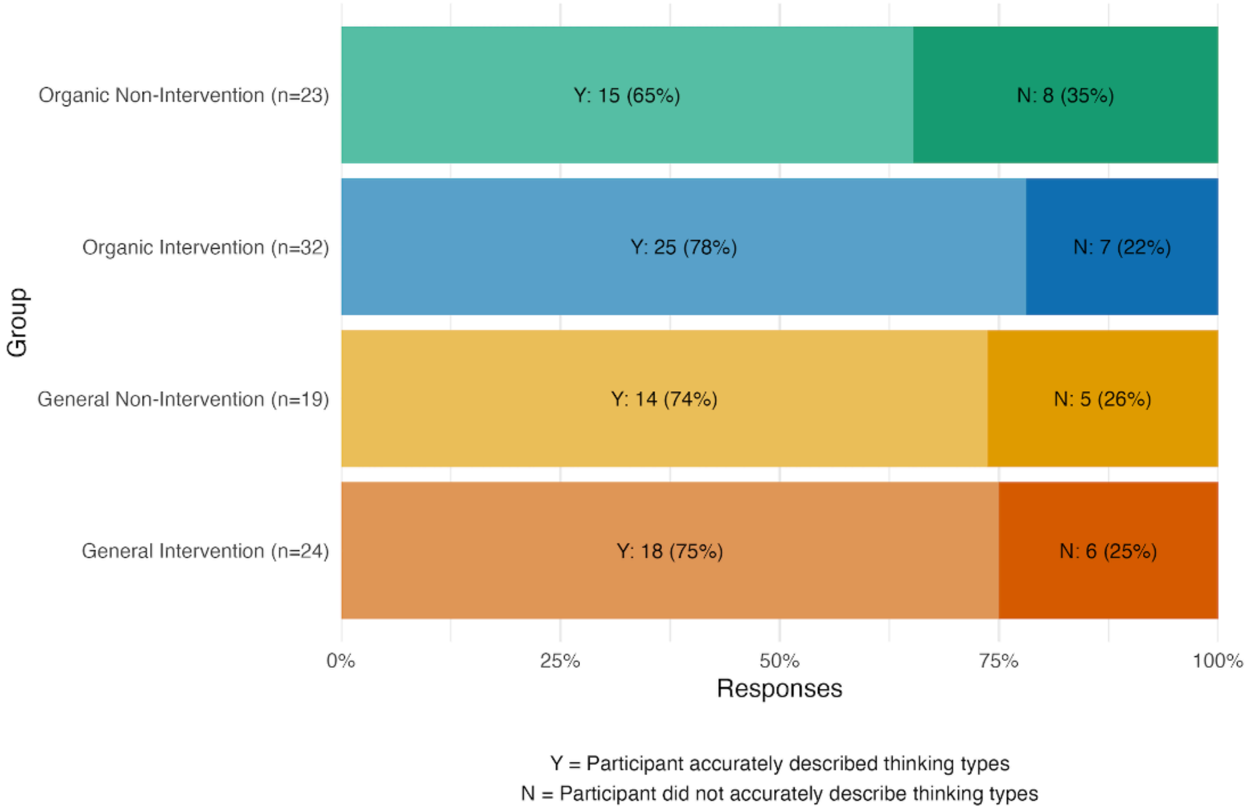


Fig. 7 Stacked bar graph demonstrating the proportion of accuracy of responses in the reflection activity

Across all predictors, there were no significant interactions based on the binomial logistic regression analysis (i.e., discipline, intervention status, and day). The model suggested that accuracy tended to increase over time for $P_{General}$ but decrease slightly for $P_{Organic}$. Accuracy at the yes/no level was relatively consistent across groups and post hoc tests did not detect any pairwise level differences.

Across all predictors, there were no significant differences across discipline, intervention status and days in the linear mixed-effects model (Fig. 7). The LMM explained little variance and suggests that accuracy may not be easily predicted but may be more task-specific. This indicates that accuracy may be affected by these broader group-level factors but may be more sensitive to task-specific characteristics or individual-level differences not captured in the current model.

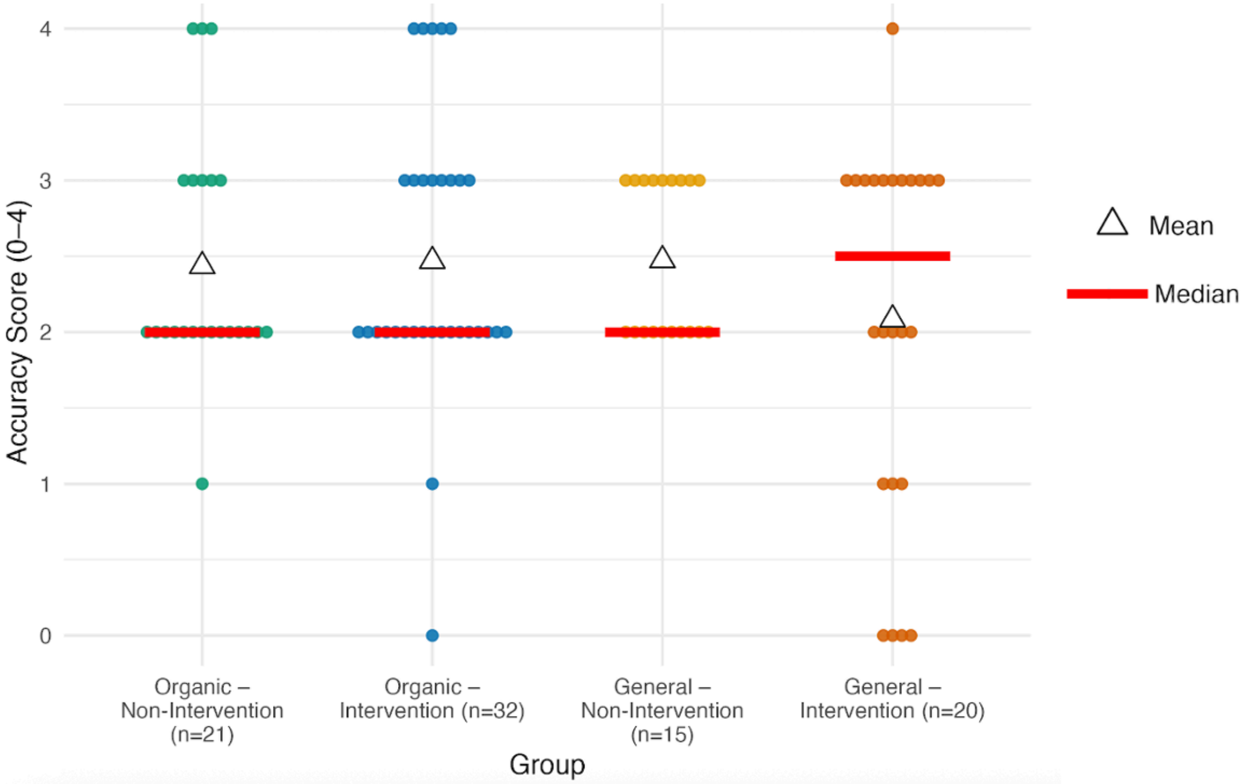


Fig. 8 Distribution of accuracy rubric scores (0-4) across discipline and intervention conditions

The accuracy rubric was applied to one prompt within the reflection activity, as other prompts extended beyond the scope of the rubric.

Theme 3: Organic participants (POrganic) demonstrated more strategic approaches and explicit metacognitive regulation to tasks compared to General participants (PGeneral) who tended to maintain their intuitive (Type I) responses with less monitoring of their approaches.

Many $P_{General}$ often rely on superficial cues (e.g., response speed or confidence) rather than a reflective assessment of their underlying reasoning process or integration of self-identified cues (Fig. 9).

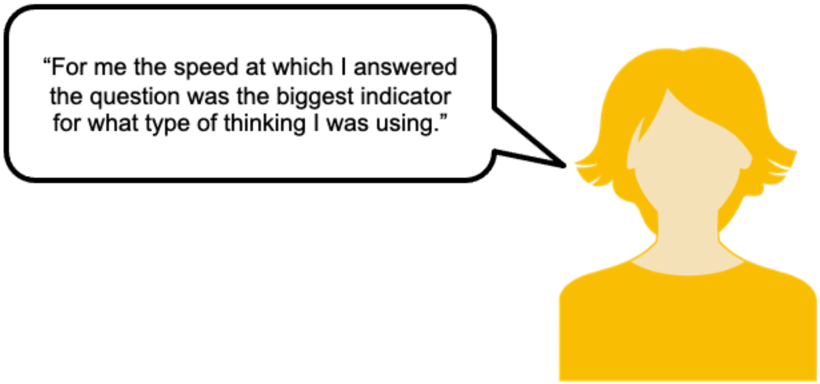
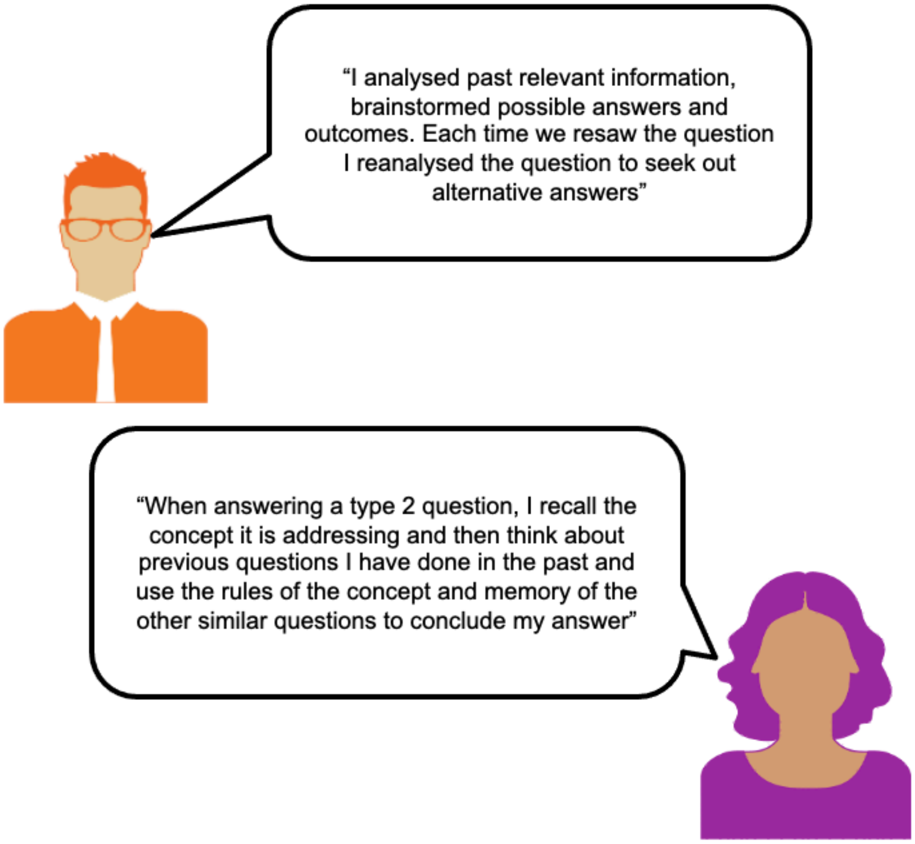

"For me the speed at which I answered the question was the biggest indicator for what type of thinking I was using."

Fig. 9 Selected quotation from participants' responses in the reflection activity

Multiple participants relied on speed of response as a surface-level cue to identify thinking type, rather than engaging in deeper metacognitive evaluation. The excerpt reflects a procedural awareness of the difference in thinking types theoretically, but not on their potential interaction. Such procedural knowledge aligns with Schraw and Dennison's (1994) framework, with distinguishing metacognitive knowledge from regulation. As a result, participants' use of superficial cues demonstrates knowledge about thinking types but not regulation of thinking processes (Schraw & Dennison, 1994). According to Schraw and Dennison, this imbalance limits strategic cognitive control, and can lead participants to rely on heuristics indicators rather than evidence-based reasoning (Schraw & Dennison, 1994). This finding is also consistent with findings in which learners struggle with their metacognitive awareness; they can use metacognitive language but do not demonstrate consistent or accurate use of it (Schraw & Dennison, 1994; Stanton et al., 2021).

The observed reliance on superficial cues among $P_{\text{Non-Intervention}}$ reflects broader reasoning difficulties documented across domains. Prior studies have established that persistent incorrect responses often stem not from conceptual misunderstanding but from challenges in reasoning processes themselves (Kryjevskaia et al., 2014; Speirs et al., 2021). Such reasoning difficulties—common to all human cognition—shape how learners engage with questions and whether they can effectively transition between intuitive and analytical thought. Kryjevskaia et al. (2014) found that learners frequently use correct conceptual knowledge to *justify* an intuitive response rather than to *question* it, mirroring the tendency in this study for participants to rationalize their initial judgments using surface-level cues such as confidence or fluency. Similarly, Speirs et al. (2021) demonstrated that reasoning shifts occur primarily when learners are confronted with information that directly challenges their intuitive models, suggesting that explicit cues are necessary for engaging Type II thinking. In this study, the absence of such cues in the $P_{\text{Non-Intervention}}$ may explain their limited engagement in deliberate monitoring or regulation of reasoning.

In contrast, P_{Organic} more frequently articulated explicit strategies and demonstrated intentional engagement with their thinking processes. Compared to P_{General}, P_{Organic} more often describe strategies such as deliberately slowing down when approaching a problem, breaking problems into simpler components, and translating discipline-specific knowledge when faced with complex or ambiguous tasks. These strategies were tied to participants' awareness of when Type II thinking was required (Fig. 10).



"I analysed past relevant information, brainstormed possible answers and outcomes. Each time we resaw the question I reanalysed the question to seek out alternative answers"

"When answering a type 2 question, I recall the concept it is addressing and then think about previous questions I have done in the past and use the rules of the concept and memory of the other similar questions to conclude my answer"

Fig. 10 Selected quotations from participants' responses to reflection activity

These responses are examples of the more consistent, intentional monitoring and regulation, in which Type II thinking was explicitly connected to reflection on one's knowledge base and strategy use by $P_{Organic}$. More often, $P_{Organic}$ evaluated the reliability of their initial response and adjusted their approach accordingly, reflecting explicit metacognitive regulation (Efklides, 2008).

By contrast, $P_{General}$ engaged less frequently in strategies aligned with Type II thinking, and more often described general problem-solving heuristics or surface-level indicators. Some participants relied primarily on familiarity and intuition while others relied on task demands (e.g., response speed) to label their thinking (Fig. 11).

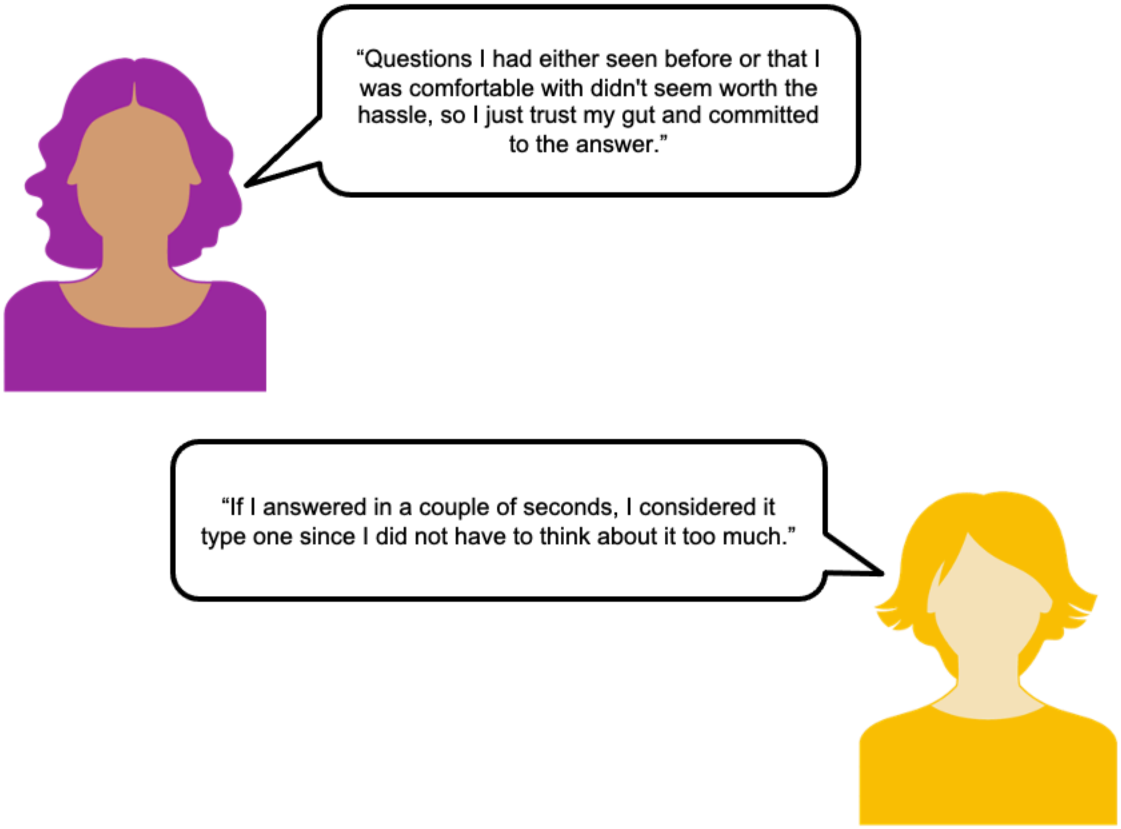

"Questions I had either seen before or that I was comfortable with didn't seem worth the hassle, so I just trust my gut and committed to the answer."
"If I answered in a couple of seconds, I considered it type one since I did not have to think about it too much."

Fig. 11 Selected quotations from participants' responses to reflection activity

These excerpts highlighted the more reactive nature of many $P_{General}$ reasoning approaches, in which surface-level cues classify thinking after they had determined their response, rather than to strategically guide their thinking type engagement. Whereas $P_{Organic}$ more often demonstrated proactive, strategic engagement with thinking types, integrating metacognitive monitoring and regulation during problem-solving rather than relying on retrospective cues.

Building on these qualitative findings, we conducted quantitative analyses to examine whether patterns of Type I and Type II thinking engagement differed systematically across discipline and task. We conducted an estimated marginal means (EMMs) to visualize patterns of Type II thinking across three identification tasks where participants' self-reported the thinking type they engaged in. Results from the linear mixed-effects model revealed a significant main effect for Identification Task 3 (estimate = −0.221, $p = 0.017$), such that $P_{\text{General\_Intervention}}$ demonstrated a decrease in Type II engagement on Identification Task 3 relative to Identification Task 1. This pattern suggests that, overall, Identification Task 3 elicited less reflective engagement than earlier intuition tasks.

A significant Discipline × Task, interaction was also observed (estimate = +0.303, $p = 0.016$), indicating that this reduction in Type II engagement from P_{Organic} as a discipline maintained or increased their engagement with Type II thinking on Identification Task 3 compared to $P_{\text{General\_Intervention}}$ (Fig. 12).

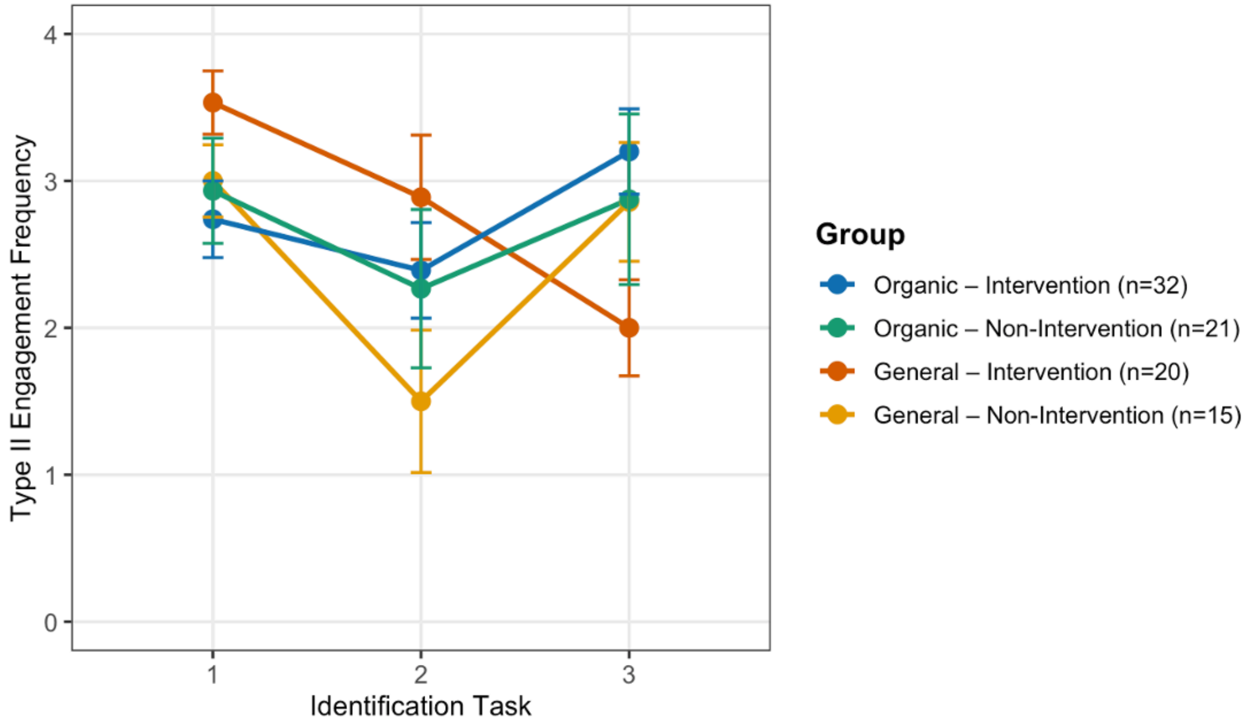


Fig. 12 Interaction plot of Type II thinking engagement as self-reported by participants across three identical tasks

Although reflective (Type II) engagement decreased on the Identification Task 3 overall, P_{Organic} sustained reflective engagement across the task. In contrast, P_{General} showed larger declines in Type II engagement, aligning with qualitative evidence of continued reliance on intuitive processing and reduced strategic reassessment.

Although the qualitative data did not support the development of a standalone theme regarding the intervention's effect for RQ3, a consistent pattern emerged in how participants described their cognitive processes. $P_{\text{Intervention}}$ more frequently used metacognitive language to monitor, label, and reflect on their thinking, which could suggest improved fluency with articulating cognitive processes in conjunction with Type I/II frameworks. In contrast, $P_{\text{Non-Intervention}}$ more often relied on superficial cues (e.g., speed and difficulty) with less evidence of deliberate monitoring or regulation. This difference was most evident in participants' descriptions of their thinking rather than in consistent differences in performance or demonstrated regulation; this could indicate that the intervention may have primarily supported participants' metacognitive vocabulary and awareness, rather than producing a robust shift in cognitive strategy. Taken together, these observations suggest that the intervention may have functioned more as a scaffold for metacognitive expression than as a mechanism for consistently altering cognitive engagement.

Limitations

The sample size was drawn from a single institution, which may limit the generalizability of findings to broader postsecondary populations, particularly those from other disciplines, institutions, or cultural contexts. Second, the metacognitive intervention was brief and delivered in a controlled research setting. Effects may differ when the context in which the intervention is delivered changes. Differences in effects may be observable when delivered in an authentic classroom environment, where time constraints, competing demands, and social dynamics could influence engagement.

We relied on participants' self-reports of their reasoning processes and their identification of thinking types. These reports are inherently subjective and may be influenced by memory bias or participants' ability to accurately reflect on their cognition (Ozturk, 2017). We collected data in this study via concurrent and retrospective reporting; this could introduce variability in the detail and accuracy levels in which participants communicate their reasoning. Such effects could be better understood via longitudinal research and repeated measures, as they could allow us to examine long-term retention, expand the population, and directly assess the impact of disciplinary experience and intervention exposure.

Implications for Teaching

One valuable direction would be to translate this work's insights into pedagogical practice. Our findings can inform how to structure instructional supports to (a) guide learners to recognize what type of thinking is being used and the appropriate contexts of use, (b) align thinking type cues with disciplinary context and assessment design, and (c) achieve outcomes such as improved regulation, transfer of reasoning strategies, and dynamic shifts of thinking. Our findings suggest that the development of empirical evaluation tools or instructional frameworks could strengthen the impact or retention of metacognitive control and understanding of Type I/II thinking. While prior research has demonstrated the benefits of metacognitive instruction for enhancing learners' monitoring and regulation of thinking, our findings provide evidence that participants demonstrated increased awareness of their cognitive processes and engagement with Type I and Type II thinking, suggesting a benefit of such instruction. These findings further indicate a need for empirical evaluation tools or instructional frameworks to support the recognition and regulation of these thinking processes.

Implications for Research

The findings of this study suggest that thinking type engagement is discipline sensitive. Future studies could further examine how disciplinary knowledge and task structure shape cognitive processing within dual-process frameworks. Future work could also focus on advancing the knowledge of how metacognitive engagement supports individuals' self-reflection and use of thinking types across different contexts.

Further work could benefit from expanding upon this paper's methodological approaches. For example, implementing methods that focus on capturing concurrent measures of thinking type reporting could offer a more dynamic understanding of shifts or thinking type usage. This approach includes extending beyond static or outcome-based measures to investigate more process-oriented approaches that capture when and why individuals transition between thinking types. Designs that involve longitudinal and repeated measures would be useful for modeling within-person trajectories of cognitive regulation and for assessing the retention of intervention-related changes over time.

Conclusion

This study examined the impact of a metacognitive intervention on learners' ability to recognize and regulate their use of Type I and Type II thinking across disciplinary contexts. Using a mixed methods design, we analyzed students' reflections to explore how they recognize, monitor, and regulate their thinking during problem-solving. Our findings align with pre-existing literature that describe how intuitive processes are often dominant under conditions of uncertainty (Bago & De Neys, 2017; De Neys, 2012; Evans & Stanovich, 2013a; Kahneman, 2011) and with more recent work demonstrating that dual process reasoning continues to play a measurable role in contemporary assessments of cognitive reflection and reasoning (Mata, 2023; Meyer et al., 2024). Our findings also align with STEM education research demonstrating that domain knowledge supports more structured and strategic problem-solving (Chi et al., 1981; Talanquer, 2012), as well as studies that show that instructional and course-integrated interventions can influence metacognitive strategy use (Blackford et al., 2023; Stanton et al., 2021). Finally, our results are also consistent with metacognition research demonstrating that learners' monitoring and judgments are often shaped by internal experiences such as confidence and perceived fluency (Koriat, 1997, 2012b), a pattern that continues to be observed in more recent work on confidence and judgment in reasoning tasks (Mata, 2023).

Our findings highlight how learners themselves recognize and interpret their thinking in terms of Type I and Type II processes. Prior research related to Dual Process Theories of Reasoning has largely focused on performance outcomes or decision accuracy. This adds a metacognitive dimension to Dual Process theory by emphasizing learners' awareness and self-description of their cognitive engagement. Although existing metacognitive research has established the importance of monitoring and regulation, our findings distinguish between the ability to articulate metacognitive processes and the ability to enact them. The intervention increased learners' metacognitive vocabulary and awareness but did not clearly/immediately translate into changes in cognitive engagement, thus a gap continues to exist between metacognitive knowledge and regulation. We also found that metacognitive engagement was not uniform across contexts and was influenced by domain-specific knowledge and expectations.

Our findings challenge the assumption that increasing metacognitive awareness alone is sufficient to change how students think during problem-solving. Instead, our findings suggest that this metacognitive intervention scaffolds more surface-level understanding of cognitive processes rather than working as a direct mechanism for shifting cognitive processing. These findings provide a foundation for future work aimed at developing more sustained and contextually embedded interventions that better support the translation of metacognitive awareness into active regulation of thinking.

Ethics declarations

Compliance with ethical standards

The study was approved by the [Institution's] Research Ethics Board (File #: H-01-25-11095) and informed consent was obtained from all participants.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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4.2 Copyright

Chapter 4 is based on a manuscript submitted for publication:
Pavao, S. C., Azad, P., & Flynn, A. B. (2026). The role of metacognitive skills in decision-making using Type I/II thinking. *Submitted to* Journal of Metacognition and Learning *(Manuscript ID: META-S-26-00247; submitted April 10, 2026).* Myself (Sylvanna Pavao) is the primary author and was responsible for the study design, data collection, instrument development, analysis, and manuscript preparation. All authours have consented to the inclusion of this manuscript into this thesis.

Chapter 5. Instrument Development

This section outlines the development of each study item that was used throughout the study. The instruments themselves can be found in Appendix A.

5.1 Demographic Questionnaire

The demographics questionnaire aimed to gather participant information to determine eligibility, obtain consent to participate, and randomly assign participants into groups. The questionnaire was administered online using SurveyMonkey.

5.2 Worksheets

This study uses the three questions from the Cognitive Reflection Test (CRT) and one additional CRT question developed by (Böckenholt, 2012) which are well-established ways to measure Type I and Type II thinking (Frederick, 2005b). Specifically, the CRT measures an individual's ability to override intuitive, incorrect Type I responses in favour of more analytical Type II responses (Frederick, 2005b) (Mata, 2023; Meyer et al., 2024; Sirota & Juanchich, 2018; A. K. Wood et al., 2016). These questions take on the form of "brain teasers" that appear to have an obvious, correct response but in fact, require more analytical approach to arrive at the correct answer. An example of a CRT question is *A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?* This question elicits an immediate intuitive response (e.g., 10 cents), but arriving at the correct answer requires inhibiting that initial impression and engaging in more deliberate, analytical reasoning.

While the CRT provides evidence for reliably assessing cognitive reflection, it mainly targets numerically framed reasoning. We developed two situation-based moral/social dilemmas to complement the CRT and extend the applicability measures. These dilemmas use the Type I/II Thinking framework. Each dilemma presents a realistic, socially relevant scenario where there are multiple justifiable responses—encountering a lost child in a mall or witnessing a dispute between friends. The social dilemma questions aim to address the gap existing across pre-existing instruments which primarily focus on constrained logic-based problems with a concrete, correct response. The dilemmas offer greater ambiguity to examine participants' spontaneous thinking preferences in situations where there is not a clear, normative answer.

5.3 Organic Chemistry Worksheet Questions

The organic chemistry questions for the worksheet comprised of five questions targeting an introductory level of knowledge to organic chemistry. In this development, we used the University of Ottawa's curriculum to create questions, using formatting seen on exams and assignments (Ogilvie et al., 2017; Flynn, 2015). We also sought out feedback from current (as off Fall 2024) organic chemistry I instructors to gain insight on questions and question formatting that students often succeed and struggle with. The goal with the decision behind what question to include versus not to include was initially based off providing a mixture of Type I and Type II leaning questions to vary perceived question difficulty. The question took one a combination of ranking, multiple choice, and short answer responses.

Two ranking-based organic chemistry questions were developed for this study: (1) ranking structures in order of increasing acidity (least to most acidic) and (2) ranking the corresponding conjugated bases in order of increasing stability (Figure 13). These tasks were selected because acid-base reasoning in organic chemistry requires the integration of multiple conceptual factors, including inductive effects, resonance stabilization, electronegativity, and charge distribution (Ogilvie, 2015; Flynn and Featherstone, 2017). As such, they are well-suited to eliciting differences between heuristic (Type I) and analytical (Type II) reasoning.

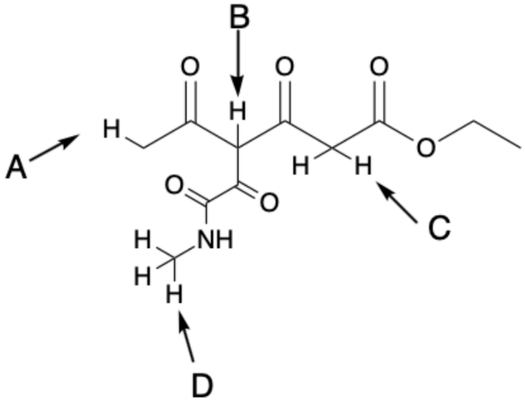

Figure 13. Example of ranking question as part of the organic chemistry problem set (On the following molecule, rank the labeled hydrogen atoms in order of increasing acidity (least (1) to most (4) acidic))

Prior research has shown that learners often simplify acid-base decisions by relying on single cues or surface features rather than integrating multiple structural factors. For example, we anticipated that participants might focus on recognizable functional groups or overgeneralize trends such as “more electronegative atoms increase acidity” without considering full conjugate base stability (Talanquer, 2014; McClary & Talanquer, 2010).

Correct responses to the ranking questions required participants to evaluate and integrate multiple stabilizing and destabilizing effects on the conjugate base, with acidity ranking deriving from relative conjugate base stability. In contrast, stability rankings required comparison of how structural features influence charge distribution and resonance delocalization.

Participants also completed stereochemistry discrimination tasks were they determined whether pairs of molecules were identical or different (Figure 14). Unlike the ranking tasks, this item was intentionally designed to be lower in conceptual load to elicit more immediate Type I reasoning. Specifically, the question avoided requiring formal stereochemical classification (e.g., enantiomers, diastereomers) to reduce cognitive load and focus attention on spatial and structural comparison. Correct responses required participants to recognize structural equivalence despite differences in representations, whereas incorrect responses were expected to arise from reliance on visual appearance, drawing orientation, or failure to mentally manipulate spatial configurations.

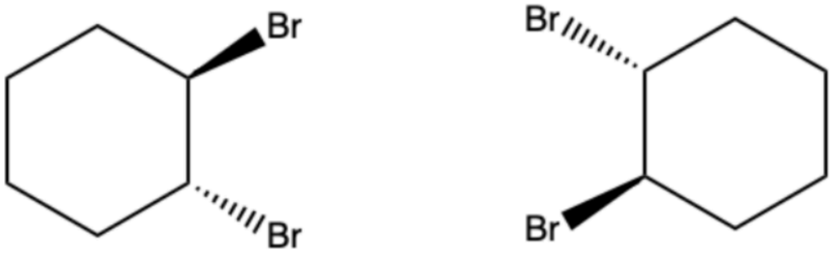

Figure 14. Example of stereochemical identification question (Are the following molecules the same or different?)

The final question was a reaction mechanism evaluation task from a question used in a previous study (Carle et al., 2020)(Figure 15). This question assesses participants’ ability to follow electron-pushing formalism without requiring consideration of additional contextual factors such as steric effects or reaction conditions. As such, this task prompts Type II rule-based approaches. The study in which this question was previously used, the most common reported error was a missing function group in the product and relates to previous work done in the field where systematic errors are common when interpreting electron flow diagram. Previous related work also reports learners commonly omitting atoms or bonds, incorrectly tracking functional groups, or fail to propagate electron movement through a mechanism (Flynn and Featherstone, 2017; Carle et al., 2020).

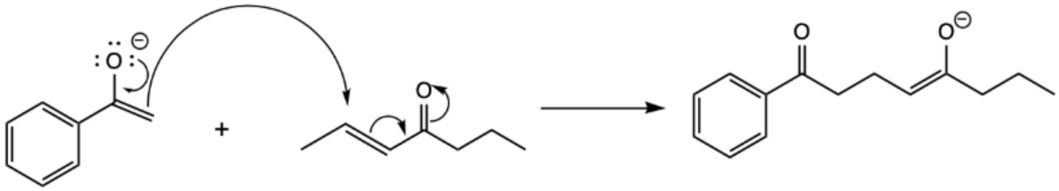

Figure 15. Example of mechanistic question (From the following mechanism, is the product correct?)

For the mechanism evaluation task, correct responses required accurate tracking of electron movement through all intermediates and retention of structural integrity throughout the mechanism. In contrast, incorrect answers were expected to reflect reliance on surface pattern matching, misapplication of the octet rule, or failure to fully follow electron flow, including misplacement or omission of functional groups during mechanistic steps.

The exact organic chemistry questions and answer key can be found in Appendix A.

5.4 Control Activity

The placeholder activity was comprised of two Ted Talk videos with follow-up multiple choice and short answer questions. The two Ted Talks were “How to Get Your Brain to Focus” presented by Chris Bailey and “You are Contagious” presented by Vanessa Van Edwards. Questions relating to the Ted Talks focused on comprehension of the video content (e.g., recall of presented facts, identification of themes, and brief summaries) (Van Edwards, 2015; Bailey, 2019). These questions required engagement with the material but did not prompt reflection on participants’ thinking processes.

5.5 Reflection Activity

The reflection activity has eight short answer prompts and one multi-select question. Participants were asked to identify which metacognitive strategies they used on worksheets. Reflection activities served as a source of validation of participants’ reported thinking, in which participants explain the reasoning behind their decisions of which thinking type they used engagement. The prompts allow for insight into participant decision-making processes and the alignment of participant interpretation with Type I/II Thinking. The completion of a reflection activity after the worksheet serves as a retrospective self-reported measurement of metacognition.

5.6 Pilot Study

All aforementioned instruments underwent prior testing in a pilot study conducted in March/April 2025. The pilot study included 32 participants and was used to evaluate potential logistical challenges of the study relating to administration and timing. From the study pilot, data collection transitioned form an in-person to an online format, and a small number of redundant items were removed from the reflection activity. No substantive changes were made to the content or structure of the primary instruments. Data from the pilot participants were retained and are presented in this manuscript alongside the main study.

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Chapter 6. Conclusion

The first of its kind, this study examined the impact of a metacognitive intervention on learners' ability to recognize and regulate their use of Type I and Type II thinking across disciplinary contexts. Using a mixed methods design, we analyzed students' reflections to explore how they recognize, monitor, and regulate their thinking during problem-solving. Our results indicate that metacognitive regulation of Type I and Type II thinking shows relative consistency in the surface-level cues learners use to identify their thinking type. However, more substantial differences emerge in learners' ability to integrate multiple cognitive cues. Higher-level regulation reflects more dynamic coordination between intuitive and analytical processes, whereas lower-quality regulation relies on simplified cues (e.g. speed or difficulty). The intervention appeared to support learners' use of metacognitive vocabulary and their ability to articulate their thinking processes but has less consistent impact on their ability to accurately identify the mechanisms underlying optimal reasoning strategies when approaching a problem.

Our findings align with pre-existing literature that describe how intuitive processes are often dominant under conditions of uncertainty (Bago & De Neys, 2017; De Neys, 2012; Evans & Stanovich, 2013a; Kahneman, 2011) and with more recent work demonstrating that dual process reasoning continues to play a measurable role in contemporary assessments of cognitive reflection and reasoning (Mata, 2023; Meyer et al., 2024). Our findings also align with STEM education research demonstrating that domain knowledge supports more structured and strategic problem-solving (Chi et al., 1981; Talanquer, 2012), as well as studies that show that instructional and course-integrated interventions can influence metacognitive strategy use (Blackford et al., 2023; Stanton et al., 2021). Finally, our results are also consistent with metacognition research demonstrating that learners' monitoring and judgments are often shaped by internal experiences such as confidence and perceived fluency (Koriat, 1997, 2012b), a pattern that continues to be observed in more recent work on confidence and judgment in reasoning tasks (Mata, 2023). Our findings highlight how learners themselves recognize and interpret their thinking in terms of Type I and Type II processes. Prior research related to Dual Process Theory has largely focused on performance outcomes or decision accuracy. This study adds a metacognitive dimension to Dual Process theory by emphasizing learners' awareness and self-description of their cognitive engagement.

Although existing metacognitive research has established the importance of monitoring and regulation, our findings further refine this distinction by separating learners' ability to articulate metacognitive processes from their ability to enact them during reasoning. This distinction suggests that metacognitive awareness, as expressed through learners' reflections and descriptions of their thinking, does not necessarily correspond to consistent or effective regulation in practice. Rather, learners demonstrate an ability to describe metacognitive concepts and identify thinking types without reliably integrating these ideas into their problem-solving approaches.

More broadly, this mismatch highlights that metacognitive knowledge and metacognitive control are not inherently aligned, and that increases in one do not automatically produce changes in the other. In this study, this mismatch refers to the divergence between learners' improved ability to articulate metacognitive concepts (e.g., using Type I/II vocabulary and describing their thinking processes in reflections) and their demonstrated ability to integrate and coordinate cognitive cues during reasoning tasks. Even when participants showed improved metacognitive vocabulary following the intervention, this did not consistently translate into more integrated or adaptive regulation of thinking. This observed dissociation between metacognitive knowledge and metacognitive control suggests that developing metacognitive instruction that targets not only awareness but also the coordination and application of regulatory processes may be necessary to support meaningful changes in how learners engage with problems.

Our findings suggest that this metacognitive intervention scaffolds more surface-level understanding of cognitive processes rather than as a direct mechanism for shifting cognitive processing. These findings provide a foundation for future work aimed at developing more sustained and contextually embedded interventions that better support the translation of metacognitive awareness into active regulation of thinking.

6.1 Limitations

The sample size was drawn from a single institution, which may limit the generalizability of findings to broader postsecondary populations, particularly those from other disciplines, institutions, or cultural contexts. Second, the metacognitive intervention was brief and delivered in a controlled research setting. Effects may differ when the context within which the intervention is delivered. This effects difference includes but is not limited to delivery in authentic classroom environments, where time constraints, competing demands, and social dynamics could influence engagement.

We relied on participants' self-reports of their reasoning processes and their identification of thinking types. These reports are inherently subjective and may be influenced by memory bias or participants' ability to accurately reflect on their cognition (Ozturk, 2017). We collected data in this study via concurrent and retrospective reporting; this could introduce variability in the detail and accuracy levels within which participants communicate their reasoning. Such effects could be better understood via longitudinal research and repeated measures as they could allow us to examine long-term retention, expand the population, and directly assess the impact of disciplinary experience and intervention exposure. Finally, we were limited to a relatively small sample size (n = 67) that may have affected potential outcomes in terms of quantitative analysis output (e.g., hypothesis testing).

6.2 Implications for Teaching

One valuable direction would be to translate this work's insights into pedagogical practice. Our findings can inform how to structure instructional supports to (a) guide learners to recognize what type of thinking is being used and the appropriate contexts of use, (b) align thinking type cues with disciplinary context and assessment design, and (c) achieve outcomes such as improved regulation, transfer of reasoning strategies, and dynamic shifts of thinking. Our findings suggest that the development of empirical evaluation tools or instructional frameworks could strengthen the impact or retention of metacognitive control and understanding of Type I/II thinking. While prior research has demonstrated the benefits of metacognitive instruction for enhancing learners' monitoring and regulation of thinking, our findings provide evidence that participants demonstrated increased awareness of their cognitive processes and engagement with Type I and Type II thinking, suggesting a benefit of such instruction. These findings further indicate a need for empirical evaluation tools or instructional frameworks to support the recognition and regulation of these thinking processes.

At the university level, the goal of instruction is not solely the transmission of disciplinary content but the development of transferable ways of thinking/skills within a discipline. As such, metacognitive processes such as monitoring, evaluating, and regulating one’s thinking are integral to how students engage with and apply disciplinary knowledge. In domains such as organic chemistry, where problem-solving requires coordinating multiple conceptual factors under complex conditions, success depends not only on what students know, but also on how they approach and regulate their reasoning. From this perspective, metacognitive instruction does not compete with content learning; rather, it supports the processes through which students apply knowledge more effectively and flexibly across contexts.

In the context of organic chemistry education, this study’s findings highlight the potential value of explicitly embedding the metacognitive module throughout instruction rather than treating them as implicit or incidental skills. For example, instructors could introduce the distinction between heuristic and analytical reasoning early in a course and revisit it regularly when engaging with common organic chemistry tasks and their associated assumptions relating to acid-base chemistry, stereochemical identification, and electron-pushing formalism. For example, course instructors could include the chemistry questions (or similar) to those presented in this study’s worksheets as they target common heuristics in the organic chemistry discipline (Figure 16). Integrating more explicit discussion of thinking processes may help students better recognize when surface-level cues are insufficient and when deeper structural or mechanistic reasoning is required.

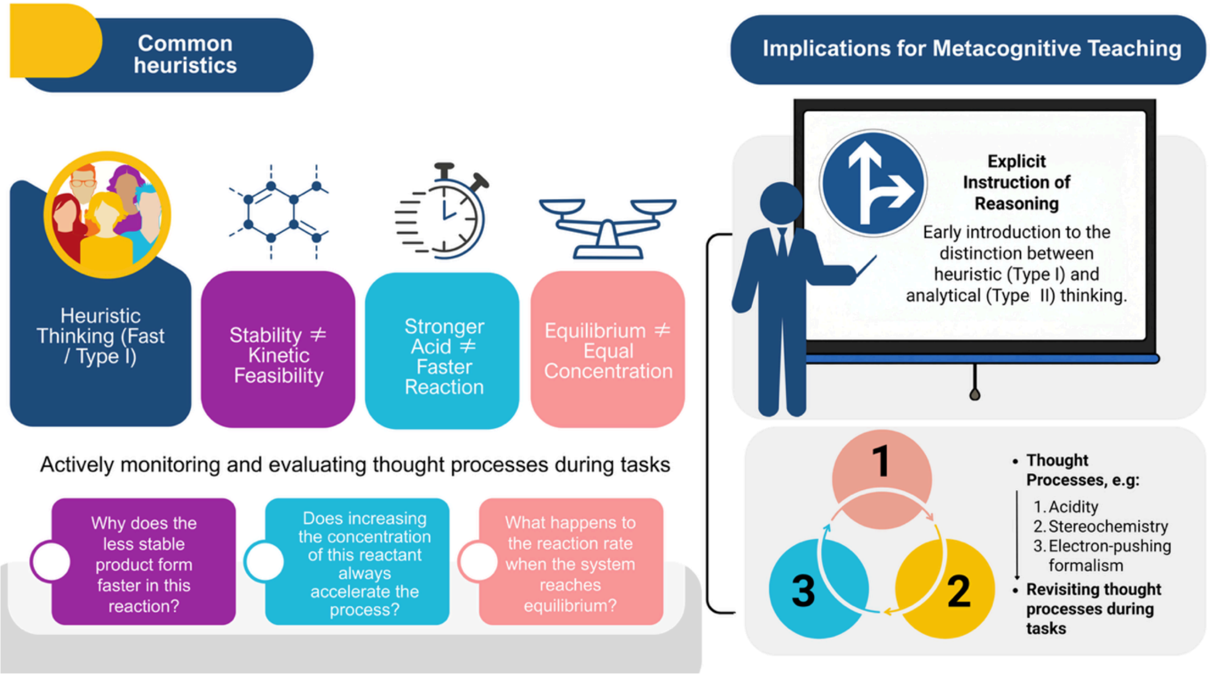
Common heuristics
Heuristic Thinking (Fast / Type I)
Stability ≠ Kinetic Feasibility
Stronger Acid ≠ Faster Reaction
Equilibrium ≠ Equal Concentration
Actively monitoring and evaluating thought processes during tasks
Why does the less stable product form faster in this reaction?
Does increasing the concentration of this reactant always accelerate the process?
What happens to the reaction rate when the system reaches equilibrium?
Implications for Metacognitive Teaching
Explicit Instruction of Reasoning
Early introduction to the distinction between heuristic (Type I) and analytical (Type II) thinking.
1
2
3
Thought Processes, e.g:
1. Acidity
2. Stereochemistry
3. Electron-pushing formalism
Revisiting thought processes during tasks

Figure 16. Illustration depicting common heuristics in organic chemistry, including example questions and advice for introducing Type I/II thinking in the learning environment

Common organic chemistry heuristics provide a useful entry point for discussing Type I and Type II thinking, but this perspective is not limited to situation where learners must override intuitive reasoning. Shifts in thinking can also occur in the opposite direction when learners over-rely on analytical Type II thinking when a Type I response would be more efficient. For example, an experienced student may be able to immediately recognize the stereochemical relationship between two molecules or identify a common reaction. A learner who instead attempts to systematically evaluate every stereocenter or reconsider each mechanistic step may arrive at the same response but with unnecessary cognitive effort. From a Dual Process Theory perspective, successful reasoning involves not only the ability to override inappropriate Type I responses with Type II thinking when needed, but also the ability to rely on appropriate Type I processes when sufficient knowledge and experience support rapid and accurate decision-making.

Similarly, Type II to Type I shifts can also occur as learners gain experience and develop more efficient reasoning patterns. For example, a novice learner may engage with Type II reasoning when identifying the most acidic proton or predicting the outcome of a reaction mechanism. With repeated exposure and practice, these analytical processes become increasingly automatic, allowing the learner to recognize relevant patterns and arriver at correct conclusion with less conscious effort. This transition reflects the development of disciplinary expertise, where knowledge and reasoning strategies that once required Type II engagement become incorporated into more efficient Type I processes.

In addition, instructional design could incorporate brief prompts following problem-solving activities (e.g., What strategy did you use to solve this?, Did you rely on a pattern or mechanistic reasoning?, Would a different type of reasoning/approach have changed your response?). Such prompts would encourage students to monitor not only the correctness of their responses but also how they produced their responses, thereby reinforcing and potentially strengthening metacognitive regulation alongside conceptual understanding. Over time, this may support students in developing more adaptive strategy selection and improving their ability to recognize how their reasoning approaches shift during problem-solving.

6.3 Implications for Research

The findings of this study suggest that thinking type engagement is potentially discipline sensitive. Future studies could further examine how disciplinary knowledge and task structure shape cognitive processing within dual-process frameworks. Future work could also focus on advancing the knowledge of how metacognitive engagement supports individuals' self-reflection and use of thinking types across different contexts. Replications of this study with a larger sample size would also strengthen the generalizability of these findings.

Further work could benefit from expanding upon this paper's methodological approaches. For example, implementing methods that focus on capturing concurrent measures of thinking type reporting could off a more dynamic understanding of shifts or thinking type usage. This approach includes extending beyond static or outcome-based measures to investigate more process-oriented approaches that capture when and why individuals transition between thinking types. Longitudinal and repeated measures designs would be useful for modeling within-person trajectories of cognitive regulation and for assessing the retention of intervention-related changes over time. Future studies should also consider whether modifications to the current design (e.g., simplifying certain tasks, refining prompts, or adding additional measures of reasoning or metacognitive engagement) may improve the clarity and interpretability of findings.

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Appendix A. Supporting Information

A1.1 Demographic Questionnaire/Recruitment

This questionnaire is administered by Sylvanna C. Pavão, graduate student, and Dr. Alison B. Flynn, Principal Investigator, at the University of Ottawa, Department of Chemistry and Biomolecular Sciences. The title of this project is Investigating the Role of Metacognitive Skills in Students' Understanding of Type I and Type II Thinking.

To learn more about the study, particularly the study design, and any associated risks or harms, the handling of confidentiality and anonymity, withdrawal procedures, etc. please read the accompanying Letter of Information. Click this link for the English version, and this link for the French version.

The purpose of this questionnaire is to gather initial data to confirm your eligibility and understand your education background. By completing this survey and signing the online consent form, you are indicating that you are interested in participating in this study and would like to be contacted to have the **online study** sent to you.

This survey should take approximately 5 minutes.

1. Having read the linked Letter of Information, I understand that by clicking the "Yes" button, I agree to take part in this study. **[multiple choice]**
    - ○ Yes, I have read the Letter of Information and consent to participate in this study
    - ○ No, I have not read the Letter of Information and do not consent to participate in this study

2. What is your school email address? **[open-response]**
3. Where are you currently enrolled for postsecondary studies? **[multiple choice]**
    - ○ University of Ottawa
    - ○ Carleton University
    - ○ Other (please specify)
4. What faculty does your program belong under? **[multiple choice]**
    - ○ Arts
    - ○ Education
    - ○ Engineering
    - ○ Health Sciences
    - ○ Law
    - ○ Medicine

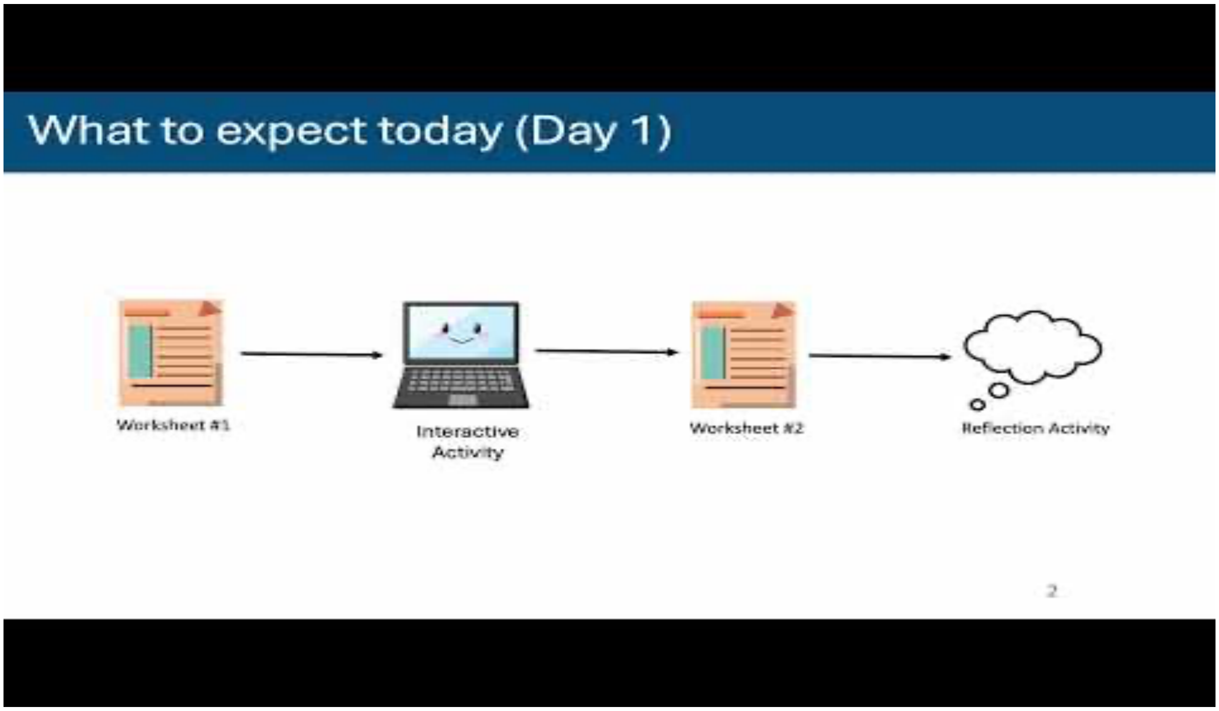
- Science
- Social Sciences
- Telfer School of Management
- Other (please specify)

5. Which of the following best describes your declared program? **[multiple choice]**
   - Biochemistry
   - Biology
   - Biomedical Science
   - Biopharmaceutical Science
   - Business
   - Chemical Engineering
   - Chemistry
   - Engineering
   - Health Science
   - Humanities
   - Human Kinetics
   - Political Science
   - Psychology
   - Undeclared
   - Prefer not to answer
   - Other (please specify)
6. What is your current year of study? **[multiple choice]**
   - 1
   - 2
   - 3
   - 4
   - 5+
   - Other (please specify)
7. Are you currently/were enrolled in any of the listed courses? **[multiple choice]**
   - CHM 1321/1721
   - CHM 2150/2520
   - Introductory Organic Chemistry Courses offered at a different institution
   - None of the above (I have never taken an organic chemistry course)
8. How familiar are you with the term metacognition? **[ranked question, 1-10]**
9. How familiar are you with the Dual Process Theories (e.g. System ½, Type I/II thinking, Bottom Up/ Top-Down approach, etc.)? **[ranked question, 1-10]**

A1.2 Data Collection

Introduction - Please watch the video below

Introduction Video



What to expect today (Day 1)

Welcome! Thank you for your participation today. This survey serves as the first of three worksheets. We ask that you respond questions as you see fit. You will not be assessed on how well you answer the questions. Instead, we are interested in how you choose to interact with questions.

If you have any questions or and technical difficulties arise, please email

Please don't use of external resources (e.g., using the internet, requesting assistance from AI, etc.). There is no time limit for completing the worksheet, please take as long as you need!

1. What is your name? (First and Last) **[open response]**
2. What is your email? **[open response]**
3. Please click the group you were provided in your participation email [**multiple choice]**
    - Blueberry
    - Mango
    - Strawberry
    - Pineapple

A1.3 General Question Worksheet

1. A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? (provide a numerical answer only, units are in cents) **[open response]**

2. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? (provide a numerical answer only, units are in days) **[open response]**

3. You are in a crowded shopping mall when you notice a child crying loudly and calling for their parents. The child looks frightened and alone. What do you do? **[multiple choice]**

- Glance around and decide if the situation needs your involvement.
- Approach the child to comfort them and ask if they need help finding their parent.
- Notify someone nearby who might be better suited to handle the situation.
- Move on. Someone else will probably step in.

4. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? (provide a numerical answer only, units are in minutes) **[open response]**

5. You are with two friends at a café, and you notice they are beginning to argue loudly, with both of them getting increasingly upset. The situation is escalating quickly. What do you do? **[multiple choice]**

- Step in and try to calm them down before things get worse.
- Politely suggest taking a break and talking later, giving everyone time to cool off.
- Wait a moment to see if they can resolve the issue on their own.
- Assess the situation and consider the underlying issue before deciding to intervene.

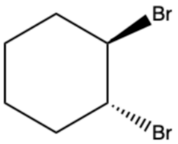
6. Jack is looking at Anne, but Anne is looking at George. Jack is married but George is not. Is a married person looking at an unmarried person? **[multiple choice]**

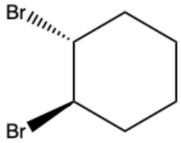
- Yes
- No
- Cannot be determined

A1.4 Organic Chemistry Worksheet

For this portion of the study, you will answer five questions centering around your knowledge of organic chemistry. The question formatting is all multiple choice, please answer them to the best of your ability. Please keep in mind that there are no penalties for incorrect answers.

1. Are the following molecules the same or different? **[open response/multiple choice]**

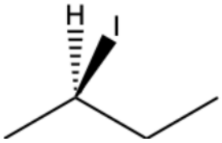


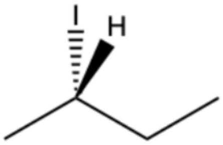


- Same
- Different
- Please explain your response (1 or 2 short sentences)

Correct response: Same

2. Are the following molecules the same or different? **[open response/multiple choice]**

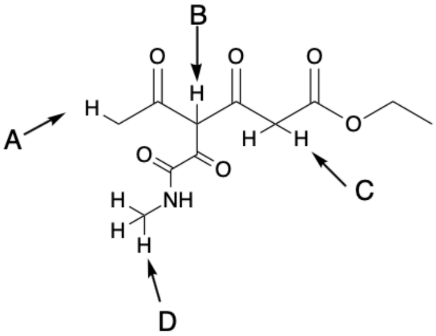




- Same
- Different
- Please explain your response (1 or 2 short sentences)

Correct response: Different

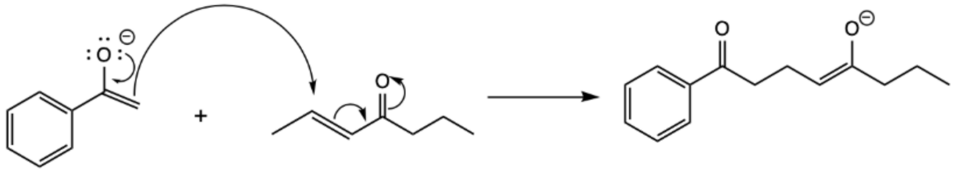
3. On the following molecule, rank the labelled hydrogen atoms in order of increasing acidity (least (1) to most (4) acidic). **[ranking]**



- A
- B
- C
- D

Correct response: D < A < C < B

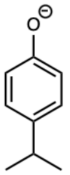
4. From the following mechanism, is the product correct? **[multiple choice/open response]**

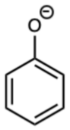


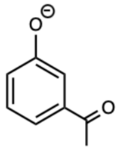
○ Yes
○ No
○ Please explain your response (1 or 2 short sentences)

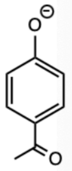
Correct response: No, the final product is missing a methyl group

5. Rank the following structures in order of increasing stability (least (1) to most (4) stable). [ranking]


A


B


C


D

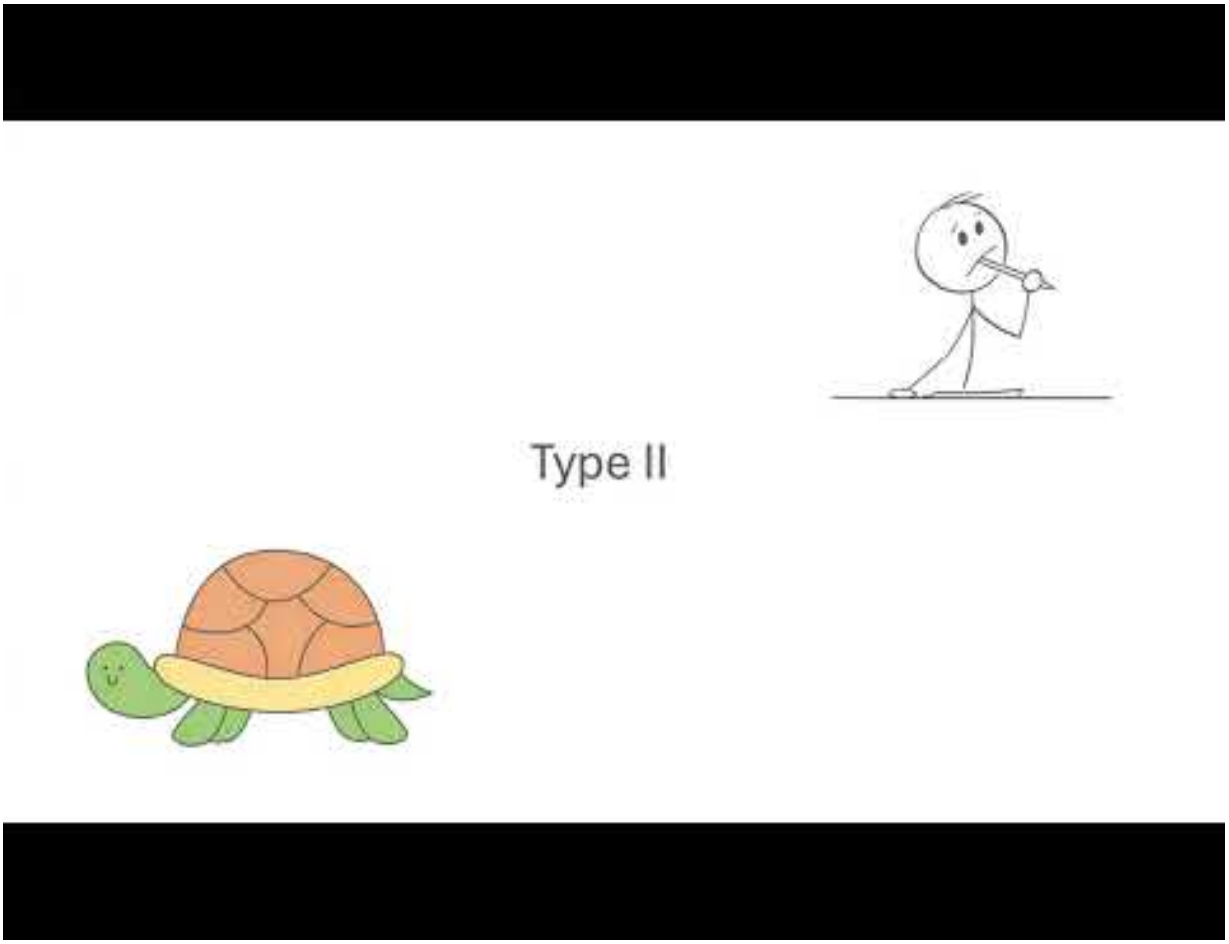
○ A
○ B
○ C
○ D

Correct response: A < B < C < D

A1.5 Identification Task

Thank you for completing Worksheet #1! Please watch the following video providing an overview on Type I/II Thinking! You will then reflect on your answers from the worksheet.

Type I/II Thinking Description



You will now be shown the same questions from Worksheet #1. What type of thinking did you engage with for each question? Please base your answer off what you actually thought/did when completing the worksheet.

1. For the question "A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?" **[multiple choice]**

- ○ Type I
- ○ Type II
- ○ I am not sure

2. For the question "In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?" **[multiple choice]**

- ○ Type I
- ○ Type II
- ○ I am not sure

3. For the question "You are in a crowded shopping mall when you notice a child crying loudly and calling for their parents. The child looks frightened and alone. What do you do?" **[multiple choice]**

- Type I
- Type II
- I am not sure

4. For the question "If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?" **[multiple choice]**

- Type I
- Type II
- I am not sure

5. For the question "You are with two friends at a café, and you notice they are beginning to argue loudly, with both of them getting increasingly upset. The situation is escalating quickly. What do you do?" **[multiple choice]**

- Type I
- Type II
- I am not sure

6. For the question "Jack is looking at Anne, but Anne is looking at George. Jack is married but George is not. Is a married person looking at an unmarried person?" **[multiple choice]**

- Type I
- Type II
- I am not sure

A1.6 Organic Chemistry Worksheet Identification Task

Identical format to A1.5 but with organic chemistry questions

A1.7 Placeholder Activity

Congratulations! You have completed the first worksheet for this study! You now begin your first interactive activity. You will be watching two Ted Talks and on the following pages, there will be a series of multiple choice and short answer questions on each Ted Talk. Link: Ted Talk #1

1. What distractions are Chris referring to in his morning routine? **[multiple choice]**

- His children
- His devices
- His dog
- His stress about work

2. What does Chris decide to do to mitigate his distractions? **[open response]**

3. When did Chris start noticing changes in his routine? **[multiple choice]**

- 3 days
- 2 weeks
- 1 week
- 5 days

4. What three aspects did Chris notice when he changed his routine? Please list them. **[open response]**

5. How long is one’s attention space before we are distracted/interrupted? **[multiple choice]**

- 30 seconds
- 45 seconds
- 40 seconds
- 1 minute

6. What is the alternative word Chris uses to describe that “Our brains are distracted”? **[multiple choice]**

- Unfocused
- Preoccupied
- Overstimulated
- Inattentive

7. What is the feeling individuals feel when we lose these distractions? **[multiple choice]**

- Impatience
- Frustration
- Boredom
- Fatigue

8. Why did Chris feel like his attention span expanded during his experiment? **[multiple choice]**

- He felt more productive
- He was more connected with his daily interactions
- He felt more balanced in his life
- He was surrounded by fewer distractions

9. What famous author does Chris reference in his talk? **[multiple choice]**

- Robert Munsch
- Sally Rooney
- J. R. R. Tolkien
- Suzanne Collins

10. What are the three main places our attention goes to when we are less distracted? **[open response]**

11. List three activities that Chris refers to in his discussion of being more present in the moment without distractions. **[open response]**

12. What is your main takeaway from Chris’ talk? Do you see yourself implementing any of his suggestions? Or do you disagree with anything he has said? **[open response]**

Now, you will watch a second Ted Talk and complete the accompanying questions.

https://youtu.be/cef35Fk7YD8

1. What are Vanessa and her team researching? **[multiple choice]**
    - Social Cues
    - Facial Expressions
    - Ted Talks
    - Conversation
2. When we first see someone, what does Vanessa say we look at first? **[multiple choice]**
    - Eyes
    - Face
    - Hands
    - Hair
3. What does Vanessa compare between the most and least viewed Ted Talks? **[multiple choice]**
    - Intonation
    - Vocal Projection
    - Eye Contact
    - Hand Gestures

4. What is Vanessa’s big idea? **[open response]**

5. What did the “catching emotions” study collect as their data? **[multiple choice]**

- Tears
- Sweat
- Hair
- Skin

6. What are the three ways Vanessa says that we are "contagious"? **[open response]**

7. What emotion is Vanessa referring to as the “safety” one?

- Calmness
- Stress
- Joy
- Fear

8. Other than facial expressions, how else do Vanessa and her team study emotions? **[multiple choice]**

- Heart Rate
- Body Language
- Voice Intonation
- Brain Imaging

9. What else did Vanessa’s team analyze using facial expressions and other elements? **[multiple choice]**

- Likeability
- Extraversion/Introversion
- Intelligence
- Openness

10. For positive/successful conversation starters, which chemical did Vanessa notice was most frequent? **[multiple choice]**

- Serotonin
- Dopamine
- Endorphins
- Oxytocin

11. What does Vanessa refer to when she says “brain hits”? **[open response]**

12. What does the final study discussed look at? **[multiple choice]**

- Singing
- Running
- Confidence
- Knitting

13. What else did Vanessa's team analyze using facial expressions and other elements? **[multiple choice]**

- ○ Likeability
- ○ Extraversion/Introversion
- ○ Intelligence
- ○ Openness

A1.8 Metacognitive Module

In this portion of the study, you will be completing an interactive module on metacognition. For all interactive activities, please click **Check** before you click **Finish** to see if your response is correct. Please click the following link to gain access to the module. Once you have completed the module, you may proceed to the next page.

1. Have you completed the full Metacognitive Module?

- ○ Yes, I have completed the entire module.
- ○ No, I have not completed the module.

A1.9 Reflection Activity

Thank you for completing the worksheet! You are now going to complete a reflection activity. In this activity, you will be asked a series of questions that require you to reflect on your decision-making and approach to problem-solving during the worksheet.

Each prompt will require you to explain how you approached each question on the worksheet. Please respond to these questions as authentically as possible, reflecting on your experiences/feelings when completing the worksheet. Just as a reminder, we are not focusing on how well you performed on the worksheet, we are interested in how you approached the questions and came to your final response.

1. For a given question, how did you decide and/or recognize the type of thinking you were engaging with? **[open response]**

2. What led you to choose a more deliberate, analytical approach (Type II) for certain question(s)? **[open response]**

3. What factors made you rely on your intuition (Type I) for certain questions? Were the questions familiar? How did that influence your thinking process? **[open response]**

When you felt confident about your intuitive answer, did you draw on past experiences or patterns? How did that lead you to trust your intuition at that moment? **[open response/multiple choice]**

- Yes
- No

Please explain your response

5. For a question you identified as Type II, can you explain what strategies you used to approach it? **[open response]**

6. Were there any questions where you initially engaged with one thinking type but then switched? If so, what led you to transition between the thinking types? Please indicate which questions you felt you made this switch (multiple responses permitted). **[open response/multiple choice]**

- Bat and Ball Question
- Lily pad Question
- Crying Child in Shopping Mall Question
- Widget Question
- Friends arguing at a café Question
- Married person looking at an unmarried person Question
- I did not switch thinking types for any question
- Please explain your response.

7. For the question “You are in a crowded shopping mall when you notice a child crying loudly and calling for their parents. The child looks frightened and alone. What do you do?” What type of thinking did you engage with, and can you elaborate why? **[open response]**

8. For the question “You are with two friends at a café, and you notice they are beginning to argue loudly, with both of them getting increasingly upset. The situation is escalating quickly. What do you do?” What type of thinking did you engage with, and can you elaborate why? **[open response]**

9. From the following list of metacognitive strategies, please choose the ones you engaged with to help inform your decision on what thinking type to use and how you decided on your approach to the question: **[multiple choice]**

- Set goals for what I want to achieve
- Sorting the relevant information
- Looking for familiar information
- Reflect on my own relevant knowledge
- Relate the question to previous ones I’ve seen
- Jot down ideas for approaching the problem
- Brainstorm multiple approaches
- Consider if my plan is optimal
- Monitor progress towards the solution
- Evaluate how well my approach is working
- Monitor whether my problem-solving/steps approach are accurate

- Note uncertainties I have with my approach
- Periodically check my approach
- Review if my solution addresses the problem
- Review my answer for mistakes
- Compare my actual solution with my previous predictions
- Summarize main takeaways
- Evaluate potential, future adjustments/strategies

A1.10 Coding Procedure and Codebook

This section outlines the codebook for the thematic analysis of this study.

Table 1. Codebook for thematic analysis of participant responses.

Theme	Categories	Description	Representative Quotes
Participants described their thinking types using self-identified cues and Type I/II criteria, but their metacognitive accuracy varied depending on how effectively they interpreted these cues.	Participants connect their thinking type to criteria metrics	Participants frequently relied on subjective experiences (such as how fast, easy, or effortful a problem felt) as indicators of whether they were using Type I or Type II thinking.	"I recognized the type of thinking based on how quickly and confidently I responded. If the answer came automatically without much effort, it was Type I. If I had to pause, analyze, and check logic or calculations, it was Type II." "Questions that seemed familiar to me or scenario questions were the ones I chose a Type I approach."
	Effort-Based Thinking Type Description	Participants recognized intuitive (Type I) thinking when their responses stemmed from previously learned heuristics, personal knowledge, life experience, or mental shortcuts.	"For me the speed at which I answered the question was the biggest indication for what type of thinking I was using, if I needed time to think then it was likely type 2, if an answer came to be with little thinking then it was likely type 1." "If it took me more time to decide on whether what the correct answer would be such as calculating or use problem-solving methods/thinking to figure out the answer, then I would consider it to be a Type II type of thinking. While for type

			I, not only does it take less time for me to figure out the answer but I was more confident with my answer and I used common knowledge/sense to solve.”
	Misapplication of prior knowledge/self-assessment of skills	Participants monitor and recognize instances of Type I thinking that draw on previous experiences or prior knowledge. Although this familiarity initially supports intuitive reasoning, it can lead to overgeneralization or misapplication when prior knowledge is used without critical evaluation.	“The factors were if I could automatically think of a method for solving the problem. The questions were familiar and it influenced my thinking process because I had already a given answer in mind and so I naturally gravitated towards how I answered previously.” “The second time answering the questions, I quickly went over the sentence to see if it was the same and since they were I already knew the answers and restated them, therefore I was using a Type 1 style of thinking where I remembered rather than analyzed.”
	Participants demonstrate inaccurate intuition monitoring	Participants recognize when intuition is guiding their response but with some inaccuracies in monitoring its applicability	“Questions I had either seen before or that I was comfortable with didn't seem worth the hassle, so I just trusted my gut and committed to the answer.” “They reminded me of the type of questions we would do in elementary school, which resulted in me not giving them much thought.”

	Participants demonstrate unnoticed or automatic thinking engagement	Participants engage in intuitive (Type I) reasoning without conscious awareness or deliberate monitoring of their cognitive process. Thinking occurs automatically or effortlessly, often without recognition that intuition is guiding the response until after reflection.	“Usually, questions that I automatically self-envisioned and had the answer to.” “For the questions that were familiar, I relied on my intuition and gut feeling, which made me answer quickly.”
	Participants demonstrated challenges in regulating reasoning when unable to label or distinguish their cognitive processes	Participants show challenges in regulating their reasoning due to limited ability to label, differentiate, or articulate their underlying cognitive processes.	“Frankly, I wasn't sure which type of thinking I was engaging in the moment until I reflected on it. I was using the key words I remembered from the video explaining these concepts. For Type I I would use ‘guts’ and ‘instinct,’ whereas Type II I would think of ‘bigger problems = more thinking.’” “I wouldn't say I thought ‘oh that was the type!! the type I thinking! I need to switch my approach, type II ENGAGE,’ but I definitely recognized that I just did the maths based off intuition and given the nature of the questions there was probably something more to it.”
	Difficulty with recognizing Thinking Type in general contexts	Participants struggle to identify or differentiate whether they are engaging in intuitive (Type I) or reflective (Type II) thinking when responding to general, non-	“Frankly, I wasn't sure which type of thinking I was engaging in the moment until I reflected on it. I was using the key words I remembered from the video explaining these concepts. For Type I I would use ‘guts’ and ‘instinct,’ whereas Type II I

		disciplinary questions.	would think of ‘bigger problems = more thinking.’” “I'm not really sure I just read the question and I didn't really feel the need to think about it anymore and I had the question.”
Participants recognized their thinking type in relation to task features and demands, but their accuracy depended on how well they interpreted the problem complexity and familiarity.	Task-Driven Transition from Type I to Type II Reasoning	Participants shift from intuitive (Type I) to analytical (Type II) reasoning when external task features—such as question format, structure, or complexity—signal the need for deeper processing. Recognition of these task cues supports deliberate, self-regulated engagement.	“At first the questions seemed simple but when I actually thought about it, I realized that I needed to spend more time on the question and to use a different approach instead of just relying on my intuition.” “I recognized that these were likely to be trick questions and I didn't feel confident in my first instinct, so I automatically switched from Type I to Type II to validate my answers.”
	Participants shift to Type II Engagement when uncertain or unsure how to handle new/ambiguous information	Participants transition from Type I to Type II reasoning when they encounter ambiguous, unfamiliar, or uncertain questions. These features disrupt automatic processing and prompt reflective analysis to resolve uncertainty.	“Initially I wanted to just help the kid (Type I), but then I realized there may be more to the situation than I am made aware of (Type II).” “At first I thought that I was logical that a married person was looking at an unmarried person… but upon further thinking I realized that one marital status of import was missing.”
	Participants Transition from Type I to Type II Thinking based on perception of task difficulty	Participants shift to deliberate, analytical reasoning when tasks are perceived as complex, challenging, or “tricky.” Recognition of these task demands disrupts automatic	“For the friend question, I initially did type 1 because I thought it’d be an automatic, agreeable response to friends arguing, but when I did it again, I realized that with a situation like that there isn’t an automatic answer and the situation would need analyzing before jumping

		responses and promotes deeper processing.	into a solution, and so giving them time to cool off would give every person in the situation time to reflect.” “These two questions appeared surface level at first but I quickly found myself questioning my logic and therefore had to utilize more complex mental techniques to solve the problem.”
	Participants determine Thinking Type Engagement Based on Second-Guessing Intuition	Participants adopt Type II thinking when ambiguous or unclearly worded questions make intuitive responses unreliable, prompting more careful interpretation.	“I first answered it using Type I thinking, since my instinct was to say ‘10 cents.’ But then I realized that answer didn’t make sense with the wording of the problem.” “Some questions had a ‘catch’ and I wanted to make sure I was not wrong.”
	Participant Recognition (or Misrecognition) of Inadequate Intuition and Resulting Thinking Type Description	Participants’ engagement with Type I and Type II thinking depended on their ability to detect when an initial strategy was insufficient. Some recognized that their intuitive response was unreliable—often triggered by uncertainty, complexity, or missed details—and deliberately shifted to analytical reasoning. Others, however, underestimated the problem or failed to identify that their approach was ineffective, leading to continued reliance on	“In a way, I used Type I thinking (gut feeling) to know how to approach a question: for some of them, the answer was immediate, and for others, my gut feeling was that I'd have to think it through to get a solution (so knowing the limitations of my gut feeling).” “The thing I noticed at first glance was if it was a social or numerical problem. Social situations come far easier to me, so those were all type I. However, numbers are harder so I slowed down on those questions and did them piece by piece. In doing so I often changed my answer a few times before choosing the one I think is right.”

		Type I thinking despite cues that deeper reasoning was required.	
Participants used confidence and familiarity to regulate and label their thinking; however, participants' overreliance on this cues often distorted judgments on whether they engaged with the appropriate thinking type for them based on a task’s expectations.	Participants rely on confidence and Familiarity as Thinking Type Cues	Participants identified their thinking type based on feelings of confidence, familiarity, or comfort with the task. They often equated these cues with intuitive (Type I) engagement and uncertainty with analytical (Type II) processing. However, such judgments were not always accurate indicators of the underlying cognitive process or took place with minimal monitoring of their applicability.	“With both of these questions I originally used Type II. However, due to this being the second time I do the experiment, I felt confident in my previous answers. Due to this, I used Type I thinking this time.” “I felt confident in my responses and didn't feel the need to change my answers.”
	Participants rely on familiarity and Pattern Recognition Driving Type I Thinking	Participants relied on Type I thinking when familiarity, repetition, or recognizable patterns made tasks feel predictable. This result in quick, automatic responses.	“The questions felt familiar to word problems I've done in the past, so it made me feel more confident about my reasoning.” “Repetition, familiar questions and surface level mental computations are what has built my intuition to be able to confidently answer a question without second guessing myself.”
	Participants rely on confidence and Effort Regulation Supporting Type I Engagement	Participants’ confidence in their initial understanding or the perceived simplicity of a problem reduced their inclination to engage in analytical reasoning. They	“I engaged with Type I thinking since this problem is more of a humanity and social problem, which means my values kicked in a lot faster than thinking to rationally see if there was a better solution.”

		trusted intuition to conserve cognitive effort, particularly when tasks seemed straightforward or well within their grasp.	“I felt confident in my responses and didn't feel the need to change my answers.”
	Variation in participant trust and reliance on Type I reasoning	Participants varied in how much they trusted and relied on intuitive (Type I) reasoning as a default mode. Some demonstrated habitual dependence on intuition, even in unfamiliar contexts, while others hesitated or sought reassurance when confidence in their intuition was low. These patterns reflect individual differences in monitoring accuracy and regulation of intuitive trust.	“I trust my intuition because I like to think it's relatively reliable and that I have good enough problem solving and social skills to give into my intuition.” “I used Type I thinking. In this case, I allowed personal experiences to influence my decision. Seeing how it has worked in the past, I applied it to the hypothetical situation given to me.”
	Participants use response Speed as a Cue for Type I Sufficiency	Participants used the perceived speed or ease of their responses as a metacognitive cue to judge whether intuitive (Type I) thinking was sufficient for the task. When answers came quickly or effortlessly, they interpreted this as evidence that further analytical reasoning was unnecessary.	“I recognized the type of thinking by determining how quickly I had thought about the question in my head; if it came immediately, I put Type 1; if I had to spend a couple of moments thinking it through, it would be Type 2.” “For me, the speed at which I answered the question was the biggest indication for what type of thinking I was using; if I needed time to think then it was likely Type 2; if an answer came to me with little thinking then it was likely Type 1.”
Intervention group	Participants Monitor and	Participants track their understanding	“I had to think about my initial response when faced with a

participants often demonstrated intentional engagement with Type I and Type II thinking by actively monitoring, describing, and regulating their cognitive processes.	Adjust Thinking Based on Comprehension and Task Cues	and adjust reasoning strategies when they notice complexity, ambiguity, or limits of intuition.	particular question. For instance, if at first glance I could easily interpret the question and answer it off the top of my head, that meant Type I. On the other hand, if I truly had to step back, visualize, and problem-solve in order to come to a conclusion, I believe I used Type II thinking." "I recognized the type of thinking I was using by paying attention to how quickly or slowly I came to an answer. If I had to slow down, work through the problem step by step, or double-check with logic or math, it was clearly Type II."
	Participants Apply Prior Knowledge and Learned Strategies when Engaging with Thinking Types	Participants actively recall and leverage previously learned concepts, rules, or reasoning strategies to guide Type II processing.	"I drew on past practice problems that I have seen many times before and also basic knowledge and understanding from the learning outcomes. This led me to believe my answer was correct because I had just previously seen this answer be the right one, so it had to be correct."
	Participants Engage in Structured and Stepwise Problem-Solving	Participants break down problems into parts, examine components, and follow stepwise or multi-path approaches to work through tasks analytically.	"Critical thinking based on information I knew already and deductive reasoning." "I analysed past relevant information, brainstormed possible answers and outcomes. Each time we resaw the question (e.g., Worksheet 2) I reanalysed the question to seek out alternative answers."
	Participants Use Patterns, Tools, and Cues to Guide	Participants act on internal or external cues, including visual aids, organizational	"I reread the question several times, breaking it into smaller pieces. Often, starting at the end and moving backwards made it

	Intentional Thinking Type Engagement	tools, clarity/obviousness, or recognition of higher-order patterns, to guide or override intuitive responses.	more clear.” “Check if I took note of all factors — make sure I understand each factor — check how each factor affects the other factors.”
	Participants Foster Reflective Type II Engagement to Refine Intuitive based Type I Responses	Participants deliberately engage Type II thinking to check, cross-validate, or refine initial intuitive judgments, supporting self-regulation and accuracy.	“I used all the knowledge I had to either choose answers that aligned with what I knew, or to eliminate the ones that didn’t. I also checked at the end of the question to see if my answer was logical.” “I recalled my original answer, then thought about whether or not that was really the appropriate response. I went over all my options again, and deduced that a different answer would have had a better impact.”
Non-intervention group (specifically General) more often showed limited intentional engagement, often relying on superficial cues or binary interpretations of thinking types rather than deliberate monitoring or regulation.	Participants Engage Type II Thinking Reactively	Participants only switch to analytical (Type II) thinking in response to immediate difficulty, failed intuition, or ambiguity, rather than as a proactive strategy.	“For many of these I had an answer pretty quickly, but when I thought about it, I realized I was incorrect and that the question needed more attention.” “At first I immediately assumed the answer was something (based on a surface-level understanding of the question). But as I paused to reread the question, I switched to Type II to further understand and break down the questions.”
	Participants Demonstrate Limited Metacognitive Monitoring of Reasoning and Thinking Type Engagement	Participants maintain their current thinking mode or switch between Type I and II without clear rationale, showing low awareness or control over cognitive processes.	“I did not switch thinking types for any question.” “From what I remember, I did not switch my answer since I had the same thought process.”

	Participants Default to Type I Thinking	Participants rely on Type I thinking by default, using gut feelings or habitual strategies, either out of comfort, perceived simplicity, or lack of perceived need for reflection.	“All situations that I found I used Type I thinking, I used Type I thinking again and likewise for Type II thinking.” “I honestly don’t remember which math-based ones I marked as Type I, but the familiarity of the questions the second round switched them all to recognize the same question and then picked the answer I chose before.”
Organic participants (Porganic) often engaged in more strategic and flexible Type II thinking, whereas General participants relied more heavily on surface-level or heuristic reasoning.	Participants Engage Type II Thinking for Complex, Multi-Step Tasks	Participants apply analytical reasoning when problems involve multiple components, steps, or increased length/complexity, beyond simple recall.	“For a Type II question, I used strategies like breaking the problem into smaller parts, writing out equations also slowed down my thinking.” “I broke down the question into more manageable pieces of information and analyzed them individually.”
	Participants Justify and Elaborate Responses when Engaging with Type II Thinking	Participants use Type II thinking to provide explanations, elaborate answers, or cross-check intuitions, enhancing accuracy and self-regulation.	“I compared what I’m given to the knowledge I have on the subject and went by process of elimination on how to decipher the right answer based on the information I could provide myself.” “I thought of previous situations I’ve been in that were similar, and considered how my actions then played out. I mapped out what steps I would have to take in order to get to a place where I could start working for an answer.”
	Participants Adjust Thinking Type Based on Uncertainty or Experience	Participants adopt analytical strategies when intuition feels unreliable or prior experience signals that adjustment is	“At first the questions seemed simple, but when I actually thought about it, I realized I needed to spend more time on the question and use a different approach instead of just relying on my intuition.”

		needed, prompting strategic shifts.	
	Participants Shift to Type II Thinking Strategies in Response to Task Demands	Participants transition to Type II thinking when tasks require additional cognitive effort, sustained engagement, or when low effort signals the need to shift processing.	“I first used Type I thinking because the answer seemed obvious, but then switched to Type II to check for other possibilities because the answer seemed too easy.” “I first used the Type I thinking approach, but then I switched to Type II because these were complex questions and I wanted to be sure there was logic behind my answer.”
	Participants Exhibit Less Frequent Self-Monitoring of their Thinking Type	Participants show limited metacognitive regulation, either maintaining their current thinking mode or switching strategies without clear rationale. They rarely evaluate the reliability of their intuitive responses or engage in deliberate, strategic Type II thinking, demonstrating a surface-level approach to problem-solving.	“From what I remember, I did not switch my answer since I had the same thought process.” “I did not switch thinking types for any question.”
	Participants Rely on Confidence and Familiarity as Thinking Type Cues	Participants base decisions on prior experience, repetition, or pattern recognition, using familiarity and subjective confidence as cues for correctness. This often leads to rapid, automatic responses with minimal reflective monitoring,	“These were questions that I initially took a fair bit of time to understand, but the next time answering them I remembered my answer and trusted the logic I used the first time around.” “I just remembered my earlier experience with the questions, read them and realized they are the same. Then just said what I said earlier.”

		even when deeper analysis could improve accuracy.	
While both groups engaged in Type I thinking, the Organic group demonstrated greater metacognitive regulation by questioning initial intuitions and verifying reasoning against knowledge, whereas the General group tended to maintain intuitive responses without systematic reevaluation.	Participant Strategically Transition from Type II to Type I Thinking	Participants shift from Type II to Type I thinking when task simplicity, perceived ease, or realization of overthinking allows them to rely on intuition, reflecting a deliberate, self-regulated adjustment.	"I started to analyze the scenario but then realized that it is something that should be an intuitive decision and switched thinking styles"
	Participants Rely on Experiences and Confidence to Guide Unmonitored Type I Engagement	Participants rely on Type I thinking when high confidence, prior experience, repetition, or reflection on past situations signals that intuitive responses are likely accurate, supporting rapid, automatic decision-making.	"I felt confident in my responses and didn't feel the need to change my answers."
	Reliance on Familiarity and Surface Cues to Guide Unmonitored Type I Engagement	Participants rely on Type I thinking when questions are familiar, straightforward, or contain superficial cues, or when gut feelings guide rapid responses, allowing effortless decision-making without deeper reflection.	"The problem looked simple, so I answered immediately without breaking it down or thinking it through in detail." "I relied on my gut feeling because the question seemed familiar and straightforward, so I didn't pause to check my reasoning."

A1.11 Accuracy Rubric

This section outlines the rubric used to assess the accuracy of participants' metacognitively ability to describe the thinking types engaged during the study.

Table 2. 4-point accuracy rubric scale used to measure participants' metacognitive depth.

Level	Level Descriptor	Potential Indicators	Notes for Scoring
4 – Sophisticated/ Accurate Description	Participant demonstrates that: Type I/II are context-dependent and can interact dynamically Speed/familiarity alone does, not determine thinking type, but also depends on task demands, understanding of the limits of their own skills, or need for verification	Mention checking/verifying initial response Recognizes that familiarity can mislead intuition Notes contextual/situation triggers for transitioning b/w thinking types References monitoring or control of thought process (e.g., “I slowed down because I wasn’t sure”)	Level reflects metacognitive calibration, fast ≠ Type I. Level describes when a participant describes why they shows awareness of their cognition, including what they know and don’t know, and when to compensate through Type II. Their identification of thinking type reflects both task features (e.g., complexity, ambiguity) and self-awareness of their confidence or limitations.
3 – Partially Accurate/Procedural Understanding	Participant identifies thinking types primarily by observable cues (e.g., time, familiarity, rule of thumb) but shows some awareness of underlying reasoning demands (e.g., analytical effort, logical steps). However, they do not appear to question whether their intuitive reasoning was appropriate or accurate.	Mentions slowing down because a question was complex or using a rule/approach they have previous experience with No reflection on potential for intuition to mislead them Limited or missed recognition on whether task content would require a shift in thinking type Mention of need for verification	Participant correctly labels their thinking type and use of the framework definition but provide limited insight beyond this, with minimal insight into reasoning or metacognitive regulation involved.
2 – Superficial Description	Participant associates Type I/II only with speed, familiarity, or effort level. Lacks	Example statements: “If I answered quickly, it was Type	Shows surface-level recall of definitions. No evidence of metacognitive

	explanation of reasoning processes or awareness of context-dependence	I" "If it felt hard, it was Type II" "Type II because I had to think longer"	monitoring or self-evaluation. No mention of double checking or questioning their response/approach
1 – Misconception or misidentification	Participant's explanation contradicts the Type I/II framework or misapplies concepts. They may assume Type II = correct or Type I = incorrect, or confuse them	Example statements: "Type I is better because I knew the answer right away" "Type II when I was unsure" Equates correctness or confidence with thinking type	When an explanation shows misunderstanding of what distinguishes the processes (i.e., attributes are reversed, or evaluation conflates thinking type with outcome accuracy
0 – No evidence/Irrelevant or non-response	Response does not provide enough information to code or is unrelated to the prompt	E.g., "I just guessed", "I don't know"	

A1.12 Statistical Analysis Table

Table 3. Mapping research questions and hypotheses to statistical analyses.

RQ/Hypothesis	Dependent Variable(s)	Statistical Test / Model	Assumptions	Assumptions Met?
RQ1/H1	Accuracy scores (binary Y/N) according to rubric	GLM for binary accuracy scores; Linear Mixed Model for accuracy scores (binary Y/N) according to rubric	GLM assumptions for binary outcomes: correct link function, independence, no multicollinearity. LMM assumptions: normality of residuals, homoscedasticity, linearity, independence conditioned on random effects, correct random-effects structure	Assumptions acceptable. No evidence of singularity, justifying removal of random effect (LMM assumptions acceptable).

RQ2/H2	Type II proportion scores	Linear Mixed-Effects Model (LMM): Type II proportion by Discipline × Intervention	Model specification; normality of DV and residuals; homoscedasticity; linearity; independence of observations; sufficient residual convergence	Assumptions acceptable.
RQ3/H3	Type II proportion according to accuracy scores (binary Y/N)	Same as RQ1/RQ2	Same as RQ1/RQ2	Same as RQ1/RQ2