Universidad del Desarrollo
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EXPLORING THE ROLE OF THE FACETS OF METACOGNITION IN THE LEARNING PROCESS OF UNDERGRADUATE STUDENTS

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Thesis presented to the Faculty of Psychology of the Universidad del Desarrollo to opt for the academic degree of Doctor in Developmental Science and Psychopathology

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April 2024

SANTIAGO

ACKNOWLEDGEMENTS

To my thesis advisor, Gabriel Reyes, for teaching me what I know about research. May this thesis serve as proof that I really listened to you. And to my thesis committee, especially Dr. Sackur, for your valuable insights throughout the development of this thesis.

To Tania Valdés, Martín Castro, and Franco Medina for making these years less boring, and also for your help and support, and to Pilar Valenzuela for surviving the chaos of the first Metaeduca project with me. Also, to my colleagues at CogSci Lab, so that they don't call me ungrateful.

Also, to all the people who contributed in one way or another so that I could finish this thesis because, for better or worse, I wouldn't have gotten so far without you.

Finally, to the Centro de Innovación Docente of Universidad del Desarrollo for financing the two studies that make up this thesis, and to Rocío Vélez and Diana Muñoz for your help during both projects. And last but not least, to the Chilean National Research and Development Agency (ANID) for the financing granted through the National Doctorate Scholarship N°21211819.

Thank you. I owe you one.

ABSTRACT

Metacognition is the human capacity to monitor and control our own psychological activity. This capacity is fundamental for several processes that involve the individual being aware of this activity, e.g., learning. Building on a substantial body of theory, metacognition is recognized as one of the main components of learning and a key predictor of academic performance. Despite its acknowledged significance, the literature in the area has yet to explore the specific aspects of metacognition that explain all these relationships. Metacognition is not a unidimensional construct but rather a construct with three facets: knowledge about our own cognitive processes (metacognitive knowledge, MK), real-time monitoring and reflection on these processes (metacognitive experiences, ME), and the regulatory strategies we use to control them (metacognitive skills, MS). In light of empirical evidence highlighting the differences between these facets and their differential role over other processes, the relevance of investigating the individual and collective roles of the facets of metacognition in the learning process becomes apparent. To address this gap, we conducted two original studies. Our first study explores how MK, ME, and MS influence associative learning and academic performance in a sample of undergraduate students. The results show that, while academic performance is related to all facets, associative learning only depends on the quality of the individual's ME. A mediated effect of MK on learning through ME and a moderating effect of the use of MS on the relationship between ME and learning are also observed. Our second study investigates the impact of MK and ME on problem-solving skills within a collaborative context. While the results did not corroborate the main objective of the study, valuable insights were gained regarding the influence of ME on the use of collaborative strategies in the classroom. In summary, our studies affirm the idea that the facets of metacognition play different roles in the learning process and offer valuable information into their relationships within educational contexts.

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LIST OF ABBREVIATIONS

2-AFC	–	Two-Alternative Forced Choice
AILI	–	Awareness of Independent Learning Inventory
MAI	–	Metacognitive Awareness Inventory
ME	–	Metacognitive Experiences
Meta-d’	–	Metacognitive Sensitivity
MK	–	Metacognitive Knowledge
MS	–	Metacognitive Skills
PS	–	Problem-Solving
SRL	–	Self-Regulated Learning

CHAPTER 1. GENERAL INTRODUCTION

‘‘*Without insight into the psychological structure and activities of the individual, the educative process will, therefore, be haphazard and arbitrary*’’ (John Dewey, 1897).

1.1. Introduction

The beginning of the 20th century witnessed rapid social changes and an expansion in both science and technology that showed the need to rethink the field of education. In this context, modern psychology, still in its infancy, saw in education an opportunity to make contributions that would have a meaningful impact and aid in its validation to the scientific community. Prominent psychologists of that time, such as Cattell, Dewey, Thorndike, Woodworth, and Spearman, proposed the first theories and built the first instruments to study the cognitive processes underlying learning in experimental contexts (for a review, see Hall, 2003).

As the century progressed, research into the learning process was influenced by changes in how psychology viewed itself. After a period characterized by the predominance of explanations based on stimuli and responses, psychology pivoted and once again affirmed the importance of studying cognitive processes, giving new strength to a construct that has been present since near the beginning of the discipline: the study of the subjective awareness of these processes (Baker & Brown, 1984). This construct – which today we call metacognition (Flavell, 1979) – has been recognized as an important aspect of learning since the turn of the century (e.g., Dewey, 1910/2018; Huey, 1908/2013; Thorndike, 1917). Although its position in psychology was threatened due to controversies related to the effectiveness of its study (Sackur, 2009), authors such as John

Flavell, Henry Wellman, and Ann Brown brought it back to the fore, placing "the active, knowledgeable, reflective learner at the centre of any adequate understanding of how learning, memory, and thinking work" (Reynolds & Wade, 1986, p. 307).

Once considered the panacea for problems in instruction and learning (Jacobs & Paris, 1987), the link between what we understand today as metacognition and education began in the late 1970s, emerging from the interest in training children who showed deficiencies in the learning process in the use of cognitive regulation strategies (Brown & Barclay, 1976). According to a 1990 meta-analysis, which followed several years of work and the accumulation of evidence in both cognitive and educational sciences, metacognition is one of the best predictors of learning and academic performance in students, even above other influential factors such as the student's cognitive and affective development, the quality of their family environment, or the classroom climate and school culture (Wang et al., 1990).

Since then, every year, new studies have been added to the corpus of evidence supporting the role of metacognition in learning and describing new strategies and programs to incorporate metacognition into school curricula and in the classroom (Perry et al., 2018). A vast body of literature indicates that students with high metacognitive capacity are better learners than their peers (Donker et al., 2014). The evidence supporting the positive effects of high metacognitive ability in the classroom is so extensive that international organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) or the Organization for Economic Co-operation and Development (OECD) recognize its importance and promote its training in educational contexts (OECD, 2019; UNESCO, 2013).

Despite this important theoretical and empirical framework, however, the relationship between metacognition and learning is unclear. Baker and Brown (1984) and other more recent authors (e.g., Boldt & Gilbert, 2022; Craig et al., 2020; Fleur et al., 2021; Tarricone, 2011; Veenman et al., 2006; Winne & Azevedo, 2014) agree that the term metacognition has traditionally been used to refer to two separate, although somewhat related, phenomena such as the monitoring of cognition and the regulation of cognition. Starting from this common point, numerous taxonomies have proposed different components and processes that derive from or accompany both phenomena (see Peña-Ayala & Cárdenas, 2015). The ever-increasing number of these "subcomponents of metacognition" added to the constant appearance of new methods to measure these subcomponents have made it difficult to systematize what we know about the influence of metacognition on the learning process (Veenman et al., 2006). In addition to this, and as might be expected, evidence in recent years shows that the relationship between metacognition and learning depends on what we call metacognition and how we evaluate it (Dent & Koenka, 2016; Ohtani & Hisasaka, 2018; van der Stel & Veenman, 2010). This raises a number of questions in the discipline, such as can we generalize the findings made using a set of metacognition tests? How can we evaluate the effectiveness of metacognition interventions in educational contexts? Or the question that motivates this thesis, what is the influence of metacognition – and/or its components – on the learning process?

To answer this question, we will take the three-facet model proposed by Anastasia Efklides (2006a, 2008)[1] as a reference framework to define the components of metacognition. This model decomposes the monitoring of cognition into two facets: metacognitive knowledge and metacognitive experiences, which represent offline and online monitoring of cognition, respectively. Meanwhile, it identifies a third facet in the regulation of cognition: metacognitive skills. The two scientific articles that comprise the bulk of this work emphasize studying how metacognitive knowledge, metacognitive experiences, and metacognitive skills are related to learning and problem-solving skills in undergraduate students. Both studies also address secondary questions, such as the relationship between the facets of metacognition and their relationship with other relevant processes in the classroom. For its part, this chapter will introduce the theoretical

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[1] To clarify, although there are other theoretical models with three facets, or components, e.g., Dunlosky & Metcalfe (2009) or Pintrich et al. (2000), throughout this thesis and in the articles that compose it, the names proposed by Efklides (2006a) will be used to describe metacognition's functions and components.

framework on which this work is built. It will begin with a brief review of the history of the study of metacognition in psychology and with a description of the taxonomy of metacognition that will be used in this thesis. Next, it is time to talk about the role of metacognition in the learning process, for which the main findings that cognitive and educational sciences have contributed to the knowledge of this topic will be synthesized. The rest of the chapter continues with the presentation of the theoretical and methodological problem that has plagued metacognition since its inception and the effect of this problem on what we know about the relationship between metacognition and the learning process. A general review of the objectives developed in the following chapters of this thesis concludes the chapter.

1.2. Towards a definition of metacognition

The study of metacognition, also known as “cognition about cognition” (Flavell, 1985, p. 104), has a long history in both philosophy and psychology (Lyons, 1986). Understood as the monitoring and control over one's own mental processes (Flavell, 1979), the construct we call metacognition originates from the convergence of at least two lines of research with important theoretical backgrounds, such as the study of cognitive monitoring and self-regulation of learning (Brown et al., 1983).

Although it is possible to trace the origins of the study of cognitive monitoring in psychology to authors such as William James (1890/2016), Charles Spearman (1927/2021, pp. 52-53), or Lev Vygotsky (1934/2020, p. 90), the formal study of this concept only began during the cognitive renaissance in the late 1950s and early 1960s[2] (Bruner et al., 1956; Miller et al., 1960). This movement, which emerged as a response to behaviourism, once again put the notion of mind and cognitive processes in the focus of

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[2] It is important to note that the cognitive renaissance – or cognitive revolution - was not a global event but was mainly confined to American psychology. The cognitive renaissance "was a non-event from a European perspective because psychology there had never gone behaviorist in the first place" (Brock, 2013, p. 35).

study in psychology (Miller, 2003). In this context, different researchers were interested in creating models that explained mental processes and how we relate to them, i.e., how we know about our own cognitive processes, how much we know about them, and what we do with that knowledge (Lyons, 1986).

One of the first attempts to subject how we know our own cognitive processes to experimental scrutiny was carried out in 1965 by Joseph Hart (Dunlosky & Metcalfe, 2009). Hart (1965), then a doctoral student at Stanford, studied feeling-of-knowing (FOK) experiences. These are a particular memory phenomenon; understood as an individual's belief that they know certain information despite not being able to retrieve this information from their memory. Hart (1965) set out to evaluate whether these beliefs are precise indicators of the real contents of a person's memory, seeking evidence of a self-monitoring mechanism over it. To this end, he applied a single-answer general information questionnaire to a group of individuals and instructed that if they did not know the correct answer, they were to judge whether they believed they could identify the correct answer from a list of options. Finally, to evaluate the accuracy of these judgments, the participants had to answer a second questionnaire with the same questions they could not initially answer, but this time with multiple-choice questions. The results showed that performance on the multiple-choice questionnaire was better when participants had prospectively indicated that they believed they could identify the correct answer from a list of options than when they thought they could not. These results revealed that people could effectively monitor the contents of their own memory, even if they could not retrieve them.

These findings, on what Hart (1967) would call the 'memory monitoring' process, constituted a turning point in memory studies at the time and were considered by some to be the future of the discipline (Tulving & Madigan, 1970). In the ensuing years, different authors focused on the experimental study of similar phenomena related to memory monitoring and learning. In this way, studies appeared that addressed at an experimental level phenomena such as the sensation of having a word on the "tip-of-the-tongue" (or

TOT states[3], Brown & McNeill, 1966), the ability to judge how easy or difficult it will be to learn something - or ease-of-learning judgments (EOL; Underwood, 1966) - and the ability to prospectively evaluate how well something has been learned - or judgments of learning (JOL; Arbuckle & Cuddy, 1969). All of these studies confirmed Hart's (1965) original findings: that individuals can monitor their own cognition and that, although this ability is far from perfect, their objective performance is above the chance level. In Hart's own words (1967, p. 196), "when people feel that they know something, it is very likely that they do know it, and when they feel that they do not, it is likely that they do not."

On the other hand, in 1971, Juola et al., in a study on how individuals can recover information from their memory, found a result indicating that memory monitoring is not a simple scanning of it but a separate process. Specifically, Juola et al. (1971) found that individuals can correctly answer that they do not know something in less time than it would normally take them to complete the search for that information in their memory. This finding, later confirmed by Kolers and Palef (1976) and others, confirmed the hints that memory monitoring was not a subprocess of - or a type of - unconscious manifestation of memory, but a process that acts in parallel.

While these findings were made in cognitive psychology in adults, developmental psychologists followed a similar line, studying the development of cognitive processes in children (Daehler et al., 1969; Hagen et al., 1970). One of the psychologists who stood out in this period was John H. Flavell, known at that time for having translated the works of Jean Piaget into English and for compiling his work in the book Developmental Psychology of Jean Piaget. Inspired by the latter's work on self-regulation in children, Flavell et al. (1966) fortuitously stumbled upon the discovery of a phenomenon that, together with cognitive monitoring, would be the cornerstone in the development of metacognition as a line of research. While attempting to study children's use of private

3 Although the study of this phenomenon was not something new in psychology, having been originally described by William James in his work Principles of Psychology (1890/2016, pp. 251-256) and studied by Woodworth (1934), the pioneers in the empirical research on this topic were Brown and McNeill in 1966.

speech through a memory-based experimental paradigm, Flavell et al. (1966) discovered that kindergarteners retrieved fewer words during the memory task than second and fifth-grade children and that, compared to them, they also presented less spontaneous verbal production during the task. The researchers noted that older children used verbalization to self-regulate their own learning, i.e., to help improve their ability to remember words. Of relevance, these children were not only aware of their use of this strategy but also of the purpose they gave it.

Contemporary research continued to delve into the use of verbalization as a strategy to improve children's performance on memorization tasks (Keeny et al., 1967; Kingsley & Hagen, 1969; Hagen & Kingsley, 1968), until, in 1970, Flavell et al. identified that the use of self-regulation strategies is related to the ability to self-monitor memory. In a study conducted with 84 children from kindergarten to fourth grade, Flavell et al. (1970) showed that older children were capable of using relatively complex memorization strategies and that, compared to younger children, they were better at predicting their memory capacity and determining when they had memorized a list of words well enough to be able to recall it later. In practice, these findings suggested that learning - in this case, of a list of words - was predicted by the correct use of learning strategies, which, in turn, was closely related to the knowledge and awareness that learner children had regarding how their own memory worked or, as Tulving and Madigan described it a few months earlier, "knowledge of their own knowledge" (1970, p. 477). This was the first empirical confirmation that cognitive monitoring and self-regulatory learning strategies might be related.

This narrative reached its culmination at a symposium organized by the Society of Research in Child Development in 1971. In this setting, John Flavell coined the concept of metamemory[4], which would define the nature of memory research in the years to come

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[4] As we will also see later, in the 1960s and 1970s many "metas" emerged (Brown, 1978; Flavell, 1976), i.e., neologisms that incorrectly used the prefix meta (from the Greek μετά, after) before a word as a form of "elevate the original meaning of such a word to a higher, more abstract philosophical level" (Thomas, 1984, p. 16).

(Ornstein & Haden, 2001) and would mark the starting point of the formal study of metacognitive processes in psychology (Dunlosky & Tauber, 2016). Metamemory - today defined as a part of metacognition (Rhodes, 2019) - was first defined as the different storage and retrieval strategies an individual uses, in addition to the intelligent monitoring and knowledge of these strategies (Flavell, 1971). This concept synthesized the work of recent years and, for the first time, gave the field of study of metacognition its own name and voice (Dunlosky & Tauber, 2016).

It is important to highlight that although the literature on metacognition seems to have placed greater emphasis on its relationship with metamemory, the study of metacognition also finds precedents in other works (Mayor et al., 1995). At the same time, in psychology, education, and linguistics, different lines of work were formed interested in the study of knowledge about and monitoring of other cognitive processes and in how these skills developed in childhood (Brown, 1978). Thus, in the 1960s and 1970s, the foundations were laid for research into the constructs that we know today as meta-communication (Watzlawick et al., 1967/2011), meta-attention (Loper & Hallahan, 1982; Miller & Bigi, 1979), and meta-learning (Biggs, 1985), to name a few.

In 1972, Gleitman et al. captured this *zeitgeist* and synthesized it in a single word: metacognition. Gleitman et al. (1972) - who at that time studied the development of grammatical reasoning (i.e., metalinguistic knowledge) in children - coined the concept of "meta-cognition" and referred for the first time to "meta-cognitive" processes to refer to a series of higher-order psychological processes that have as their object other cognitive processes, such as memory or language, "as if the homunculus perceived the operations of a lower-order system" (p. 161). This way, metacognition would be expressed as a conscious reflection[5] on other lower-order processes.

[5] Importantly, the discussion about whether the occurrence of metacognitive activity requires conscious awareness or not has extended from the origin of the concept to the present (Lau & Rosenthal, 2011). Although its relevance to the literature in the area is greater, its discussion is beyond the scope of this thesis.

However, the appearance of this concept went unnoticed until a few years later, when Flavell took it up again and offered us its first formal definition. In a brief chapter entitled *Metacognitive aspects of problem solving*, Flavell (1976) describes the relevance of metacognition in intelligent behaviour and problem-solving. In it, Flavell defines metacognition as "one's own knowledge concerning one's own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data" (p. 232), to add a few lines below that "metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data in which they bear" (p. 232). According to the author, metacognition acts as a source of executive control that allows the individual not only to determine how, where, and when to use the strategies available to face a certain problem but also allows them to know about these strategies.

Flavell's definition collects the main lines of research of the time, i.e., the study of cognitive monitoring and self-regulation of cognition. It presents them as the primary functions of a single psychological construct. This idea represents a central point for the literature, which has been largely respected over the years and which is still considered relevant today (Boldt & Gilbert, 2022; Craig et al., 2020; Fleur et al., 2021; Tarricone, 2011; Veenman et al., 2006; Winne & Azevedo, 2014).

In perspective, attempts to develop a taxonomy of metacognition began with Flavell (1979), who described the aspects that make up the monitoring of cognition, and with Brown et al. (1983), who proposed a bifactor model that incorporates the regulation of cognition. This last model would be complemented in the following years by Paris et al. (1984) and by Schraw and Dennison (1994, Fig. 1a), who incorporated new subcomponents within each factor. Later, in the early 1990s, a new model of metacognition would appear, this time proposed by Nelson and Narens (1990). This model (Fig. 1b) moved away from the hierarchical models that preceded it to describe metacognition as a dynamic process that arises from the interaction between two levels of cognition: an object-level and a meta-level. Thus, the functions of metacognition are manifested through communication between both levels: monitoring occurs when the meta-level receives information from the object-level, while control – or regulation – occurs when the meta-level modifies the object-level.

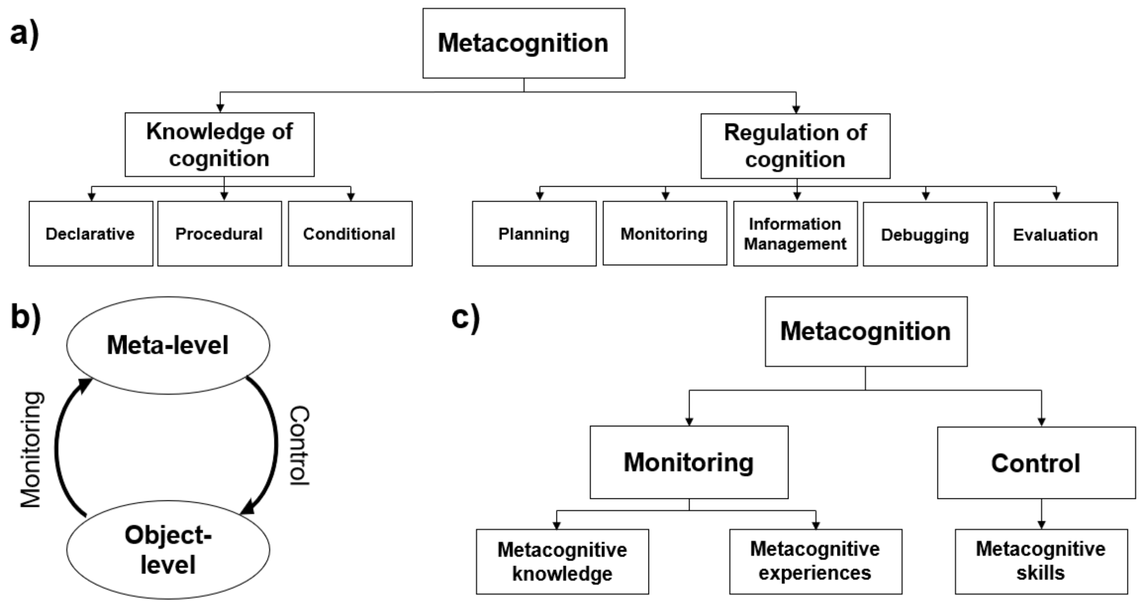

Fig. 1. (a) Hierarchical model of metacognition with two components and eight subprocesses, proposed by Schraw and Dennison (1994). This model extends the models previously proposed by Brown (1978) and Paris et al. (1984). (b) Dynamic model of metacognition proposed by Nelson and Narens (1990). (c) Extract from the multifaceted metacognition model proposed by Efklides (2008).

Today, metacognition models are based on the ideas of Flavell (1979), Brown et al. (1983), and Nelson and Narens (1990) to explain metacognition as a hierarchical but, at the same time, a dynamic phenomenon, with two main functions and some subcomponents, which interact and constantly give feedback to each other. Based on this, in recent years, three facets of metacognition have been proposed (Dunlosky & Metcalfe, 2009; Efklides, 2006a, 2008; Pintrich et al., 2000): *metacognitive knowledge*, *metacognitive experiences*, and *metacognitive skills* (Fig. 1c).

Metacognitive knowledge (MK) corresponds to a person's declarative knowledge about their own cognitive abilities, the different tasks they can face, and the strategies they can use to solve them (Flavell, 1979). This knowledge is composed of facts, beliefs, and episodes, retrieved thanks to long-term memory, and have their origin in personal experiences, interaction with others, and in the individuals' own culture (Dunlosky & Metcalfe, 2009; Heyes et al., 2020). The MK has two main characteristics: (1) it can contain false or useless information, a product of distortions in memory or unreliable introspections (Lehmann et al., 2022; Norman, 2020), and (2) it is accessible by the conscious experience of the individual and declarable, which means that it is possible to evoke it and communicate it verbally or non-verbally (Squire, 1986). Due to the above, MK has been studied mainly through self-report questionnaires, which evaluate individuals' beliefs regarding various aspects of their cognition (Craig et al., 2020). Notable in this area are the Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994), a questionnaire that evaluates individuals' beliefs regarding their monitoring and self-regulation, and the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich & de Groot, 1990), which assesses metacognition, use of strategies and motivation. Both questionnaires were designed to be used in educational contexts and have been translated and validated in different languages (Roth et al., 2015). Given how easy it is to administer these instruments and the possibility of being applied to large groups of students simultaneously, MK has been widely investigated in ecological studies, mainly by educational psychologists (Veenman, 2011).

For their part, metacognitive experiences (ME) correspond to the judgments and sensations that emerge in an individual about a cognitive activity being carried out at this moment (Flavell, 1979). While MK represents offline monitoring of cognitive activity, since it is not necessarily connected to concurrent cognitive activity, ME represents online monitoring of cognition (Dunlosky & Metcalfe, 2009). Both forms of monitoring are linked through a feedback loop: while MK feeds the ME, the latter provides information that allows the former to be updated (Efklides, 2008; Lehmann et al., 2022). Like MK, ME can also present errors, which can be caused by external factors such as stress (Reyes et al., 2015), drugs (Hauser et al., 2017), the social context (Gajdos et al., 2019), and/or by internal factors such as cognitive overload (Meier & Zimmermann, 2015; although cf., Peng & Tullis, 2021). Regarding their evaluation, ME have been studied mainly by cognitive psychologists through behavioural tasks carried out in laboratories that seek to provoke judgments and/or sensations in an individual regarding their own mental activity (Lai, 2011). These judgments and/or sensations manifest themselves as feelings of knowing (Nelson, 1984), confidence judgments (Fleming, 2023), or learning judgments (Jang et al., 2020), among others, or they can be inferred from the direct verbal report of the individual (Ericsson & Simon, 1980). Since these experiences do not necessarily represent the individual's actual ability[6], ME are typically contrasted with an objective measure of ability, such as performance, which has given way to the use of objective measures of an individual's ME, such as metacognitive accuracy (Nelson, 1984) or metacognitive efficiency (Fleming & Lau, 2014).

Metacognitive skills (MS) encompass the deliberate strategies employed by students to regulate their cognition in pursuit of specific learning objectives (Efklides, 2008; Tarricone, 2011). These skills have been associated with executive functions (Fleur et al., 2021; Marulis et al., 2020; Roebers, 2017), however, their relationship, remains a subject of ongoing debate and exploration within the academic literature (Bryce et al., 2015). MS are interconnected with other facets of metacognition, as an individual's set of MS is shaped by their MK, while the deployment of these skills is triggered by both MK and ME (Efklides, 2008, 2009; Metcalfe, 2009). Inexperienced students may struggle with using these strategies in demanding tasks due to the cognitive demand related, whereby,

[6] We shall refer to the tendency of an individual to overestimate or underestimate their performance on a task independent of their actual performance on it as *metacognitive bias*. Recent studies show that this bias is positively related to measures of MK (Lehmann et al., 2022).

experienced students can benefit more from MS use (Dignath & Büttner, 2008). Educational and cognitive psychologists have explored MS through online methods, including observation protocols and behavioural tasks that analyse the real-time utilization of these strategies (Pintrich et al., 2000; Undorf et al., 2021). While certain offline instruments are available, it can be argued that they primarily evaluate declarative knowledge rather than the actual utilization of metacognitive strategies (Brown et al., 1983; Pekrun, 2020; Preiss et al., 2016). For clarity, Table 1 shows how these three facets of metacognition manifest in the human experience.

Table 1

The facets of metacognition and their manifestations as a function of monitoring and control. From Efklides (2006a, p. 4).

Monitoring		Control
Metacognitive knowledge	Metacognitive experiences	Metacognitive skills
Ideas, beliefs, 'theories' of	Feelings	Conscious, deliberate activities and use of strategies for
Person/self	Feeling of familiarity	Effort allocation
Task	Feeling of difficulty	Time allocation
Strategies	Feeling of knowing	Orientation/monitoring of task
Goals	Feeling of confidence	requirements/demands
Cognitive functions	Feeling of satisfaction	Planning
Validity of knowledge	Judgements/estimates	Check and regulation of cognitive
Theory of mind	Judgment of learning	processing
	Source memory	Evaluation of the processing outcome
	information	
	Estimate of effort	
	Estimate of time	
	Online task-specific	
	knowledge	
	Task features	
	Procedures employed	

This metacognition model is anything but static, with new concepts and operationalizations of the described facets appearing every few months. Despite this, metacognition is still the subject of study of many areas of psychology, highlighting among them, for their production and impact, educational psychology (Norman et al., 2019). In this next section, a brief review about the study of metacognition in educational psychology will be presented with a focus on the main subject of this thesis, the relationship between metacognition and learning.

1.3. Metacognition in the learning process

In tracing the evolution of the relationship between metacognition and learning, it is pivotal to delve into the early perspectives of influential psychologists. As previously stated, the first mentions of the relationship between metacognitive processes - introspective, at that time- and learning in psychology precede the coining of the concept of metacognition by almost 60 years. John Dewey (1910/2018) and Edward Thorndike (1917), for example, described the relevance of what today we would call MS, during the learning of reading and writing. A few years later, Lev Vygotsky described the role that reflective cognition and intelligent, volitional control over attention and memory processes - i.e., what we today call meta-attention and metamemory - play in the early years of school life (1934/2020).

However, it was not until the 1960s and 1970s that metacognition, as such, would break into cognitive and educational psychology. In this period a major shift occurred in psychology with respect to the way it approached the study of learning. After a period characterised by an emphasis on the environmental characteristics that shape the learning process, according to which the learner is essentially a passive organism responding to these external influences (Munn, 1954), there was a return to the study of the individual characteristics of the learner involved in this process or, in the words of Baker and Brown, a shift towards "the learner's side of the learner - environment equation" (1984, p. 5). As a result of European and Soviet influence, and the work of Bruner and Flavell, the lion's share of attention migrated towards the learning strategies used by school children.

During this pivotal period, researchers like Flavell studied students' use of various self-regulatory learning strategies, along with knowledge and control over that repertoire, i.e., metacognition (Flavell et al., 1970). Influenced by this work, Brown drew attention to the "deficiencies" in the use of self-regulatory strategies that may be at the basis of learning problems (Brown & Barclay, 1976). During her work, Brown argued for the importance of designing interventions to improve children's metacognitive skills and of studying metacognition with students in natural contexts (Baker & Brown, 1984; Brown, 1975). This work plus the growing interest in understanding the contribution of metacognition to learning (Paris & Winograd, 1990b; Wang et al., 1990), led educational psychologists of the time to become interested in making the learning process in the classroom more "metacognitive" (Derry & Murphy, 1986).

Concomitant with the shift from teacher-centred to student-centred education, self-regulated learning (SRL) models gained greater preponderance in the study of this association (Chen & McDunn, 2022; Low & Jin, 2012). According to SRL models, a student's ability to attain their learning goals depends on metacognitive, behavioural, cognitive, and motivational/affective processes (Panadero, 2017). At the core of SRL are four main phases: planning and goal-setting, monitoring, control, and evaluation (Low & Jin, 2012). Monitoring is enabled by both MK and ME which enable individuals to assess their understanding and identify the challenges along the learning path. Planning, control, and evaluation are facilitated by MS that allow the individual to plan strategies according to their own capacities, select and employ appropriate solutions for the challenges ahead, and to evaluate the results and update their MK based on the effectiveness of the approaches employed (Efklides & Metadillou, 2020). In essence, metacognition is an indispensable scaffold within SRL models (Winne & Hadwin, 1998). Because of its relevance, metacognition and SRL have often been mistakenly used as synonyms in the literature (Dinsmore et al., 2008; Pintrich et al, 2000). In addition, metacognition serves as a mediator in the way in which students approach the content they seek to learn (Efklides, 2011; Pintrich, 2000).

Similarly, research highlights the role of metacognition during problem-solving (PS). In this sense, theoretical models such as the Metacognitive Activity during Problem-Solving Model proposed by Goos et al. (2000) suggest that metacognition is relevant in the different stages of PS. Before solving a problem, individuals assess their knowledge regarding the problem and the strategies available for its resolution (i.e., they draw on their problem-specific MK). During PS, individuals monitor their progress and try to identify and correct their errors by using appropriate strategies (i.e., they draw on their MK and MS). Finally, after PS, individuals evaluate their use of strategies and the results obtained from them.

The interest in studying the relationship between metacognition and learning has attracted the attention of cognitive and educational psychologists alike. In its own way, each discipline has been interested in particular questions related to this topic. While cognitive psychologists have sought to understand the mechanisms that explain this relation, educational psychologists have concentrated on how to improve learning through metacognition (Koriat, 2007). The first studies in both areas appeared in the 1980s (e.g., Babbs & Moe, 1983; Baird, 1986; Baker, 1982). Some years later, Wang et al. (1990) made one of the first attempts to synthesize these findings. In a literature review that included 179 studies on the factors that influence learning, Wang et al. identified metacognition as the individual variable that best predicted learning over other cognitive, motivational, or psychomotor variables. More recent studies have shown that these results continue to be valid. Specifically, Donker et al. (2014), in a meta-analysis of 58 papers on the topic, presented evidence that metacognition, and in particular MS, are among the best predictors of learning on a list that covered more than 20 aspects related to this topic. Other recent meta-analyses have also supported this relation (de Boer et al., 2018; Dent & Koenka, 2016).

Along the same line, other studies have shown that metacognition could be a better predictor of learning than even the individual's own intellectual capacity (Ohtani & Hisasaka, 2018; Veenman & Beshuizen, 2004). For example, in 2004, Veenman and Beishuizen showed that in the case of novel contents metacognition explained almost ten times more variance in learning than did intelligence. Similarly, Ohtani and Hisasaka (2018) showed in a meta-analysis on 118 studies that the metacognition-learning relation continued to be significant even if the effect of intelligence on learning was controlled.

The studies in which both disciplines have contributed to the understanding of the metacognition-learning relation do not end there. Indeed, several studies have addressed this relation on at least three different levels. First, the influence of metacognition on academic learning in different subjects such as history (Poitras & Lajoie, 2013), foreign languages (Raoofi et al., 2013), and STEMs (Dori et al., 2018). Second, the relation of metacognition with forms of learning in specific contexts. In this aspect, there are studies on the influence of metacognition on learning through digital media (Devers et al., 2018), learning without external feedback (Hainguerlot et al., 2018), social learning (Heyes et al., 2020), and SRL (Panadero, 2017) among others. Finally, how metacognition predicts the development of other academic abilities such as mathematical reasoning (van der Stel & Veenman, 2010), linguistic abilities (Haberkorn et al., 2014), problem-solving skills (Metcalfe & Wiebe, 1987), and the transfer of learning (Paris & Winograd, 1990a).

However, in spite of the wide knowledge about how metacognition and learning are related, most of these studies obtained their results from the use of different instruments to evaluate both variables (Veenman et al., 2006), which leads each one to use their own conceptualizations and operationalizations. The root of this problem, as well as its implications for educational psychology, will be discussed below.

1.4. A multi-faceted problem

1.4.1. *A theoretical problem*

The defining problem of metacognition is also conceptualised as a structural problem of the psychological discipline. According to Brown et al. (1983), in metacognition four independent, although interrelated, historical problems of psychology converge: (a) the status of verbal reports as sources of information, (b) the notion of executive control borrowed from information processing models, (c) the self-regulation processes during learning, and (d) the transition from other-regulation to self-regulation. The treatment of the first of these problems led to what we know today as metacognitive monitoring, whereas the other three gave rise to the function we call metacognitive control (Bråten, 1991; for more details, see section 1.2).

On the other hand, although also related to the above, since its formalisation in the second half of the 1970s and up to the present day, the study of metacognition has spread from developmental, cognitive, and educational psychology to other areas, such as comparative psychology (Smith et al., 1995), social psychology (Frith, 2012), clinical psychology (Wells, 1995, 2011), neuropsychology (Hauser et al., 2017), and cognitive neurosciences (Baird et al., 2013; Fleming et al., 2010). Each of these disciplines took an interest in different aspects of metacognition and used them to construct new theories, concepts, definitions, and measuring instruments (Norman et al., 2019).

The number of theoretical influences in metacognition and the diversity of the disciplines that study it have made defining metacognition difficult. Brown et al. (1983) illustrated this situation early by saying that metacognition is "not only a monster of obscure parentage but also a many-headed monster at that" (p. 137). Every year, new heads spawn from the neck of this hydra, and others more threaten to be born, thanks to the ever-growing number of publications that describe new - and difficult to reconcile with each other - components, mechanisms, subprocesses, and ways of operationalizing metacognition (Azevedo & Aleven, 2013; Peña-Ayala & Cárdenas, 2015; Veenman et al., 2006).

Thus, every year we witness a proliferation of different concepts preceded by the adjective "metacognitive", such as adequacy (Wokke et al., 2017), sensitivity (Maniscalco & Lau, 2012), efficiency (Fleming & Lau, 2014), judgements (Rosenthal, 2000), feelings (Koriat & Levy-Sadot, 1999), or scaffolding (Molenaar et al., 2011). While some of these concepts broadly impact the literature, others are short-lived or confined to very specific contexts. Moreover, these new concepts are often indistinguishable from earlier concepts. For example, concepts such as regulation of cognition (Jia et al., 2019), metacognitive control (Shimamura, 2008), metacognitive regulation (Fernández-Duque et al., 2000), procedural metacognition (Schneider & Lockl, 2008), metacognitive skilfulness (Van der Stel & Veenman, 2010), self-control (Mayor et al., 1995), self-management (Paris & Winograd, 1990), metacognitive activity (Peña-Ayala & Cárdenas, 2015) or executive control (Roebers, 2017) have been used in different publications to describe the same phenomenon, specifically, the regulation of strategies used to control one's own cognitive processes.

The lack of consensus regarding issues such as what the components of metacognition are, what we call them, and how they relate to each other brings us to the main problem facing the field of metacognition today: the lack of a single taxonomy accepted by the community and applicable across the different disciplines interested in the study of the phenomenon.

Unfortunately, this is not a new problem: just five years after giving us the first definition of the concept, Flavell (1981) recognized that metacognition is, by its very nature, a "fuzzy concept". In this regard, Henry Wellman - Flavell's co-author in some seminal articles on metamemory - and other authors were categorical in stating that the concept of metacognition serves mainly to cover a range of ill-defined processes that interact with each other and that share certain family resemblances (Kitchener, 1983; Schoenfeld, 1987; Wellman, 1983). One of the first handbooks on its study was heavily criticised because of the lack of a common conceptual framework among the different articles that made up the book:

> Unfortunately, and in spite of all the empirical research that has been done, metacognition has remained a concept that is both difficult to define and to put

> into operation. […] A sense of contradiction becomes apparent as one reads the articles about metacognition compiled in *Metacognition, Cognition, and Human Performance* (Reynolds & Wade, 1986, p. 307).

Later, Jacobs and Paris (1987) noted how surprising it was that, at that time, detailed definitions of metacognition had not yet appeared in the literature, adding that, despite the usefulness that metacognitive theory represented for the models of learning of the time, many researchers viewed the concept with suspicion due to a lack of agreement on such basic matters as its definition. Some years later, some authors would describe the "uncomfortable feeling about the 'fuzziness' of the concept" as one of the main problems of this period (Borkowski et al., 2000, p.2).

As a result, since the 1980s, a significant number of academics have chosen to clarify the idea by examples and/or cases rather than by providing a definition (Schmitt, 1986; Wellman, 1983). More recently, a literature review in education showed that only 32% of the articles on metacognition reviewed (39 out of 123) explicitly defined the construct (Dinsmore et al., 2008).

1.4.2. *A methodological problem*

The theoretical confusion about what metacognition is has brought with it methodological confusion (Azevedo, 2009), as many definitions of the concept bring with them new operationalizations and new ways to assess it (Craig et al., 2020; Ozturk, 2017; Veenman, 2005). As mentioned in section 1.2, when describing the facets of metacognition, instruments for assessing metacognition are mainly divided into two main groups: offline measures and online measures (Fleur et al., 2021).

Offline measures are characterised by not assessing the occurrence of the phenomenon itself, but at a later time (Siegelman et al., 2018). For this, they rely on retrospective reports that query the participant about their knowledge and use of monitoring and control strategies in general contexts (i.e., no reference to a specific task, Saraç & Karakelle, 2012). Common measures of this type are, for example, self-report questionnaires or structured interviews, which do not need an experimental context and can be applied to large numbers of people at once (Veenman, 2011). On the other hand, online measures directly assess how metacognitive processes unfold throughout a cognitive enterprise, offering insight into the mechanisms involved in it (Siegelman et al., 2018). These measures are typically circumscribed to a specific domain or task, and among the most commonly used measures of this type, we find think-aloud protocols, accuracy ratings, and systematic observation (Saraç & Karakelle, 2012), which are applied in experimental contexts where other intervening factors can be controlled (Ohtani & Hisasaka, 2018).

Due to its use in the articles that make up Chapters 2 and 3 of this thesis, we believe it is important to dig deeper into accuracy rating measures, particularly metacognitive efficiency (Fleming & Lau, 2014). Accuracy ratings are measures that seek to assess the accuracy of an individual's ME by comparing a measure of ME with the actual performance on the task that gives rise to them (Jang et al., 2020). Since the 1980s, a plethora of accuracy ratings measures have emerged in the literature, e.g., gamma correlation coefficients (Nelson, 1984), area under the type-2 receiver operating characteristics curve (Fleming et al., 2010) and metacognitive sensitivity (meta - d', Maniscalco & Lau, 2014). This measure, derived from signal detection theory (Green & Sweets, 1966), quantifies how well an individual can detect their correct and incorrect responses in a task through their own confidence judgements, assuming that a correct response should be accompanied by high confidence and an incorrect one by low confidence (Maniscalco & Lau, 2012). An individual's metacognitive efficiency corresponds to their metacognitive sensitivity controlled by their real performance on the task that elicited said judgements (meta - d'/d', Fleming & Lau, 2014). Typically, the calculation of metacognitive efficiency involves two levels: a (first-order) cognitive task from which the subject must answer a series of 2-AFC trials and a (second-order) confidence trial linked to the first-order task on a trial-by-trial basis, from which the subject must monitor their performance on the first-order task (see Fig. 2). Since its appearance and despite some criticism (e.g., Rahnev, 2023), this measure has been established as a gold-standard in the literature (Rausch & Zehetleiner, 2023) with many publications making use of it every year[7].

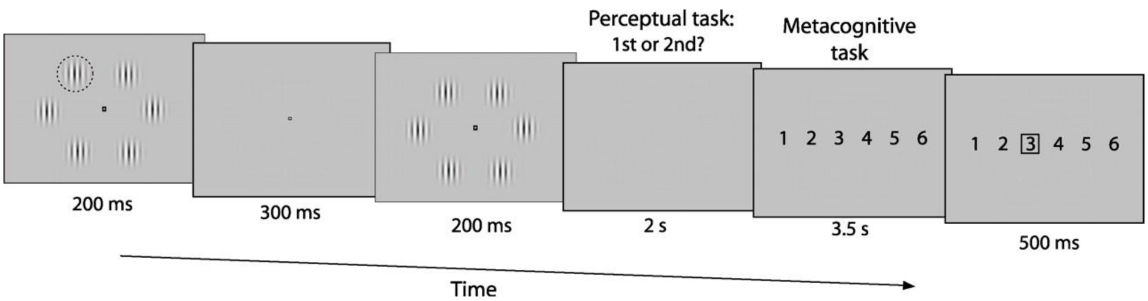

Fig. 2. Visual metacognition task (from Fleming et al., 2010). In each trial, participants are presented with two scenes with six Gabor patches each. The first-order task consists of identifying in which of the two scenes one of the Gabor patches presented a different contrast. After that, participants have to answer the second-order task, in which, on a scale from 1 to 6, they have to indicate the degree of confidence in their previous answer. The first-order task is designed so that, without the participants' knowledge, the performance of all participants is always around 71% (García-Pérez, 1998). From this, two sensitivity scores are obtained (Green & Sweets, 1966): first-order sensitivity, which represents the participant's ability to detect the scene with the different Gabor patch correctly, and metacognitive sensitivity, which represents the participant's ability to accurately monitor, through their confidence, their performance on the visual test. Metacognitive efficiency is obtained by dividing metacognitive sensitivity by first-order sensitivity.

Now, returning to offline and online measures, it seems to be obvious that the type of instrument we use to assess metacognition allows us to account for different facets of it, i.e., while offline measures allow for easy measurement of MK; ME and MS need to be measured online, as the processes that trigger them are occurring. Early on, Brown et al.

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[7] As of December 11th, 2023, an advanced search for the concepts "metacognitive efficiency" and "metacognitive sensitivity" in the MEDLINE and APA PsycInfo databases shows that they have been used in 255 articles since 2014.

criticised authors who purported to use offline measures to assess the occurrence of metacognitive processes, commenting that "asking children to describe general processes that they might use in imaginary situations is the least favourable circumstance for producing verbal reports that are closely linked with the cognitive processes under discussion" (1983, p. 94), while more recent research indicates that both types of measures do indeed contribute to different components of metacognition (Lehmann et al., 2022; Saraç & Karakelle, 2012). However, as mentioned above, most articles in the field either do not make this distinction explicitly and speak of metacognition in general terms, regardless of the type of measure used (Dinsmore et al., 2008), or distinguish between the different components, but when assessing them, they are combined into a single measure (Pintrich & de Groot, 1990). As a result, the relative importance of each facet of metacognition in processes such as learning has received little attention in the literature (Dent & Koenka, 2016). This begs the question of whether the findings made in the study of metacognition using different types of instruments are comparable, or whether what we know about metacognition as applied to other areas of study is influenced by the different ways of measuring this construct.

The answer to the latter question, at least in educational psychology, is yes: what we know is influenced by the methods used to evaluate metacognition. Studies in recent years seem to have confirmed that what we know - or what we think we know - about the effect of metacognition on academic performance - a product of the learning process - is partly explained by the type of instrument used to assess metacognition (Dent & Koenka, 2016; Ohtani & Hisasaka, 2018). For example, in 2016, a meta-analysis conducted on 81 independent samples to quantify the impact of SRL and different metacognitive processes on academic performance revealed that the type of instrument used played a moderating role when studying the relationship between metacognitive processes and academic performance (Dent & Koenka, 2016). Specifically, the authors found that the relationship with academic performance was significantly stronger when using online instruments to assess metacognition than offline instruments under both fixed- and random-effects assumptions ($\Delta r = .24$). Like previous studies (e.g., Saraç & Karakelle, 2012), the authors conclude by stressing the importance of incorporating different instruments, accounting for both types of measures, in assessing metacognitive processes (Dent & Koenka, 2016).

In this vein, two years later, another meta-analysis of 137 independent samples found a similar result when studying the relationship between metacognition, intelligence, and academic performance (Ohtani & Hisasaka, 2018). The results of this meta-analysis confirm the results of Dent and Koenka (2016), showing that when metacognition is assessed through online instruments, it presents a stronger relationship with academic performance than when offline instruments are used ($\Delta r = .16$). Otherwise, the moderating effect of instrument type remains statistically significant, even when controlling for other moderators, such as participant age and assessment context. Explanations for these divergences between the two measures range from memory biases associated with self-report (Craig et al., 2020), the domain specificity of metacognition (Lehmann et al., 2022; Veenman et al., 2006), to, of course, the component of metacognition that each instrument assesses.

Synthesising this entire chapter so far, the variety of theoretical influences on metacognition, coupled with the ubiquity of the construct in human experience, has caused many disciplines to take an interest in studying it (Brown et al., 1983; Dunlosky & Metcalfe, 2009; Norman et al., 2019). This, in turn, has given rise to multiple models, definitions, operationalisations, and methodologies for studying metacognition, which do not necessarily communicate with each other (Fleur et al., 2021; Kuhn & Dean, 2004; Son, 2007; Veenman et al., 2006). Finally, the lack of common agreements and standards among disciplines studying metacognition regarding when to use one methodology or another has led to certain results depending on the informed or uninformed decision of the researcher conducting the study (Dent & Koenka, 2016; Ohtani & Hisasaka, 2018).

At the moment, we do not know whether these problems exist in other aspects of the learning process and not just in academic performance. However, inquiring into how different facets of metacognition, as assessed by different types of instruments, relate to different elements of the learning process is crucial not only for the literature but also for the application of this knowledge in the classroom.

1.5. Experimental studies

Based on the above, the main aim of this thesis is to investigate the relationship between metacognition and the learning process in undergraduate students, considering not only one aspect of metacognition but the three facets described in the modern literature (Dunlosky & Metcalfe, 2009; Efklides, 2008; Pintrich et al., 2000). The three facets of metacognition will be studied using offline and online instruments. Specifically, we will use self-report questionnaires, which will allow us to capture students' knowledge and beliefs about their own skills and strategy use (i.e., MK). We will also use behavioural tests, which will allow us to study students' monitoring and regulation of their cognitive processes and products (i.e., ME and MS, respectively).

The main hypothesis of this thesis is that the components of metacognition will have different effects on different aspects of the learning process. In particular, ME and MS will have a stronger relationship with aspects involved in the learning process itself, such as associative learning or problem-solving skills. In comparison, MK will have a stronger relationship with the products of the learning process, such as academic performance. This is not to deny the effect that students' knowledge and beliefs (i.e., MK) may have on the students' learning process; however, we believe that this effect will be given indirectly through the effect of MK on the other facets, similar to what was proposed by Efklides (2008).

At this point, it is important to mention that the study of ME in the two articles that make up this thesis will be based on the study of metacognitive efficiency. As previously mentioned, this is a measure that seeks to quantify the accuracy of confidence judgments and was born in the field of visual metacognition (Fleming & Lau, 2014), although it has been successfully extrapolated to other contexts, e.g., memory and other sensory modalities (Faivre et al., 2018; McCurdy et al., 2013). Unlike measures such as JOL or

FOK, metacognitive efficiency does not have a large body of theory to support its use in educational contexts; however, in recent years, there have been important attempts to learn more about how confidence judgments operate in different research contexts and about the sources of information that feed them (e.g., Rahnev et al., 2020; Rahnev et al., 2022).

In the first article of this thesis, the research focuses on exploring the relationship of the three facets of metacognition with associative learning and the academic performance of undergraduate students. For this, we consider not only the individual effect of the three facets but also different models incorporating two or more facets. MK was measured through two self-report questionnaires. ME were operationalized as metacognitive efficiency in a memory-based metacognition task, and MS as participants' use of the option to ask for help during the latter task. The results corroborate a differential effect of metacognition facets on learning and academic performance, consistent with the main hypothesis of this thesis. Furthermore, it provides us with information about the role of MK as a source of information for ME, indirectly impacting learning through ME.

Meanwhile, in the second article of this thesis, the research focuses on understanding the role that MK and ME have in problem-solving skills. In this opportunity, MS were not directly assessed; however, the context of the study urges the use of MS, particularly the use of collaborative strategies among participants. In addition, variables such as attitude towards social interdependence and feelings of anxiety were measured to assess how these factors may influence the relationship between MK, ME, and problem-solving skills. Our results did not allow us to corroborate the main objective; however, we found evidence that makes it possible to hypothesise a relationship between metacognition and attitude towards collaboration in anxiogenic contexts.

CHAPTER 2. EXPLORING THE RELATIONSHIP BETWEEN METACOGNITION FACETS AND LEARNING

Barrientos, M., Sackur, J. & Reyes, G. Exploring the relationship between metacognition facets and learning.

2.1. Introduction

The relationship between metacognition and learning has been widely studied since the 1980s; however, many of these works approach metacognition as a single construct without considering its different components. Despite the years of literature on the topic, there is little information about how these facets (i.e., metacognitive knowledge, metacognitive experiences, and metacognitive skills; Efklides, 2008) and their interrelationships relate to the learning process.

From this, we wanted to investigate how the three facets of metacognition relate to learning, individually and collectively. For this, 73 participants answered two self-report questionnaires – the Metacognitive Awareness Inventory and the Awareness of Independent Learning Inventory – that allowed us to evaluate their metacognitive knowledge, and a memory-based metacognition task – adapted from McCurdy et al. (2013) and Undorf et al. (2021) – which allowed us to evaluate their metacognitive experiences and skills. To assess their learning, participants completed a researcher-paced associative learning task and were also asked about their academic performance as a proxy measure of learning.

2.2. Results

When analysing the individual relationship between each facet and learning, we only found a significant and positive relationship between metacognitive experiences and learning, but not with the other facets. In contrast, the academic performance measure showed statistically significant relationships with all facets of metacognition. When evaluating more complex models, we identified two relevant results. First, a mediation analysis showed that the metacognitive experiences of the participants completely mediate the effect of metacognitive knowledge on learning. Second, a moderation analysis revealed an interaction between metacognitive experiences, the use of metacognitive skills, and learning. Specifically, students who use these skills show more stable learning scores regardless of their metacognitive experiences.

2.3. Discussion

The results of this article allow us to highlight the differential role that the components of metacognition play in learning. In particular, associative learning depends on a smaller number of factors compared to academic performance, which is affected in some way by each of the components evaluated. We believe that the way learning is assessed can explain how metacognition acts on it. Furthermore, the role of metacognitive knowledge as a source of information for metacognitive experiences is confirmed, which, in turn, directly affects associative learning. Finally, we hypothesize that asking for help acts as a source of information parallel to that provided by individual monitoring skills. In this way, although no concrete evidence supports the trainability of cognitive monitoring, interventions on the use of strategies are proposed as an alternative.

2.4. Paper

Exploring the relationship between metacognition facets and learning

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Statements and Declarations

Funding

This study was funded by a research grant from the Centro de Innovación Docente (CID) at Universidad del Desarrollo to MB & GR, by ANID Becas/Doctorado Nacional N° 21211819 to MB and by the Fund for Science and Technology (FONDECYT) Grant N° 1221785 to GR.

Competing Interests

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics and Consent

The study was reviewed and approved by the Comité de Ética Institucional en Investigación at the Universidad del Desarrollo. All participants provided their written informed consent to participate in the study.

Author Contributions

MB and GR contributed to the study concept and design. MB collected and analysed the data. JS provided feedback throughout the project. All authors wrote the manuscript and approved it for submission.

Data and Code Availability

The datasets and code used in this study can be found at https://osf.io/kqsr7/

Abstract

Metacognition is the monitoring and control of one's own cognitive processes. The benefit of metacognition on learning and academic performance has been widely studied. However, metacognition is not a unitary construct but rather consists of different components, e.g., knowledge about one's own cognitive processes and products (metacognitive knowledge), the online monitoring of said processes and products (metacognitive experiences), and the ability to regulate both (metacognitive skills). Few studies have explored whether these three components -and how variations in them- affect learning. To examine this issue, we assessed 73 undergraduate students who had to answer two self-report questionnaires and perform two behavioural tasks aimed at evaluating metacognition facets and associative learning. We also asked participants about their academic performance. The results show that learning is only related to metacognitive experiences, while academic performance is related to all facets. We also found evidence on how metacognition facets jointly influence learning. First, a mediation analysis yielded that the impact of metacognitive knowledge on learning was mediated entirely by metacognitive experiences. Second, a moderation analysis showed that using metacognitive skills influences the effect of metacognitive experiences on learning. Our results highlight the differential role of metacognition facets on learning and academic performance.

Keywords: metacognitive knowledge; metacognitive experiences; metacognitive skills; associative learning; academic performance.

1. Introduction

Metacognition, defined as the monitoring and regulation of one's own cognitive processes and products (Flavell, 1976), is a higher-order psychological process ubiquitous to most work in psychology (Efklides, 2008). As such, it has been the object of study in multiple subdisciplines, standing out – due to its production and impact – in educational and cognitive psychology (Norman et al., 2019). One common interest between the two fields is understanding the role of metacognition in the process of learning (Fleur et al., 2021). Considerable evidence, in both educational and cognitive psychology, points to the fact that people with better metacognitive ability show better academic performance (Donker et al., 2014; Wang et al., 1990) and, overall, are better learners than their peers (Clerc & Clément, 2016; Hainguerlot et al., 2018).

Although there is a significant theoretical and empirical body supporting the role of metacognition in learning, a common problem in some of these investigations is that they treat metacognition as a unitary construct and not as a complex process made up of multiple components (Dinsmore et al., 2008; Tarricone, 2011). This problem seems to arise from a theoretical and methodological distancing between both educational and cognitive sciences (Kuhn & Dean, 2004; Son, 2007), which has led them to differ in their definitions, operationalisations, and foci of interest (Azevedo & Aleven, 2013; Veenman et al., 2006). In practice, this distancing has led to problems such as conceptual 'fuzziness' (Azevedo, 2020; Dinsmore et al., 2008), a lack of a common language between the two disciplines – with some findings simply being 'lost in translation' between them – (Fleur et al., 2021; Mayer, 2017), and to some results being dependent on which methodology is used to carry out the study (Dent & Koenka, 2016). Regarding the latter, it has been observed that when metacognition is assessed through behavioural tasks or observation protocols, the relationship between metacognition and learning is more robust than when metacognition is measured using self-report questionnaires (Jacobse & Harskamps, 2012; Ohtani & Hisasaka, 2018). Based on this, this article aims to contribute to understanding the relationship between metacognition and learning, considering different instruments to evaluate metacognition that account for its various facets. However, to understand this problem, we must first understand the three facets of metacognition.

1.1. The facets of metacognition

Several models of metacognition propose that it comprises three interrelated facets: metacognitive knowledge, metacognitive experiences, and metacognitive skills (Dunlosky & Metcalfe, 2009; Efklides, 2008; Pintrich et al., 2000). Metacognitive knowledge (MK) corresponds to the declarative knowledge that a learner has regarding their abilities, the tasks they perform, and the strategies they employ (Flavell, 1979). This is influenced by feedback from one’s own metacognitive experiences (Efklides, 2008), but it also has a social origin in the interaction with others, one’s own culture, etc. (Heyes et al., 2020). MK has been studied through offline methods, such as self-report questionnaires that assess students' beliefs and ask them to recreate their use of metacognitive strategies from long-term memory (Craig et al., 2020; Dent & Koenka, 2016). Given the ease of their assessment and the possibility of being evaluated in large groups at once, MK has been extensively studied in natural settings, mainly by educational psychologists (Veenman, 2011).

For their part, metacognitive experiences (ME) correspond to the feelings and judgements that emerge in a learner while performing and processing a task (Flavell, 1979). Just as MK represents offline monitoring of cognition, given its disconnection from cognitive activity itself, ME represents online monitoring of cognition (Dunlosky & Metcalfe, 2009). Feeling of knowing, judgements of learning, tip-of-the-tongue states, and judgements of confidence correspond to experiences of this type (Fleming & Lau, 2014; Jang et al., 2020; Norman et al., 2016; Schwartz, 2006). ME are influenced by affective (Coulot et al., 2021; Reyes et al., 2015) and social factors (Gajdos et al., 2019) and by MK itself (Efklides, 2008; Lehmann et al., 2022). ME have been studied mainly by cognitive psychologists in artificial settings using online methods, such as behavioural tasks that seek to elicit judgements or feelings from the student regarding their own mental activity (Lai, 2011).

Finally, metacognitive skills (MS) refer to the strategies a learner deliberately uses to control their cognition in pursuit of a learning goal (Efklides, 2008; Tarricone, 2011). MS have been associated with executive functions (Fleur et al., 2021; Marulis et al., 2020; Roebers, 2017), although their relationship with them is a matter of debate (Bryce et al., 2015). They are related to the other facets of metacognition, since an individual's set of MS is given by their own MK, while their deployment is triggered by their MK and ME (Efklides, 2008, 2009; Metcalfe, 2009). MS have been studied by both educational and cognitive psychologists via online methods, such as observation protocols and behavioural tasks, that seek to analyse the use of strategies while they occur (Pintrich et al., 2000; Undorf et al., 2021).

1.2. A multi-faceted problem: How do metacognition facets relate to learning?

The literature seems to agree on the association between metacognition and learning. Indeed, early researchers like Brown et al. (1978) and Flavell (1979) highlighted the importance of metacognitive skills in the learning process. During the 1980s, this relationship became more relevant with the development of conceptual models and instruments that made it possible to understand and evaluate the use of metacognitive skills in educational contexts (Brown et al., 1983; Paris & Winograd, 1990). Building on this, in 1990, Wang et al. published one of the first reviews comparing the role of socio-emotional and cognitive processes (including metacognition) on learning. The results showed that metacognition was the best predictor of good learning outcomes, even above other variables such as socioeconomic background or motivation (Wang et al., 1990). In the following years, self-regulated learning models gained greater preponderance in the study of this association (Chen & McDunn, 2022). According to these models, a student's ability to learn will be explained by behavioural, cognitive, metacognitive, motivational, and affective factors (Panadero, 2017). Metacognition, specifically, allows for the monitoring and orchestration of the other factors involved in the process, in addition to serving as a mediator in the way in which the individual approaches the content he seeks to learn (Efklides, 2011; Pintrich, 2000; Winne & Hadwin, 1998).

However, the effect of metacognition on learning seems to be sensitive to the – previously mentioned – conceptual problems associated with the study of metacognition. For example, a meta-analysis carried out on 149 samples (Ohtani & Hisasaka, 2018), identified that the context in which metacognition was studied plays a moderating role in the relationship between metacognition and academic achievement, with research conducted in experimental settings showing larger effect sizes than research conducted in classrooms (Δr = .15). Similarly, the type of instrument used to measure metacognition also plays a moderating role in this association. Specifically, online methods showed stronger effect sizes than offline methods (Δr = .16). This effect remained statistically significant after controlling for other moderators (Ohtani & Hisasaka, 2018). These findings corroborate previous meta-analyses and research that revealed similar results (Dent & Koenka, 2016; Veenman & Spaans, 2005). We believe that these results are not necessarily related to the methods employed but to the facet of metacognition assessed through each method. Although some authors already stated that different instruments evaluate different facets of metacognition (Brown et al., 1982; Pintrich et al., 2000), many investigations in the field do not specify which facet they evaluate, nor the definitions they occupy and, instead, refer to metacognition in general terms or implicitly. A review by Dinsmore et al. (2008) showed that only 32% of articles about metacognition in education explicitly define the concept. This led to talk of the effect of metacognition – as a whole – on learning, and no focus was placed on the particular facets that could actually be involved in this relationship (Azevedo, 2020; Pintrich et al., 2000).

Furthermore, we know little about the combined effect that the facets of metacognition have on learning. In general, it has been observed that the facets of metacognition are correlated with each other -e.g., MK and ME (Jang et al., 2020; Lehmann et al., 2022), or ME and MS (Undorf et al., 2021)-, however, the interplay between them and its role in learning -if any- has not been much explored outside of self-regulated learning research (Peña-Ayala & Cárdenas, 2015). Theoretical models, such as Efklides' (2011), propose that MK could act as an information source for ME, which, in turn, mediates the relation between the person and performance in a task. Regarding MS, understanding how metacognitive monitoring (i.e., MK and ME) influences the use of MS in learning contexts has been largely neglected by metacognition research (Undorf et al., 2021).

In short, we will not know how metacognition helps learning if we do not make the distinction between which facets of metacognition are involved in the process of learning. For this reason, we believe it is important to study the different facets of metacognition separately, their interactions, and how they relate to the process of learning. In the present study, our main objective is to investigate how the facets of metacognition (i.e., metacognitive knowledge, experiences, and skills) are related to learning. For this, we conducted a within participant study with university students. Participants filled two questionnaires (AILI and MAI) meant to operationalize their levels of metacognitive knowledge (MK) and they reported the Grade Point Average (GPA) as an index of their academic success. We engaged them in a first laboratory experiment where we measured their metacognitive experiences (ME) by means of confidence judgements and their metacognitive skills by means of a ask-for-help (AFH) procedure. In a second laboratory experiment, we tested their learning efficiency on an associative learning task. We predicted that better metacognitive knowledge would be associated with better metacognitive skills and experiences and that both would in turn positively impact the two forms of learning efficiency that we measured.

2. Materials and methods

2.1. Participants

73 Chilean undergraduate students (63% women) ages 18 through 42 (M = 22.2 years, SD = 3.6 years) were recruited for the study from several universities in Santiago, Chile, through a non-probability voluntary response sampling method. An a priori power analysis using G*Power v.3.1.9.7. (Faul et al., 2007) revealed a minimum sample size of N = 43 was required to achieve 80% power for detecting a small effect at a significance of $\alpha = .05$. Inclusion criteria required that all participants had normal or corrected-to-normal vision and were native Spanish speakers. Participants received a compensation of CLP$10,000 (~ USD$12) after completing all tasks. The ethics committee of the Universidad del Desarrollo approved the study. All participants gave written informed consent to participate in the study.

2.2. Procedure and Tasks

Undergraduate students were invited to participate through posters and flyers distributed in several universities. Participants performed two sessions scheduled approximately one week apart (M = 7.8 days). The first session was online, and participants were asked to respond to two self-report questionnaires to evaluate their metacognitive knowledge and learn about their educational background. Participants accessed the questionnaires through a Google Forms link provided via email by a research assistant. In the second session, participants were invited to the laboratory, where they were asked to perform two behavioural tasks: a memory metacognition task and an associative learning task. Both were coded in PsychoPy v2022.2.1 (Peirce et al., 2019). Participants completed the tasks on a laptop in a quiet and dimly lit room. The order of the questionnaires and tasks was counterbalanced in both sessions.

2.2.1. *Self-report questionnaires*

For the evaluation of the knowledge and beliefs of participants about their own learning (i.e., MK), we decided to use two self-report questionnaires: the *Awareness of Independent Learning Inventory* (AILI) and the *Metacognitive Awareness Inventory - Shortened Version* (MAI - SV). AILI was created for higher education students (Meijer et al., 2013).

We decided to use it because it evaluates metacognition based on a three-component model similar to the one used in this study. AILI has 45 items with Likert-type responses that range from 1 to 7. We used the Spanish-translated version of the AILI by Pérez-Acuña et al. (2020). Reliability analyses in our data showed a good internal reliability for AILI (Cronbach's α = .832) and an acceptable reliability for all subscales (Cronbach's α = 0.618, 0.639, and 0.663, respectively). Moreover, MAI - SV is an abridged version of MAI (Schraw & Dennison, 1994), one of the most, if not the most, used questionnaire in educational research regarding metacognition (Harrison and Vallin, 2018). It evaluates metacognition through two main components: knowledge of cognition and regulation of cognition. This version was based on the Spanish validation (González-Cabañes et al., 2022), with 19 items with true or false responses. Nonetheless, internal reliability analyses showed non-acceptable reliability for MAI (Cronbach's α = 0.449) and both subscales (Cronbach's α = 0.621, and 0.117, respectively). Subsequently, the MAI questionnaire was excluded from further analyses. Finally, we used a sociodemographic questionnaire where we asked participants several questions regarding their education, such as the university where they study and years of education. We also asked participants for their GPA, which they answered on a 1-5 interval scale with higher scores reflecting higher grades.

2.2.2. *Memory metacognition task*

This task combined elements from previous tasks by McCurdy et al. (2013) and Undorf et al. (2021). It evaluates ME through the confidence in a (first-order) memory task and MS using an 'ask-for-help' (AFH) option. The task has four blocks with 50 trials each. The first two blocks comprised a memorisation phase and a test phase, while the last two blocks added an ask-for-help phase at the end (see Fig. 1a). In the memorisation phase, participants were presented with 50 Spanish words displayed simultaneously in a 10 x 5 array and asked to memorise as many as possible for 60 seconds. The words were generated from the EsPal Database (Duchon et al., 2013). They were four to six letters long, with one to three syllables, a familiarity rating from 5.0 to 7.0, and had no diacritical marks (i.e., accents, tildes, nor umlauts). In the test phase, participants were presented with two words and asked to identify which was in the studied array. Only one of the words was randomly selected from the array; the other was a decoy selected from the same database, following the same criteria. Each decoy was a novel word, i.e. it had not been seen previously and would not be seen later by participants. After each choice, participants were asked to estimate the confidence in their own decision using their mouse. We used a discrete scale from 1 (*I chose randomly*) to 5 (*I am sure of my answer*).

During the third and fourth blocks, participants were told they could ask for help if they were unsure of their answers. After the confidence scale, participants were given the option to submit their responses and proceed with the next trial or ask for help. If they asked for help, participants were shown the answer of a previous participant with a high accuracy for two seconds. Actually, the help was randomly generated with an 80% chance of being correct. Immediately after, participants repeated their decision and their confidence estimation. The last two blocks incorporated a performance-based score to encourage the strategic use of the AFH option. Participants were awarded two points for each correct answer and were penalised with minus two points for each incorrect one. Additionally, each time they asked for help, one point was deducted from their score. Participants were informed of their score after each trial.

2.2.3. *Associative learning task*

Associative learning was assessed through an experimenter-paced task with five blocks and 24 trials each. Stimuli were 24 cue-response word pairs. As with the metacognition task, the words were generated from the EsPal Database (Duchon et al., 2013) and followed the same criteria regarding length, familiarity, and absence of diacritical marks. Importantly, none of the words were used in both tasks at the same time. The 24-word pairs were selected from a pool of 45 pairs based on their low semantic, phonological, and perceived similarity, so these factors would not bias the participants' answers (for details, see Supplementary Material A). During the task, participants were asked to identify the word associated with a certain cue. After a fixation cross, participants were shown a cue at the top of the screen and two words at the bottom for five seconds. One of the words at the bottom was associated arbitrarily with the cue. Participants had to click on the word they thought was associated with the cue. After their selection, feedback was shown on the screen for one second, telling participants if they were correct or incorrect (see Fig. 1b). Participants were instructed to guess the answer if they did not have enough information to decide. Although the same 24-word pairs were used during the five blocks, the distractors differed for each trial.

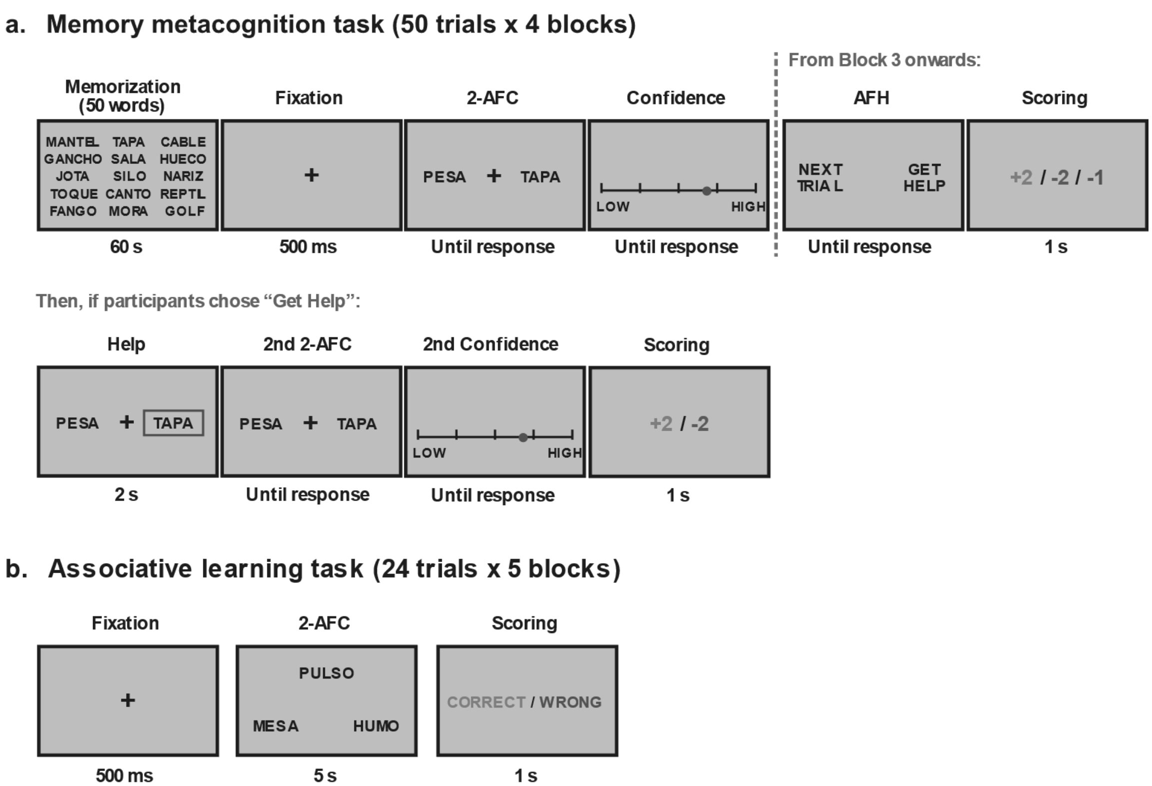

Fig. 1. (a) shows the structure of the metacognition task. Participants were asked to memorise as many words as they could. Once the stimuli presentation had finished, they were presented with 50 "2-AFC + confidence" trials. Participants were asked to indicate which word was in the previously memorised set and to estimate their confidence in their

decision. From the third block, there were two rule changes. First, participants were given the choice to get help before continuing to the next trial. If they chose the “Get Help” option, they were presented with “the response of a previous participant” and had to redo the whole trial. The help had an 80% chance of being correct. Second, a feedback score system was included. Participants were scored 2 points for each correct response and -2 for each wrong one. They were also charged 1 point each time they asked for help. Figure (b) shows the structure of the associative learning task. Participants were asked to identify which word in the lower half of the screen was associated with the cue in the upper half. The words were associated arbitrarily. After their response, participants received feedback indicating if their response was correct or wrong. The task was composed of 120 trials divided into five blocks.

2.3. Statistical analysis

Seven participants were excluded from further analyses due to technical and/or human errors during data collection. We checked normality for all continuous variables. All analyses were performed using JASP v.0.17.2.1 (JASP Team, 2023) and R v.4.3.1 (R Core Team, 2023). First, we evaluated how each metacognition facet relates to learning. Then, we performed statistical analyses to assess the collective impact of the three facets on learning. Finally, since GPA was codified as an ordinal variable, we performed Kendall's tau (τ) correlations, in order to evaluate how each metacognition facet relates to GPA. For clarity, we assessed each metacognition facet and associative learning as follows:

2.3.1. *Metacognitive knowledge (MK)*

We calculated MK scores from the AILI questionnaire. We calculated a total score, as well as scores for its three dimensions: *metacognitive knowledge*, *metacognitive skills*, and *metacognitive responsiveness*.

2.3.2. *Metacognitive experiences (ME)*

We calculated ME scores separately for blocks 1-2 and 3-4 of the metacognition task. We assessed ME through *metacognitive sensitivity*[1] (meta-d'; Maniscalco & Lau, 2012), that is, the efficacy with which an individual's judgements of confidence discriminate between their own correct and incorrect answers, and through *metacognitive efficiency*[2] (meta-d'/d'; Fleming & Lau, 2014), that is, metacognitive sensitivity relative to one's own performance. We used Matt Craddock's R implementation of Maniscalco and Lau's MATLAB functions (Craddock, 2021).

2.3.3. *Metacognitive skills (MS)*

We assessed MS using two indicators. First, to assess the regulation of performance due to the deployment of MS, we quantified the improvement in accuracy attributed to AFH in blocks 3-4 of the metacognition task. In each trial where the AFH option was selected, we compared the changes in accuracy pre- and post-AFH. Second, we quantified the efficiency with which participants used the AFH option to regulate their performance. To do that, we divided the change in accuracy due to AFH by the number of times each participant used the AFH option.

2.3.4. *Associative learning*

An individual learning score was calculated through the area under each participant's accuracy curve across the five blocks. Considering that participants responded randomly on the first block – since they were only learning the association between words – we established that accuracy score (acc_0) as a baseline from which we could measure the

[1] Metacognitive sensitivity is a measure derived from signal detection theory (Macmillan & Creelman, 2004), which quantifies the precision with which an individual's confidence scores discriminate between correct and incorrect answers, considering high confidence in a correct answer as a correct discrimination and *vice versa* (Maniscalco & Lau, 2012).

[2] Metacognitive efficiency is a measure widely used in studies on visual metacognition, which aims to reduce the metacognitive sensitivity's confidence bias associated with first-order performance. This is calculated as the division of metacognitive sensitivity by first-order sensitivity, i.e., the precision with which the subject detects the relevant stimuli (Fleming & Lau, 2014).

learning across the blocks. After that, we calculated the area under the learning curve, summating the trapezoids defined by the change in the accuracy across one block. Then, we removed the area between ground level (acc = 0) and our baseline (acc_0) for all blocks. Finally, we standardised the scores, dividing them by the maximum area achievable for each participant. From the above, we could calculate the learning score using the formula (1):

$$Learning = \frac{\sum_{i=1}^{n}\left(\frac{acc_i + acc_{i-1}}{2}\right) - n * acc_0}{n * (1 - acc_0)} \quad (1)$$

with acc_i representing the accuracy on the i-th block and n, the number of blocks (in this case n = 5). Learning curves for all participants can be observed in Supplementary Material A.

3. Results

Tables 1 and 2 report the descriptive statistics for the questionnaires, the learning task, and the memory metacognition task. We found no significant differences while comparing by sex (all *p*s > .080) or career (all *p*s > .214). We also found no correlations between the variables we studied and the years of schooling (all *p*s > .110) nor the lag between both sessions (all *p*s > .124). Next, since blocks 3-4 of the memory metacognition task had two special conditions (i.e., the feedback system and the AFH option) that were absent in blocks 1-2, we decided to study the effect these added variables had on performance in the task (Table 2). First, to study the effect of the feedback, we calculated the change in first- and second-order scores for blocks 3-4 (pre-AFH) minus scores for blocks 1-2. We found a statistically significant diminution in response times ($t(65) = -3.03$, $p = .004$, $d = -0.37$), and a statistically significant increase in both first-order sensitivity ($t(65) = 2.12$, $p = .038$, $d = 0.26$) and confidence scores ($t(65) = 7.32$, $p < .001$, $d = 0.90$). We found no other significant differences (all *p*s > .053). Second, to assess the effect of AFH, we calculated the variation in blocks 3-4 post- and pre-AFH. In this case, we found a statistically significant increase in accuracy ($t(65) = 2.21$, $p = .031$, $d = 0.27$), and a statistically significant decrease in both response times ($t(65) = -4.96$, $p < .001$, $d = -0.61$), and metacognitive efficiency ($t(65) = -3.09$, $p = .003$, $d = -0.38$). Other variables showed no significant differences between post- and pre-AFH (all *p*s > .093). Due to the differences in first- and second-order performance attributed to both special conditions, we subsequently used metacognitive experiences (ME) scores obtained from blocks 1-2 of the memory metacognition task.

Table 1. Descriptives for the questionnaire scores and the learning task ($n = 66$).

Variable	*M* (*SD*)
Age	22.26 (3.71)
Scholarity (in years)	15.36 (2.36)
AILI	179.15 (21.86)
Knowledge	64.38 (7.61)
Responsiveness	52.29 (7.79)
Regulation	62.49 (10.41)
Learning	.61 (.16)

Next, we investigated how associative learning -as evaluated by the learning task- was related to the three metacognition facets. First, while comparing with metacognitive knowledge (MK), we found no correlations between the AILI scores and our measure of learning (all *p*s > .06). Next, regarding ME, we found a weak and positive correlation with both confidence ($r = .37$, $p = .002$) and metacognitive sensitivity ($r = .39$, $p = .001$). Finally, regarding metacognitive skills (MS), we found no correlation between our MS measures and the associative learning score (all *p*s < .065). In sum, only two ME measures showed a statistically significant correlation with associative learning. Now, as both confidence and metacognitive sensitivity are susceptible to performance bias, we used multiple regression to assess if both relations continued to be significant after accounting for first-order sensitivity (d'). We found that confidence ($\beta = .30$, $p = .034$) and metacognitive sensitivity ($\beta = .34$, $p = .021$) are significant predictors of learning, even after controlling for first-order performance bias.

Table 2. Descriptives and change between blocks for the metacognition task (*n* = 66).

Variable	Blocks 1-2 *M* (*SD*)	Blocks 3-4 (Pre AFH) *M* (*SD*)	Blocks 3-4 (Post AFH) *M* (*SD*)	$B_{3\text{-}4} - B_{1\text{-}2}$ Δ*M*	$B_{3\text{-}4\ Post} - B_{3\text{-}4\ Pre}$ Δ*M*
First-order performance					
Accuracy (acc)	.77 (.07)	.79 (.07)	.80 (.06)	.02	.01*
Response time (rt)	2.43 (0.67)	2.26 (0.64)	2.11 (0.57)	-0.17**	-0.16***
Sensitivity (d')	1.34 (0.39)	1.45 (0.40)	1.51 (0.36)	0.11*	0.06
Metacognitive experiences					
Confidence	3.52 (0.47)	3.88 (0.49)	3.90 (0.51)	0.36***	.02
Metacognitive sensitivity (meta-d')	1.31 (0.48)	1.35 (0.51)	1.30 (0.49)	0.04	-0.05
Metacognitive efficiency (meta-d' / d')	1.01 (0.35)	0.95 (0.34)	0.87 (0.30)	-0.06	-0.08**
Metacognitive skills					
Accuracy improvement[1]	-	-	.02 (.02)	-	-
AFH efficiency[1]	-	-	.31 (.41)	-	-

Statistical significance: * $p < .05$, ** $p < .01$, *** $p < .001$.

[1] Excluding 10 participants that never used the AFH option (n = 56).

Then, we tried to evaluate a model that combined the two forms of monitoring -MK and ME- with associative learning. Given the aforementioned role of MK as a source of information and bias for ME (Efklides, 2008; Lehmann et al., 2022) and following methodological considerations by Angler & De Boeck (2017), we investigated mediation models with learning as the outcome, MK measures as predictors, and metacognitive sensitivity as the mediator (Fig. 2a). We found an indirect effect of the subscale metacognitive knowledge of the AILI on learning, mediated by metacognitive sensitivity (β = .112, 95% CI [.01, .24]). That is, the knowledge or beliefs of an individual about their own processing and problem-solving abilities (i.e., MK) predicts the accuracy with which they monitor their own cognitive performance (i.e., ME), which in turn predicts cognitive performance itself (i.e., learning). We found no effects when we evaluated the remaining AILI subscales.

Given that MS measures showed no effect on associative learning and considering that several participants never used the AFH option during the metacognition task, we decided to evaluate differences between participants who asked for help and those who did not (for more information on AFH use, see Supplementary Material B). We tested if the relation between metacognitive sensitivity and learning changed depending on the use of AFH (categorised as 0 = never asked for help, 1 = asked for help at least once). To test this hypothesis, a hierarchical multiple regression was performed. In the first step, three variables were included: metacognitive sensitivity, first-order sensitivity (in order to account for performance bias), and use of AFH. The three variables accounted for significant variance regarding learning ($R^2 = .21$, $F(3, 62) = 5.39$, $p = .002$). Next, the interaction term between metacognitive sensitivity and the use of AFH was added. The resulting model had additional predictive worth over the first model ($\Delta R^2 = .11$, $\Delta F(1, 61) = 10.18$, $p = .002$) with metacognitive sensitivity ($b = .41$, $t = 3.94$, $p < .001$), the use of AFH ($b = .56$, $t = 3.65$, $p < .001$), and their interaction ($b = -.36$, $t = -3.19$, $p = .002$) as significant predictors of associative learning. The interaction plot (Fig. 2b) shows a shallower slope for participants who asked for help versus those who did not. At lower metacognitive sensitivity scores, participants who asked for help showed better learning than participants who did not. However, this trend disappears at higher metacognitive sensitivity scores, with participants showing similar associative learning scores regarding whether they asked for help or not.

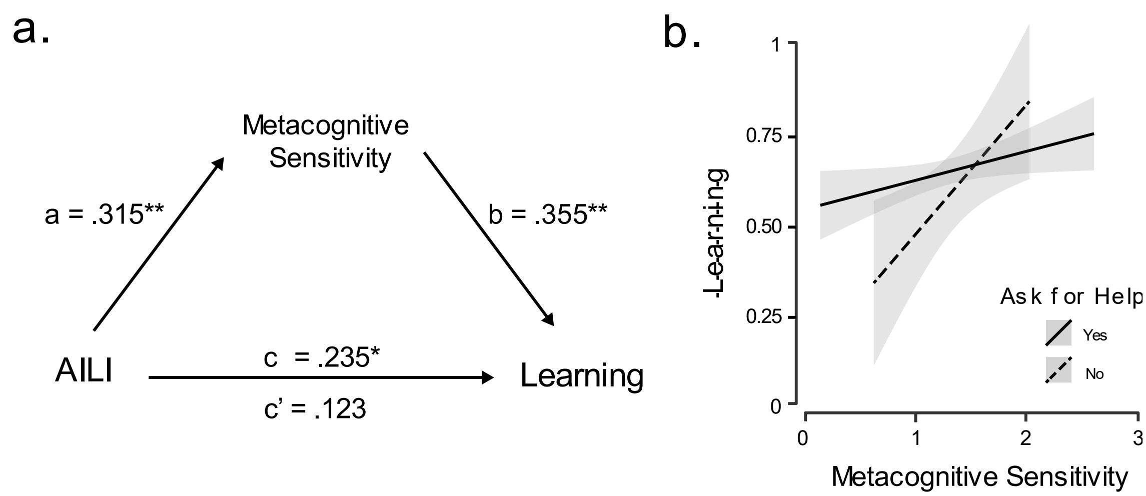

Fig. 2. (a) shows the indirect effect of the AILI’s subscale *metacognitive knowledge* on associative learning mediated by metacognitive sensitivity. Figure (b) shows the regression of metacognitive sensitivity on associative learning using the AFH option. n = 66.

Finally, we decided to assess how the three metacognition facets related to the academic performance of participants, evaluated through self-reported GPA. First, while comparing MK to GPA, we observed positive correlations between GPA and total AILI ($\tau = .21$, $p = .028$), in addition to the AILI’s subscales metacognitive responsiveness ($\tau = .19$, $p = .046$) and metacognitive regulation ($\tau = .19$, $p = .048$). Next, regarding ME, we found a weak and positive correlation with metacognitive efficiency ($\tau = .19$, $p = .045$). Finally, while comparing to MS, we found a negative relation between AFH efficiency and GPA ($\tau = -.21$, $p = .049$). That is, participants with better grades are worse at asking for help than participants with lower grades, or, in other words, the improvement of accuracy relative to the number of times they ask for help is worse in participants with better grades. In summary and opposed to what we found when comparing metacognition facets and associative learning, we found that all three of them were related to self-reported GPA.

4. Discussion

The main objective of this article was to study how the different facets of metacognition (i.e., metacognitive knowledge, experiences, and skills) are related to learning, both individually and collectively. Following the literature in cognitive psychology and educational psychology, we operationalised metacognitive knowledge (MK), experiences (ME) and skills (MS) as beliefs and knowledge regarding one's own mental processes, self-monitoring via confidence judgements of one's own performance on a task, and the use of the option to ask for help during a task to improve one's own performance, respectively.

Regarding how the facets of metacognition are related to learning individually, our results show that only the ME are related to it. Specifically, we found a positive relationship between participants' metacognitive sensitivity and their performance on the learning task, i.e., individuals who best monitor their performance through their confidence judgments are also the best learners. Confidence judgements – and their accuracy – are critical components of the self-regulated learning process, allowing the learner to better allocate cognitive resources to the tasks at hand (Mengelkamp & Bannert, 2012). Importantly, and contrary to most examples in the literature (such as studies that use JOLs or FOKs; Jang et al., 2020; Schwartz, 2008), participant's ME were assessed outside of the learning task, which points towards the influence of general monitoring skills in the learning process.

On the other hand, when comparing learning with MK and MS, we did not find significant correlations. Although this contradicts previous reports in the literature (e.g., Aghaie & Zhang, 2012; Desoete et al., 2003; Dunlosky et al., 2003), we believe that our results could be due to the type of task implemented to assess learning, which triggers low-level associative mechanisms where knowledge about and the use of strategies by the participants do not play a significant role. Previous research reports that both MK and MS are beneficial when students transfer learning from familiar to novel contexts (Bransford et al., 1999). In this sense, our learning task may have been unable to trigger said processes in the students. Future research should ask whether the cognitive complexity involved in a learning task determines the facets of metacognition that could be involved.

When evaluating the role that metacognition facets have collectively on learning, we found two important results to highlight. First, we found a mediation effect between MK and learning through ME. In other words, we find that an individual's beliefs and knowledge about their metacognitive ability predict their cognitive self-monitoring ability, which, in turn, predicts their learning. This result is consistent with what was evidenced by Jang et al. (2020) and proposed by Efklides (2008), who suggest that an individual's beliefs shape their ability to self-monitor their own cognitive processes. Following the results from Lehmann et al. (2022), it could be said that MK acts as a base level – or a bias – in constructing ME, such as confidence judgements. In turn, ME has been proposed as a link between the subjective experience and beliefs about learning and actual learning (Winne & Hadwin, 1998). Learners need to contrast their knowledge and beliefs about the learning process with real experiences, in order to use that knowledge effectively during actual learning. Second, we found that the relationship between ME and learning is moderated by the use the participants made of the option to ask for help during the task. Specifically, we found that the participants who used the option to ask for help showed more stable learning scores, with less variation between subjects relative to their level of ME. By contrast, the participants who did not use this option show a steeper slope: lower learning scores when their ME is low and similar to other students when their ME is higher. Using strategies allows students less proficient in the online monitoring of their own performance to obtain learning outcomes similar to other learners with greater metacognitive ability. Although the learning task used in this study did not allow participants to ask for help, the effect could reflect the use of other self-regulatory strategies or changes in self-monitoring other than confidence judgements (Undorf et al., 2021). These results may hint at a differential role of both monitoring and control aspects of metacognition on learning, with control of cognition acting as a complementary system that improves performance in learners with low monitoring skills.

Finally, we also asked participants for their GPA, in order to have a proxy measure of learning and academic achievement, which we also compared with all facets of metacognition. We found that the self-reported GPA score was related to the three facets of metacognition. In line with the literature in the area (Abdelrahman, 2020; Young & Fry, 2008), we found a positive relationship between different measures of MK and academic performance, i.e., individuals who believe they are good learners do indeed have better grades than their peers. We also found a positive relationship between ME and academic performance, i.e., individuals who are better at monitoring their own performance have better grades. Contrary to what was observed when comparing the learning task, we found evidence of a similar influence of both the individual's knowledge and beliefs and their own cognitive self-monitoring on academic performance. Hypothetically speaking, we can suggest that since academic performance is an outcome that depends on multiple factors, such as beliefs, motivation, and social factors and not only learning skills (Gębka, 2013; Hidayatullah & Csíkos, 2023), it is widely related to more aspects of metacognitive ability. In contrast, learning (as operationalised in this study) seems to be restricted to the student's ME only. Consistent with what has been stated previously, it is essential to investigate the effect of the complexity of the learning context on the metacognitive processes employed throughout. Finally, and contrary to our expectations, we observed a negative relationship between one of our measures of MS and academic performance. Specifically, we found that participants who used the ask-for-help option more efficiently had worse grades. We believe that additional studies are necessary to determine the relevance of this finding.

The present study showed that metacognition facets have different influences on both learning and academic performance and that the interaction between them is also relevant to students’ learning outcomes. We believe that additional emphasis should be placed on studying and, more importantly, systematising what we already know about the relationship between the different aspects of metacognition and, in turn, the relationship that these have with learning, academic performance, and other relevant processes in educational contexts. This effort should prove useful for both theoretical and practical research in education. Nonetheless, this research is not without limitations. For example, using different instruments to evaluate each of the variables considered in the study induces noise in the experimental protocol that could have been avoided if only one task had been developed to evaluate the variables we were looking for. In the same way, the wide range of instruments and ways of operationalising the facets of metacognition undoubtedly leads us to wonder if our conclusions would continue to be true if we used other instruments or procedures. Future research should continue to explore this question using different methodologies. Positive or negative results will provide more information not only about the role of metacognition in the learning process but also about the structure of metacognition.

5. References

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2.5. Supplementary material

Supplementary Material A. Learning Task

A.1. Selection of cue-stimulus pairs.

The list of words used was generated from the EsPal database (Duchon et al., 2013; https://www.bcbl.eu/databases/espal/), considering the phonology of Latin American Spanish. Words were four to six letters long, with one to three syllables, a familiarity rating from 5.0 to 7.0. Subsequently, words with diacritical marks (tildes, accents and/or umlauts) were excluded from the list. The result was a list with 865 words, from which 60 cue-stimulus pairs were randomly formed.

To rule out pairs of words that could facilitate the association between the words during the task, the 60 pairs were evaluated by a sample of 14 Chilean native Spanish-speaking participants. The evaluation criteria were phonological similarity ("How similar are the sounds of both words?"), semantic similarity ("How close are the meanings of both words?") and perceived similarity ("How related do you consider that the two words are in relation to each other?"). The scores for each criterion were averaged, which yielded a total similarity score for each pair of words. From this, the 24-word pairs with the lowest total similarity score were selected. Descriptives of the 24 pairs can be seen in Table S1.

The distractors used in the task were randomly selected in each trial from a subsample of the original list of 865 words. This subsample was randomly created so that the words used in this task and the metacognition task could not be repeated.

Table S1. Descriptives of the three similarity criteria and familiarity scores for the 24 cue-stimulus pairs used in the learning task.

Cue - Stimulus	Phonological similarity *M* (*SD*)	Semantic similarity *M* (*SD*)	Perceived similarity *M* (*SD*)	Total similarity *M* (*SD*)	Familiarity *M* (*SD*)
Firma - Tira	1.50 (0.73)	1.00 (-)	1.14 (0.35)	1.21 (0.21)	5.71 (0.01)
Pulso - Mesa	1.29 (0.45)	1.00 (-)	1.00 (-)	1.10 (0.14)	5.81 (0.77)
Mantel - Recado	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	5.84 (0.47)
Bronce - Folio	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	5.85 (0.76)
Sirena - Regla	1.07 (0.26)	1.07 (0.26)	1.00 (-)	1.05 (0.03)	6.00 (0.26)
Jersey - Colmo	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	6.06 (0.38)
Edad - Feria	1.00 (-)	1.07 (0.26)	1.00 (-)	1.02 (0.03)	6.29 (0.63)
Fuego - Chicle	1.00 (-)	1.07 (0.26)	1.00 (-)	1.02 (0.03)	6.62 (0.14)
Premio - Umbral	1.07 (0.26)	1.14 (0.35)	1.07 (0.26)	1.10 (0.03)	5.63 (0.62)
Viaje - Jefe	3.07 (0.88)	1.93 (0.80)	1.64 (0.72)	2.21 (0.62)	6.37 (0.17)
Luna - Lucha	3.57 (0.82)	1.00 (-)	2.00 (0.76)	2.19 (1.06)	5.63 (0.33)
Piloto - Salida	1.14 (0.52)	1.64 (0.89)	1.57 (0.73)	1.45 (0.22)	5.91 (0.72)
Portal - Seguro	1.00 (-)	1.00 (-)	1.00 (-)	1.00 (-)	6.05 (0.07)
Juerga - Anillo	1.00 (-)	1.21 (0.41)	1.14 (0.35)	1.12 (0.09)	5.94 (0.19)
Trampa - Cubo	1.00 (-)	1.36 (0.61)	1.14 (0.35)	1.17 (0.15)	6.10 (0.14)
Novio - Centro	1.07 (0.26)	1.21 (0.56)	1.07 (0.26)	1.12 (0.07)	6.41 (0.28)
Grito - Cuadro	1.00 (-)	2.29 (1.28)	1.93 (1.16)	1.74 (0.54)	6.07 (0.25)
Huevo - Nivel	1.07 (0.26)	1.14 (0.35)	1.00 (-)	1.07 (0.06)	6.35 (0.09)
Rasgo - Mezcla	1.14 (0.35)	1.14 (0.35)	1.21 (0.41)	1.17 (0.03)	5.02 (0.00)
Frasco - Olvido	1.00 (-)	1.14 (0.35)	1.14 (0.35)	1.10 (0.07)	5.68 (0.33)
Llave - Llama	3.50 (0.91)	1.07 (0.26)	1.57 (0.73)	2.05 (1.05)	5.90 (0.83)
Reptil - Tenis	1.36 (0.48)	1.14 (0.35)	1.43 (0.49)	1.31 (0.12)	6.01 (0.14)
Fuente - Gusto	1.00 (-)	1.21 (0.41)	1.07 (0.26)	1.10 (0.09)	5.86 (0.48)
Chisme - Crimen	1.07 (0.26)	1.14 (0.35)	1.07 (0.26)	1.10 (0.03)	5.16 (0.02)

A.2. Learning task

We decided to calculate an individual learning score based on the area under the learning curve of each participant in order to reduce the impact of the ceiling effect on task performance. For this same purpose, different configurations of the task were tested seeking to increase the variability in the results. Based on a pilot study carried out on a sample of 26 participants (77% women), we decided to cut the task at 5 blocks (Figure S1A), because after that point no significant differences were observed between blocks in the performance of the tasks (*p*s > .106). Figure S1B shows the learning curves for participants in the study.

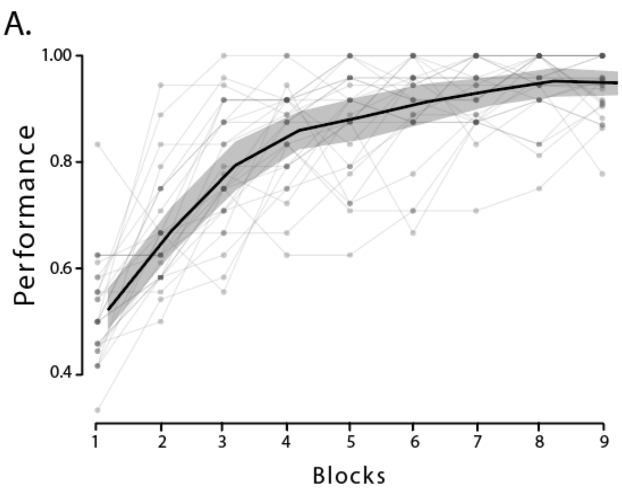

Figure S1. A) Learning curve of the pilot study (*n* = 26). B) Learning curves of the study participants (*n* = 66).

Supplementary Material B. Ask for Help analyses.

Based on the data obtained in the metacognition task, we decided to explore the factors that may explain the decision of the participants to ask for help or not in a given trial. Given the impossibility of determining why they did not use this option, we decided to exclude from these analyses the 10 participants who never asked for help with the task. Our sample was 56 students (*M* = 21.79 years, *SD* = 2.76, 55% female), who asked for help 403 times in total (*M* = 7.20, *SD* = 8.14). We decided to consider three factors that might influence an individual's decision to ask for help or not on a given trial (Goupil et al., 2015; Undorf et al, 2021): the difficulty of that trial, the reported confidence in that trial, and the accuracy with which an individual monitors their performance on the trial, which we evaluated via the metacognitive efficiency in blocks 1-2.

We used logistic regression to determine the effect that difficulty in memorising each stimulus (operationalized as one minus the average performance of all participants on that stimulus) has on the probability of asking for help on a trial. We found that the difficulty of the trial does affect the probability of asking for help (*OR* = 2.89, 95% *CI* [1.35, 6.18], $p = .006$). Since the difficulty of a trial is an objective parameter to which the participant does not have explicit access during the task, we decided to test how a subjective parameter (i.e., their confidence report) affects their probability of asking for help. Using logistic regression, we found that individual confidence (reported on a discrete scale of 1 to 5) does affect whether or not to ask for help (Figure S2A). Specifically, participants have 72.5% less odds of asking for help on a trial with confidence equal to 2 than on a trial with confidence equal to 1. While, on trials with confidence equal to 3, 4, or 5, the odds of asking for help drop by 88.6%, 95.4%, and 99.6%, respectively (Table S2). Next, we decided to assess how participants' metacognitive efficiency influences the likelihood of asking for help. Using logistic regression, we found that the odds of asking for help on a given trial increase by 106% for each 1-point increase in participants' metacognitive efficiency (*OR* = 2.06, 95% *CI* [1.56, 2.72], $p < .001$, Figure S2B), suggesting that individuals who are better at monitoring their mental states are more likely to ask for help during the task.

Table S2. Logistic regression of the probability of asking for help in a trial with confidence in that trial as a predictor (*n* = 56).

Coefficients	B	S.E.	Exp(B) with 95% CI
Confidence (2)	-1.29	0.14	0.275*** (0.209 - 0.362)
Confidence (3)	-2.18	0.17	0.114*** (0.082 - 0.158)
Confidence (4)	-3.07	0.20	0.046*** (0.031 - 0.069)
Confidence (5)	-5.48	0.35	0.004*** (0.002 - 0.008)

Statistical significance: *** p < .001

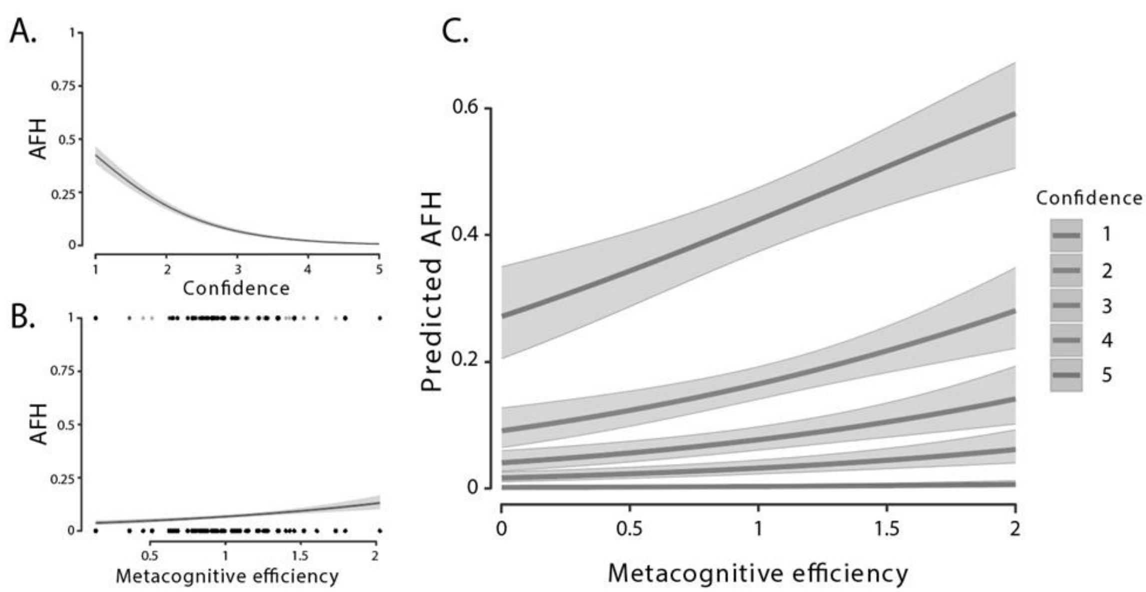

Figure S2. (A) shows the probability of asking for help in a single trial with confidence in that trial as a predictor. Figure (B) shows the probability of asking for help in a single trial with metacognitive efficiency as a predictor. Figure (C) shows the probability of asking for help in a single trial with confidence and metacognitive efficiency as predictors. (*n* = 56).

Finally, we decided to assess the joint effect that both variables (confidence and metacognitive efficiency) have on the probability of asking for help in a trial. We performed a multiple logistic regression on the probability of asking for help with confidence and metacognitive efficiency as predictors. We found that participants have 73.1% less odds of asking for help on a trial with confidence equal to 2 than on a trial with confidence equal to 1. While, on trials with confidence equal to 3, 4, or 5, the odds of asking for help drop by 88.7%, 95.5%, and 99.6%, respectively. In turn, the odds of asking for help increase by 97.4% for each 1-point increase in the metacognitive efficiency of the participants (Table S3). In Figure S2C, we can see that the odds of asking for help are higher in trials with low confidence, but they increase when those who report such confidence are participants with high metacognitive efficiency.

Table S3. Logistic regression of the probability of asking for help in a trial with confidence in said trial and the participant's metacognitive efficiency as predictors. (n = 56).

Coefficients	B	S.E.	Exp(B) with 95% CI
Confidence (2)	-1.32	0.14	0.269*** (0.203 - 0.354)
Confidence (3)	-2.18	0.17	0.113*** (0.081 - 0.157)
Confidence (4)	-3.10	0.20	0.045*** (0.030 - 0.067)
Confidence (5)	-5.47	0.35	0.004*** (0.002 - 0.008)
Metacognitive efficiency	0.68	0.15	1.974*** (1.474 - 2.644)

Statistical significance: *** p < .001

CHAPTER 3. STUDENTS WITH HIGH METACOGNITION ARE FAVOURABLE TOWARDS INDIVIDUALISM WHEN ANXIOUS

Barrientos, M.S., Valenzuela, P., Hojman, V. & Reyes, G. (2022). Students with high metacognition are favourable towards individualism when anxious. *Frontiers in Psychology*, *13*, 910132. https://doi.org/10.3389/fpsyg.2022.910132

3.1. Introduction

As mentioned, the problem caused by the multiple methods of assessing metacognitive ability is not only relevant to what we know about the relationship between metacognition and learning but also to other processes in education, such as problem-solving. Additionally, the effect of social and affective processes experienced in the classroom cannot be underestimated if we want to understand the phenomenon fully.

From this, the main objective of this study was to analyse how metacognitive knowledge –assessed through the self-report questionnaire Metacognitive Awareness Inventory – and metacognitive experiences – operationalized as metacognitive efficiency (Mratio; Fleming & Lau, 2014) during a visual perception task – are related to the performance observed in a problem-solving task, which was relevant to the educational context of the participants. Although we did not assess metacognitive skills in this study, we promoted a study context in which the use of regulatory learning strategies, such as collaboration, could emerge. In addition to this and given our interest in understanding these variables in a more natural setting than the one presented in the first paper, our secondary objective was to study the role that social interdependence – assessed through the Social Interdependence Scales self-report questionnaire – and anxiety – assessed through the self-report questionnaires State-Trait Anxiety Inventory state version and Positive Affect and Negative Affect Schedule – had on these relationships.

3.2. Results

The results did not allow us to corroborate our main objective: neither metacognitive knowledge nor metacognitive experiences showed a relationship with problem-solving. Additional tests, however, enabled us to establish a link between the accuracy of metacognitive experiences, anxiety, and social interdependence. Combining these variables into a single statistical model allowed us to identify that – in the face of higher levels of anxiety – students who are more precise in their cognitive monitoring report more individualistic attitudes in the classroom.

3.3. Discussion

Although the results of this article do not support the hypothesis held regarding the role of the different components of metacognition in problem-solving, we believe that they provide us with information about the role that metacognitive experiences play in the regulation of learning. Contrary to expectations, we show that more precise cognitive monitoring can lead students to show more individualistic attitudes in contexts of greater anxiety. We hypothesize that these attitudes account for a self-regulatory mechanism that allows us to avoid anxiogenic situations in the future.

3.4. Paper

Students with high metacognition are favourable towards individualism when anxious.

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Abstract

Metacognitive ability has been described as an important predictor of several processes involved in learning, including problem-solving. Although this relationship is fairly documented, little is known about the mechanisms that could modulate it. We decided to evaluate the impact of self-knowledge on problem-solving and, in addition, we inspected whether emotional (self-reported anxiety) and interpersonal (attitudes towards social interdependence) variables could affect the relationship between metacognition and problem-solving. We tested a sample of 32 undergraduate students and used behavioural tasks and self-report questionnaires. Contrary to what we expected, we found no relationship between metacognition and problem-solving performance, nor a significant moderating effect when including emotional and interpersonal variables in the model. In contrast, we observed a significant moderating model combining metacognition, self-reported anxiety, and attitudes towards social interdependence. It was found that participants with high metacognition reported attitudes unfavourable towards interdependence when they felt high anxiety. These results suggest that already anxious individuals with high metacognition would prefer to work alone rather than with others, as a coping mechanism against further anxiety derived from cooperation. We hypothesise that in anxiogenic contexts, metacognition is used as a tool to compare possible threats with one's own skills and act accordingly, in order to maximise one's own performance. Further studies are needed to understand how metacognition works in contexts adverse to learning.

Keywords: metacognition, problem-solving, social interdependence, anxiety, virtual classroom.

1 Introduction

Metacognition refers to an individual's ability to know their own mental states (Flavell, 1979). Every day we generate metacognitive outcomes by estimating several aspects of our behaviour, such as the time elapsed prior to making a decision (Corallo et al., 2008), the effort required to make it (Naccache et al., 2005) or the degree of confidence associated with it (Koriat et al., 1980). This phenomenon exhibits individuals' conscious access to their own mental states (Proust, 2013), where these pieces of subjective information are critical to behavioural planning and control (Nelson & Narens, 1990). Now, metacognition has an impact on how we relate to others (Nichols & Stich, 2003; Shea et al., 2014) and in fields where said interactions are relevant, such as education (Norman et al., 2019). In particular, in educational sciences, it has been reported that individual metacognitive ability is one of the best predictors of learning and academic performance, even above other cognitive and motivational variables (Dent & Koenka, 2015; Ohtani & Hisasaka, 2018; Wang et al., 1990). Along the same lines, a positive relationship between the use of metacognitive skills and problem-solving performance has also been reported (Bakar & Ismail, 2020; Davidson & Sternberg, 1998).

Regarding the latter, problem-solving (hereinafter, PS) is a research topic that has widely captured attention in cognitive science and education (Jonassen & Hung, 2012). It has been attributed a fundamental role in learning processes (Anderson, 1993), and today it is considered a relevant skill for the development of competencies in the 21st century (OECD, 2019). In cognitive science, PS constitutes an act involving the execution of a complex, multi-step sequence of goal-oriented processes, such as evaluating and planning, to arrive at an unknown solution (Bartley et al., 2018). Consistently, in education, PS has been defined as a capacity to engage in cognitive processes aimed at understanding and solving situations that do not have an obvious method of resolution (OECD, 2013). Although everything indicates that PS is a relevant construct to understanding school achievement, there is no clarity regarding how it participates in the cognitive architecture of learning. One possibility suggested in the literature is that cognitive, metacognitive, and motivational processes are involved in PS (Mayer, 1998). The first refers to the set of processes involved in the processing, representation, and resolution of the problem; the second, to the monitoring and control of cognitive processes; while the last one, to the emotional disposition of who solves the aforementioned problem. This model agrees with literature that suggests that the relationship between metacognition and PS occurs especially on complex problems that require a wide deployment of cognitive resources (i.e., non-insight problems), and not so on insight problems, in which the solution emerges spontaneously in consciousness (Metcalfe & Wiebe, 1987). In this way, metacognition would play an active and continuous role in the conscious administration of the cognitive resources used during the resolution of a problem (Stuyck et al., 2022). Given the importance that has recently been given to the study of metacognition and PS (Azevedo, 2020; English & Gainsburg, 2016; Perry et al., 2018), and its already mentioned connection, it becomes relevant to combine both phenomena in a single study that aims to clarify their relationship.

On the other hand, different studies have shown that the way in which metacognition is operationalized and evaluated is relevant to understanding the impact it has on skills such as academic performance, learning, or PS itself (Bakar & Ismail, 2020; Dent & Koenka, 2015; Ohtani & Hisasaka, 2018). Precisely, these studies have shown that online measures, e.g., experimental tasks and think-aloud protocols, are better predictors of these variables than offline measures, e.g., self-report questionnaires and interviews. This was early noted by Brown et al. (1982), who questioned the validity and reliability of offline measurements arguing that they would assess beliefs regarding the skills, rather than the skills themselves. Due to this, in this article, we intend to study the relationship between metacognition and PS using instruments of both types. Similarly, literature in the area describes emotional and interpersonal processes that interact with both metacognition and PS, and therefore could affect the reported relationship between both constructs. Regarding emotional processes, recent research has reported that these can alter the metacognitive capacity of individuals, specifically, high levels of stress and anxiety are negatively associated with the efficiency in monitoring one's own mental states

(Barrientos et al., 2020; Culot et al., 2021; Reyes et al., 2015; 2020). Similar results have been reported in the study of PS, where a negative influence of stress on PS performance has been evidenced (Alexander et al., 2007; Nair et al., 2020). Another possible modulator of this relationship are interpersonal variables such as cooperation. In this regard, it has been reported that metacognitive monitoring training in cooperative learning contexts displays better results than in competitive or individualistic learning contexts (Pesout & Nietfeld, 2020). This triad made up of cooperation, competition and individuality has its roots in the theory of social interdependence, widely used to guide instructional design towards cooperative environments and thus favour the development of competencies for the 21st century (Johnson & Johnson, 2014). In turn, it has also been suggested that collaborative social interactions would be beneficial for processes such as decision-making and PS (Bang & Frith, 2017; Haataja et al., 2021; Sills et al., 2016).

Based on the above and given that, as far as we know, the literature in the area exhibits a lack of studies that focus on the emotional and interpersonal mechanisms that could affect the relationship between metacognition and SP, we designed a study that explores these relationships in undergraduate students. For this purpose, we used a set of self-report questionnaires and behavioural tasks. To assess the participants' metacognition, we used both offline and online measurements. For the former, we used a self-report questionnaire, the Metacognitive Awareness Inventory (Schraw & Dennison, 1994). For the latter, we implemented a 2-AFC computer task in which the participants had to indicate their confidence in their own decisions (Fleming et al., 2010). For PS, we designed a non-insight problem-solving task ad hoc to the disciplinary context of the participants. Finally, as emotional, and interpersonal variables, we evaluated the self-reported feeling of anxiety (STAI-S; Spielberger et al., 1968), positive and negative affects (PANAS; Watson et al., 1988), and attitudes towards social interdependence in the classroom (Johnson & Norem-Hebeisen, 1979). We hypothesise that individuals' metacognition will be a reliable predictor of PS, in line with what is reported in the literature. We also hypothesise that the aforementioned relationship will be modulated by anxiety, affects and attitudes towards social interdependence.

2 Material and Methods

2.1 Participants

32 first-year undergraduate students (27 women) participated in the study. The average age of the participants was 19.97 years (*SD* = 2.02, range = [18 - 26]). Although the initial sample consisted of 100 undergraduate students, only 32 answered all the questionnaires and correctly performed the online metacognition task. All participants had normal or corrected-to-normal vision. They received no direct compensation for their participation, although a prize (~ USD$150) was raffled among participants who completed the study. All participants gave written informed consent to participate in this study. The study was approved by the Comité de Ética Institucional en Investigación at Universidad del Desarrollo.

2.2 Instruments and Procedure

2.2.1 Session 1

Participants were asked to respond to a perceptual task to evaluate their metacognitive efficiency, and a series of self-report questionnaires to evaluate their metacognitive awareness, attitude towards social interdependence, and state anxiety levels. Both the task and the questionnaires were coded using PsychoPy (Peirce et al., 2019) and uploaded to the Pavlovia webpage. Participants had two weeks to access the tasks, through a link to the webpage provided by a research assistant, on a computer or laptop in a quiet and dimly lit place.

Perceptual Confidence Task.

Stimuli were arrays of six vertical Gabor patches on a grey background, presented on an imaginary circle at the centre of the screen. Participants were asked to perform the task in a dimly lit room and at a distance of 50 cm from the monitor. The task consisted in deciding in which of two arrays of Gabor patches -presented in a sequence- one Gabor patch with higher contrast was presented. After that, participants were asked to estimate their confidence in their decision (Fig. 1). The experimental session comprised 6 blocks of 50 trials each with a pause between each block. The structure of each trial was the following: after a fixation cross (500 ms), participants were presented the two arrays for 200 ms each, separated by an interval of 300 ms. In one of the arrays, one random Gabor patch had a higher contrast. Participants had to decide when was presented that Gabor, by pressing the "Q" (first array) or "W" (second array) key on their keyboard. During the experiment, contrast varied on a trial-by-trial basis according to a 1-up 2-down staircase method to adjust the individuals' performance to 71% (Garcia-Pérez, 1998). After their response, participants were asked to give an estimate of their confidence about their decision on a scale from 1 ("totally random") to 5 ("completely sure").

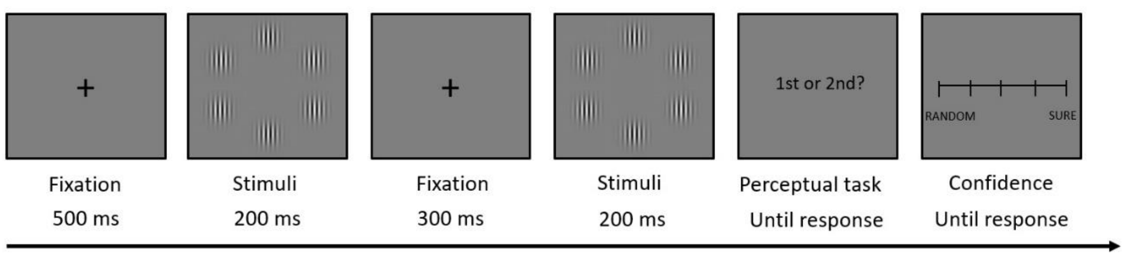

Figure 1. Structure of a single trial in the perceptual confidence task. Participants viewed each stimuli array for 200 ms and had to decide which had a different contrast Gabor patch. Immediately after their response, participants had to evaluate their confidence level in their own decision on a continuous scale from "at random" to "secure". The task comprised 50 training and 300 experimental trials.

Self-report questionnaires.

Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994): This scale assesses beliefs about one's own cognitive monitoring and regulation. The version used in this study has 52 items, with Likert-type responses that range from 1 to 5 and was translated to Spanish and validated by Huertas et al. (2014), which showed a high internal reliability for the instrument (Cronbach's α = .94).

Social Interdependence Scales (Johnson & Norem-Hebeisen, 1979): These three scales evaluate the attitudes of students towards cooperation, competition, and individualism in the classroom. The scales have 22 items and high internal reliability indices (Cronbach's α = .84, 85 and .88, respectively).

State-Trait Anxiety Inventory, state version (STAI-S; Spielberger et al., 1968): This scale assesses state anxiety, i.e., the transitory experience of anxiety at the moment the participant answered the questionnaire. The Chilean version (Vera-Villaroel et al., 2007) has 20 items, with Likert-type responses that range from 1 to 4, and high internal reliability (Cronbach's α = .92).

Positive Affect and Negative Affect Schedule (PANAS; Watson et al., 1988): This scale assesses both positive and negative dimensions of affect. The Chilean version (Dufey & Fernández, 2012) has 20 items, with Likert-type responses that range from 1 to 5, and high internal reliability for both scales (Cronbach's α = .86 and .88).

2.2.2 Session 2

About two weeks after they were asked to complete session 1, participants were instructed to perform a non-insight problem-solving task.

Problem-solving task.

We developed a non-insight, open-ended problem-solving task related to a specific class from the student's career. Two lecturers from said class helped us with the design of the task and allowed us to evaluate participants during class hours. The task begins with a description of a problematic situation, followed by four questions. Each one was aimed to assess a different process involved in problem-solving (OECD, 2010), namely: a) exploring and understanding, b) representing and formulating, c) planning and executing, and d) monitoring and reflecting. The rubric described four performance levels for each question, which were scored from 1 to 4. The total score for this problem corresponds to the sum of the scores obtained in each question.

2.3 Statistical Analysis

All analyses were performed using JASP v.0.13.1 (JASP Team, 2022) and R v.4.1 (R Core Team, 2021). Cronbach's alpha showed an acceptable reliability level on all scales (all α > .72). Two participants were excluded from the analysis due to being outliers in several questionnaires at a time. In order to calculate metacognitive efficiency, we used the perceptual confidence task scores to calculate meta-d'/d' for all participants (Fleming & Lau, 2014). This measure is an SDT approach and is conceptualised as the second-order (i.e., confidence) sensitivity relative to the first-order (i.e., perceptual task) sensitivity (Maniscalco and Lau, 2012). It represents an unbiased measure of an individual's ability to monitor their own performance through the confidence in their decisions. We used Matt Craddock's R port of Maniscalco and Lau's MATLAB functions (https://github.com/craddm/metaSDT) and thank him for making these available to the community.

In order to obtain a robust measure of social interdependence, we calculated a composite score combining the three scales from the Social Interdependence Scales questionnaire. Given the theoretical valences of these three scales, we calculated social interdependence as the subtraction of the average of the z-scores of cooperation and competition minus the z-score of individualism. That way, positive values mean a favourable attitude towards interdependence, while negative values mean an attitude towards independence.

3 Results

First, we analysed linear associations between metacognition and PS, attitudes towards social interdependence (Cooperation, Competition, Individualism, and the composite measure), and emotional indexes (STAI and PANAS). We inspected how metacognition, operationalised as metacognitive efficiency and metacognitive awareness (MAI), predicts

PS performance. Contrary to our expectations, results indicated no significant correlation between metacognitive efficiency and PS performance ($p > .453$). The same analyses repeated over metacognitive awareness reveal the same pattern: no significant association between both constructs ($p > .959$). Then, we inspected a possible association between metacognition and emotional indexes. We found that metacognitive efficiency showed a negative and moderate correlation with self-reported anxiety ($r = -.413$, $p < .05$), meanwhile metacognitive awareness showed no relation with any of those indexes (all *p*s > .158). Finally, we investigated metacognition and social interdependence. Metacognitive efficiency showed no significant association with the composite measure of social interdependence or its subscales (all *p*s > .119), and metacognitive awareness only showed a marginally significant correlation with the cooperation subscale ($r = .346$, $p = .061$). These results are summarised in Supplementary Material 1. Interestingly, we analysed and found no relation between both online (i.e., metacognitive efficiency) and offline (i.e., MAI and its subscales) measures of metacognition (all *p*s > .137). However, further analysis using Bayes factors and the alternating conditional expectations algorithm (ACE; Breidman & Friedman, 1985) suggests that this may result from a lack of statistical power rather than a true null effect (all $BF_{01} < 1.85$), particularly given the small sample size.

In order to further inspect the relationship between metacognitive efficiency and the other variables studied, we factorised the metacognitive efficiency scores in two groups: a group with low metacognition ($n = 16$, $M = .693$, $SD = .215$) and a group with high metacognition ($n = 14$, $M = 1.313$, $SD = .204$). We used a score of 1.0 as the threshold to separate both groups, following Fleming and Lau (2014) who proposed it as a theoretically ideal value of metacognitive efficiency. Logistic regression was used to analyse if metacognitive efficiency levels were related to PS, interdependence, and emotional indexes. We found that social interdependence predicted metacognitive efficiency levels (see Table 1). Indeed, the odds of having high metacognition decreased almost three times for each 1-point increment in social interdependence ($OR = .324$, 95% C.I. [.114, .920], $p < .05$). Next, and given its relationship to metacognition, self-reported anxiety was added as a predictor to this model in order to better explain the results. The resulting model was significantly better than the first one (ΔX^2 = 6.157, p < .05, $R^2_{C\&S}$ = .337). It was found that controlling by self-reported anxiety, the odds of having high metacognition decreased almost four times for each 1-point increment in social interdependence (*OR* = .261, 95% C.I. [.074, .923], p < .05). Likewise, controlled by social interdependence, the odds of having high metacognition decreased 11% for each 1-point increment in self-reported anxiety (*OR* = .899, 95% CI [.815, .991], p < .05). These results suggest that individuals with high metacognition tend to exhibit a poorer attitude towards social interdependence behaviours, such as cooperation or competition (see Figure 2a).

Table 1. Hierarchical logistic regression of metacognitive efficiency levels with interdependence and self-reported anxiety as predictors. N = 30.

Model	Variables	B	S.E.	Exp(B) with 95 % CI	R^2
1	Interdependence	-1.126	.532	.324* (.114 - .920)	.186*
2	Interdependence	-1.345	.645	.261* (.074 - .923)	.337*
	Anxiety	-.107	.050	.899* (.815 - .991)	

Statistical significance: * p < .05.

Note: R^2 calculated by the Cox-Snell formula

For simplicity, we investigated if a single subscale of social interdependence could better explain these results. We found that, although by itself it could not predict metacognitive efficiency levels (p = .057), Individualism was a significant predictor when controlled by self-reported anxiety. Specifically, the analyses showed that the odds of having a high metacognition increased by 19% for each 1-point increment in individualism (*OR* = 1.187, 95% CI [1.008, 1.398], p < .05) if controlled by the anxiety scores. This finding reinforces what was previously reported and shows that the effect on metacognitive efficiency levels depends mainly on an increase in attitudes favourable to independence, rather than a decrease in attitudes favourable to interdependence. It also shows that self-reported attitudes towards individualism and self-reported anxiety are intertwined in their relation to metacognition.

Finally, to understand the relationship between these three variables, a three-stage hierarchical linear regression was conducted with metacognitive efficiency as the dependent variable. Individualism was entered at stage one, self-reported anxiety at stage two, and their interaction at stage three. The analysis showed that individualism was not a significant predictor of metacognition by itself ($p = .347$). Incorporating self-reported anxiety into the model explained an additional 17.5% of variance ($\Delta F(1,27) = 5.97$, $p < .05$). Finally, the incorporation of the interaction between individualism and self-reported anxiety explained an additional 11.4% of variance ($\Delta F(1,26) = 4.36$, $p < .05$). When all predictors were included in the model, self-reported anxiety and its interaction with individualism were proved to be statistically significant predictors of metacognitive efficiency (both *p*s < .05). As seen in Table 2, the final model itself was also statistically significant and predicted a 32.1% of the variance of metacognitive efficiency ($F(3,26) = 4.09$, $p < .05$). At last, we analysed the relationship between metacognitive efficiency and individualism after dividing self-reported anxiety by its median (Figure 2b). We found that the group with higher anxiety ($n = 15$, $M = 50.67$, $SD = 7.59$) showed a positive relation between metacognition and individualism ($r = .529$, $p < .05$), meanwhile the group with lower anxiety ($n = 15$, $M = 32.4$, $SD = 6.07$) showed no relation at all ($p = .911$). These results suggest that individuals with high metacognition tend to have attitudes favourable towards individualism, but only when they feel high anxiety.

Table 2. Hierarchical linear regression on metacognitive efficiency with individualism, self-reported anxiety, and their interaction as predictors.

Model	Variables	B	S.E.	β	R^2	ΔR^2
1	Individualism	.009	.010	.178	.032	--
2	Individualism	.010	.009	.190	.207*	.175*
	Anxiety	-.014	.006	-.419*		
3	Individualism	-.05	.03	-.975	.321*	.114*
	Anxiety	-.05	.018	-1.524*		
	Interaction	.002	.001	1.664*		

Statistical significance: * $p < .05$. $N = 30$.

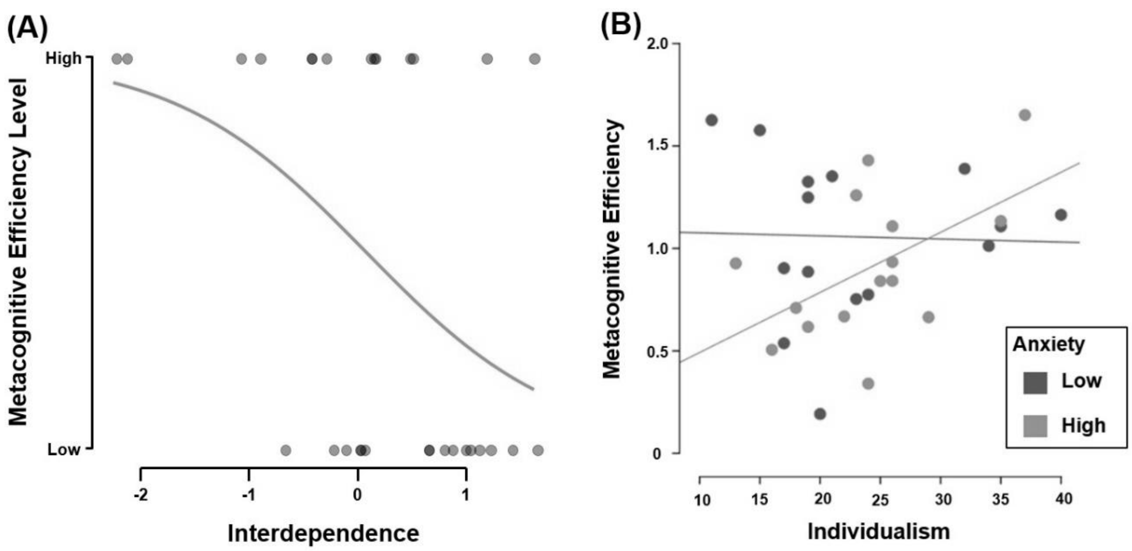

Figure 2. A) Logistic regression of interdependence on metacognitive efficiency levels. B) Regression of individualism on metacognitive efficiency by self-reported anxiety levels. $N = 30$.

4 Discussion

The main goal of this paper was to study the relationship between PS performance and two different measures of metacognition. These two measures were metacognitive awareness, evaluated through the MAI (Schraw & Dennison, 1994), and metacognitive efficiency (Fleming and Lau, 2014). To better understand the relationship between both constructs, we also considered the attitude of the students towards social interdependence, self-reported anxiety, and positive and negative affects.

The analyses showed no relationship between PS performance and metacognition. Although positive relations between both variables have been vastly observed and discussed (Azevedo, 2020; Davidson & Sternberg, 1998; Veenman, 2012), other studies have failed to show these results before (Jacobse & Harskamps, 2012). We hypothesised that this result could be caused by two main reasons. On the one hand, different measurements of metacognition have been shown to not relate in the same way to PS. For example, Jacobse and Harskamps (2012) investigated how three measurements of metacognitive ability (two online and one offline) predicted PS performance. They found that, even though the two online measures - a think-aloud protocol and a novel instrument - were strongly related to PS, the offline measure - a self-report questionnaire - was not related to it. Similarly, recent meta-analyses have shown that offline measures of metacognition are worse predictors of learning and academic performance than online measures (Dent & Koenka, 2015; Ohtani & Hisasaka, 2018). Those results point out that a subjective measurement of metacognition -such as the MAI- may not predict concrete skills such as PS performance. Concerning the online measure, although we had one, metacognitive efficiency has been scarcely used in educational studies and its relationship to other measures has not been studied thoroughly (Fleur et al., 2021). Furthermore, in comparison to other online measures, metacognitive efficiency has some qualities that make it different, namely, it lacks the biases that judgements of confidence or learning have, it is independent from first-order performance, and its relationship to consciousness is not well-known (Rahnev et al., 2021). A possibility is that metacognitive efficiency -

evaluated by a perceptual task- represents a primary self-regulatory mechanism without conscious access to cognitive processes (cf. Nisbett & Wilson, 1977) and, as that, does not have an impact on the way in which individuals modulate more complex processes such as PS and learning. If that is true, it remains to be seen if evaluating metacognitive efficiency via more cognitively complex tasks, such as a memory task (Fleming et al., 2014), brings better results. Finding this relation would mean that specific aspects of the memory metacognitive efficiency -probably shared with other online measures of metacognition, but not with perceptual metacognitive efficiency (Rouault et al., 2018)- are related to PS performance.

Interestingly, we found a negative relationship between metacognitive efficiency and self-reported anxiety. This result reinforces previous findings (Barrientos et al., 2020; Culot et al., 2021; Reyes et al., 2015; 2020) and gives relevance to the inclusion of emotional variables in similar studies. Indeed, the COVID-19 pandemic has had an impact on the anxiety that students report (Yang et al., 2021) and on the coping mechanisms they use (Babicka-Wirkus et al., 2021), which lead us to the main finding of this study. We found a negative relationship between metacognitive efficiency and self-reported attitudes towards social interdependence in the classroom. Further analyses evidenced that this relationship was mostly explained by individualism which showed a positive relationship to metacognitive efficiency. In other words, participants who are more skilled in monitoring their own mental states declare to be more favourable towards individualistic behaviours. Furthermore, the data shows that this relationship is more common for students who report feeling high anxiety levels. While the bulk of literature on metacognition and social interdependence tends to focus on the positive aspects of the interrelationship between cooperation and metacognition (Frith, 2012; Grau et al., 2018; Smith and Mancy, 2018), our findings give hints that point in the opposite direction. We hypothesise that, in an already anxiogenic context, individuals with high metacognition would prefer to work alone rather than with others, as a coping mechanism against further anxiety derived from collaborative work. Speculatively speaking, individuals with high metacognition could be better at reading their environment and own capabilities and adapting to changes in any of them, in order to maximise their performance. It remains to be seen if this is true, and if the effect is not explained by personality factors such as behavioural inhibition that could lead participants to retreat from social interactions in anxiogenic contexts.

Sociocultural practices, such as collaboration or cooperative learning, are developed in a setting of community activity or conditions, and it is these conditions that modulate how this collaboration develops (Hedegaard, 2019; Mejía-Arauz et al., 2018; Rogoff, 1998). In other words, the relationship that people have with collaboration and how it is performed is dialectically defined by the social or interactional context in which this activity is carried out. In the Chilean case, the educational scenario has been described as an individualistic scenario, where the educational policy’s logic is framed in accountability and individual incentives (López et.al., 2018), which also reflects a tendency towards classroom methodologies that are more individual and teacher-centred than collective and focused on the interaction between students (Martinic et al., 2013; Preiss, 2011). It is possible that students feel comfortable in individual learning spaces, while in collective contexts they feel in an unknown territory where they have fewer tools available. Thus, in an anxiogenic time, such as the context of a pandemic, with computer-mediated interaction and, with peers who do not know each other face to face, it could be expected that students prefer not to participate in group activities, even more so students with a high metacognitive efficiency, that is, students that know what they know and what they don't.

Nonetheless, our study had limitations, namely the low sample size and the instruments’ selection. The low sample size could lead us to not find relations between variables due to their low effect and/or the low statistical power of our analyses (i.e., type-II errors). Indeed, post-hoc analyses and a review of studies with similar variables suggest a sample size at least twice as large (Desender & Sasanguie, 2022; Taouki et al., 2022). Concerning the instruments’ selection, our study relied too heavily on self-report questionnaires. Those have been criticised for being inherently biased and representing beliefs rather than the processes themselves (Craig et al., 2020). Studies of this type would benefit from objective measures of emotional distress and interdependence in participants. In line with this, future research should aim at replicating this study in classrooms to evaluate if the attitudes towards interdependence translate into social behaviours coherent with them. It would be interesting to see if these attitudes affect the quantity and quality of interactions in the classroom, and how they relate to the metacognitive ability of the students. In the same line, an experimental replication manipulating the stress level that participants feel could help us understand if individuals with high metacognition are better suited to adapt to changes in their environment, being collaborative in favourable contexts and individualistic in adverse ones. Finally, further focus should be put on studying how metacognitive efficiency relates to a) problem-solving skills and b) other measures of metacognition. Integrating what different academic fields know about metacognition should be a priority, to better understand, evaluate and train this ability in various settings. As far as we know, there is a lack of literature that seeks to explain what we know about metacognition in educational settings. Even though the positive influence of metacognition in aspects such as learning, academic performance or PS is widely known, the mechanisms that explain these relationships are not well documented. In the same line, despite being extensively used and studied in cognitive sciences and neuroscience, metacognitive efficiency, and its gold-standard measure: meta-d'/d', have been rarely used in education. We think that its use and study in educational studies should be encouraged as a way to build conceptual and methodological 'bridges' between both fields.

5 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6 Author Contributions

All authors contributed to the study concept and design. MB and PV collected the data. MB and GR analysed the data. All authors drafted the article and approved its final version for submission.

7 Funding

This work was supported by a research grant from the Centro de Innovación Docente (CID) at Universidad del Desarrollo to GR and VH, and by ANID Becas/Doctorado Nacional 21211819 to MB.

8 Data Availability Statement

The database generated for this study can be found at the Open Science Framework (OSF) at https://osf.io/ajb6c/

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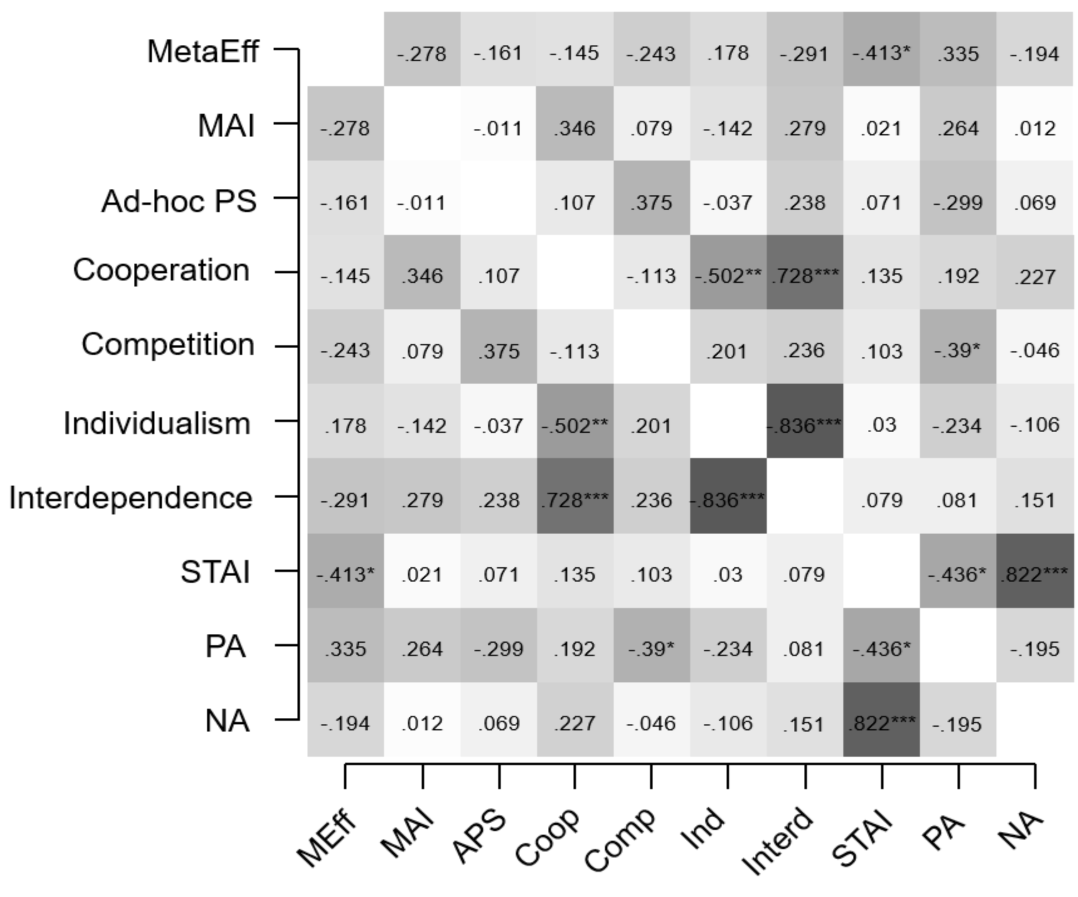
3.5. Supplementary material

Supplementary Figure 1



Supplementary Figure 1. Heatmap of linear regression coefficients. MetaEff and MAI represent both measures of metacognitive ability. Ad-hoc PS represents the total score of the problem-solving task. Cooperation, Competition, and Individualism are the subscales of the Social Interdependence Scale, while Interdependence equals the composite measure obtained from them. Finally, STAI, PA and NA are three measures of emotional indexes: self-reported anxiety, positive affect, and negative affect, respectively. $N = 30$.

CHAPTER 4. GENERAL DISCUSSION

4.1. Overview

The main objective of this thesis was to investigate the relationship between metacognition and the learning process in undergraduate students. Metacognition is the awareness, monitoring, and regulation of one's own cognitive processes (Brown et al., 1983; Flavell, 1979). In this thesis, we operationalise metacognition based on the three facets described in the literature (Dunlosky & Metcalfe, 2009; Efklides, 2008; Pintrich et al., 2000): metacognitive knowledge (MK), metacognitive experiences (ME), and metacognitive skills (MS). MK is the knowledge we have about our own cognitive processes, such as our strengths and weaknesses, the learning strategies that work best for us, and the signals that tell us if we are learning (Flavell, 1979; Pintrich, 2002). ME are the reflections we make about our own learning, such as when we realise that we do not understand something or when we feel confident during a certain task (Efklides, 2006a; Flavell, 1979; Jia et al., 2019). Finally, MS are the strategies we use to control our own learning, such as when we set goals, make plans, and use self-regulation strategies to control our performance during a task (Brown, 1987).

In the scientific literature, it is common to find the idea that metacognition is beneficial to the learning process (e.g., Goldstein & Calero, 2022; Krieger et al., 2022; Pintrich, 2002; Veenman et al., 2005; Wang et al., 1990). This idea is also echoed in non-academic institutions' statements and programs, where it is also common to find mentions of the positive role that metacognition plays in the learning process (e.g., Education 2020, 2022; Education Endowment Foundation, 2023; National Research Council, 2012; OECD, 2016, 2019; UNESCO, 2013). Moreover, this idea forms the basis of many educational interventions around the world (e.g., Iturrieta et al., 2018; Perry et al., 2018; Soto-Córdova et al., 2023; Terlecki & McMahon, 2018; Zheng et al., 2021). However, this idea has no solid empirical basis. Indeed, much of the research that examines the relationship between metacognition and learning considers metacognition a unidimensional construct without paying attention to the facets that compose it or, even worse, generalising results obtained from the study of a single measure of metacognition to the entire construct (Dinsmore et al., 2008; Hong et al., 2016; Pintrich & de Groot, 1990).

This is problematic when we consider that several studies show that the components of metacognition are not necessarily connected (Lehmann et al., 2022; Saraç & Karakelle, 2012; Sperling et al., 2004), and indeed, there is evidence that not all metacognitive activity is beneficial to the individual (Desender & Sasanguie, 2021; Norman, 2020). Therefore, by conceptualizing metacognition as a composite of multiple components rather than a unidimensional construct, it is possible to identify elements of metacognition that may not inherently promote learning but rather exert a neutral or even detrimental influence.

To address this question, I drew inspiration from theoretical models that present a three-component taxonomy of metacognition. Since the origins of the concept in the 1970s, metacognition has been recognised as a psychological construct with two main functions and an ever-changing number of components (Tarricone, 2011). To our knowledge, an empirical study of how these different functions and components relate to other psychological processes, such as learning or problem-solving skills, has rarely been done, and not precisely to reveal the differential role that the components of metacognition might have on these processes (e.g., Jang et al., 2020; Zepeda & Nokes-Malach, 2023). The few sources of information that shed light on this issue are meta-analyses (Dent & Koenka, 2016; Muncer et al., 2022; Ohtani & Hisasaka, 2018) comparing research using different instruments to study different aspects of metacognition in relation to learning-related processes.

Despite the prevailing belief regarding the positive impact of metacognition on learning, this thesis seeks to provide information about the gap in the empirical evidence mentioned above. This, coupled with the importance of confirming metacognition and its facets as beneficial to education, justifies this work.

4.2. Summary of findings

This thesis included two original studies. The first one investigated the influence of the three facets of metacognition on associative learning and academic performance. In contrast, the second one investigated how MK and ME are related to problem-solving skills in a context conducive to using collaborative strategies in the classroom. In the following, I will focus on the most relevant findings of both studies.

First, we found a positive relationship between associative learning and ME, but no relation with MK and MS. In other words, the better an individual is at reflecting on their own psychological activity, the better they are at learning. This result affirms the positive contribution of ME to the learning process, specifically highlighting its role in confidence judgements. Confidence, and especially the accuracy with which one makes confidence judgments, is a key part of the learning process (Hainguerlot et al., 2018; Mengelkamp & Bannert, 2012). Retrospective confidence judgments allow an individual to assess their current state of knowledge about the content being learned, update their mental models, allocate available cognitive resources, and take actions that enable them to improve their learning (Bransford & Schwartz, 1999; Mengelkamp & Bannert, 2012; Robey et al., 2017). Importantly, only correct judgments will enable the individual to accomplish these steps (Dunlosky & Rawson, 2012). Even if confidence judgments are not explicitly requested, as in our learning task, evidence suggests that individuals naturally engage in these judgments (Aguilar-Lleyda et al., 2021). This result indicates that students could benefit from interventions that specifically target enhancing the accuracy with which they judge their own learning.

Regarding the impossibility of corroborating a relationship between learning and the other facets, it has been noted that MK and MS are involved in more complex learning modalities, particularly those involving novel tasks, where the individual must transfer knowledge about similar tasks and the strategies useful for their resolution from past experiences (Bransford et al., 1999; Veenman & Beshuizen, 2004). Although students who know more strategies and use them more efficiently are better learners than their peers in certain contexts (Stanton et al., 2021), it is evident that different forms of learning trigger different cognitive and metacognitive resources. While we did not find that MK and MS had a direct relationship with associative learning, we found two models that comprise these variables and are worth mentioning.

On the one hand, we found an indirect effect of MK on associative learning mediated by ME. That is, an individual's knowledge about their own psychological activity explains their self-monitoring accuracy, which, in turn, explains their learning. This result is consistent with models that propose MK as a source of information - or bias - that feeds into ME (Efklides, 2006b, 2008; Lehmann et al., 2022). Confidence ratings depend on prior knowledge regarding person and task characteristics (Dinsmore & Parkinson, 2011), which also affects their calibration (van Loon et al., 2013). This result reinforces the importance of intervening in the accuracy with which students judge their learning and indicates that one way to do this is to design interventions to improve students' MK. The focus should not only be on increasing self- and strategy knowledge, but also on the procedural and conditional knowledge needed to identify the best strategies for specific learning situations.

On the other hand, we found that the previously reported relationship between ME and associative learning was moderated by MS. Specifically, individuals who used more self-regulatory learning strategies show a gentler slope in their relationship between ME and learning than those who never used these strategies. Put another way, individuals with high metacognitive sensitivity did not exhibit a significant difference in learning outcomes based on the implementation of self-regulatory strategies. Conversely, individuals with low metacognitive sensitivity who used strategies showed higher learning outcomes than those who did not. Although participants did not have the option to ask for help during the associative learning task, this effect may reveal the use of other regulatory strategies (Undorf et al., 2021). These results suggest that using MS could serve as an "equalizer", giving students with low self-monitoring skills an alternative to improve their learning (De Boer et al., 2018; Donker et al., 2014). Thus, effective and less effective learners differ both in the accuracy of their own metacognitive judgements and in their use of strategies. From this, we can hypothesise that the monitoring and control functions of metacognition could act in a complementary way, giving rise to two types of pathways to learning: one based on self-monitoring and the other based on strategy use (Vrugt & Oort, 2008).

Second, we also found that academic performance directly relates to all three facets of metacognition assessed. Many studies have consistently demonstrated that high academic achievement is closely linked with metacognition, even when controlling for intelligence and other cognitive variables (Ohtani & Hisasaka, 2018; Vrugt & Oort, 2008). Our results showed that both MK and ME were positively related to academic performance, whereas MS was negatively related, specifically in individuals who were more efficient at asking for help and had worse academic performance. The first results confirm the relationship between metacognitive monitoring and academic performance vastly reported in the literature (Wagener, 2016); meanwhile, the findings regarding MS contradict our hypotheses. In retrospect, it is important to stress the nature of the choice to ask for help, which differs from other experimental situations. While some authors highlight the relevance of instrumental help-seeking in educational contexts (for a review, Li et al., 2023), our task was based on executive help-seeking, i.e., participants did not ask for hints to try and solve the problem by their own, they asked for the answers to the problem (Undorf et al., 2021). Regarding this point, it has been reported that students who prefer executive help perceive themselves as more academically incompetent than their peers (Butler, 2006; Karabenick & Berger, 2013), offering a potential explanation for the observed negative relationship with academic performance.

Finally, our results in the second study did not allow us to corroborate if MK and ME are directly related to problem-solving skills. Although the results do not allow us to answer the main objective of this thesis, i.e., the role of metacognition facets on the learning process, some findings provide information about the use of metacognition in the classroom. Specifically, we found a positive relationship between ME and individualism among students who report feeling anxious. Although these results contradict what the literature suggested (students with high metacognition tend to be more collaborative than their peers; Grau et al., 2018; Smith & Mancy, 2018), these investigations do not consider the effect of anxiety on this relationship. Our results lead us to hypothesise that students who more precisely monitor their own internal states tend towards individualism as a coping mechanism when facing uncertainty in an anxiogenic context. While the literature mainly describes the effects that anxiety can have on certain aspects of learning, such as reduced confidence (Silaj et al., 2021) or impaired problem-solving skills (Llera & Newman, 2020), some studies show that students with high metacognition or who engage in self-regulatory cognitive strategies are less susceptible to these emotions (Brady et al., 2018; Legg & Locker, 2009). Whether these differences depend on changes in the use of certain strategies (as the results of this article might suggest) warrants further study.

These results contribute to our knowledge about how different facets of metacognition influence associative learning and academic performance. Notably, our findings support the thesis that the importance of the facets of metacognition varies across different aspects of the learning process. Chein and Schneider articulate this idea by stating that "the metacognitive system aids the learner in establishing the strategies and behavioural routines that support the execution of the task" (2012, p.79). We hypothesise that the metacognitive system would also be able to establish the metacognitive mechanisms necessary to accomplish specific learning goals. This suggests that while basic aspects of learning may only elicit one metacognitive facet, more complex elements may require specialised metacognitive processes. An example of the metacognitive system in action is evident in learning within novel contexts (Bransford et al., 1999; Veenman & Beshuizen, 2004). It is speculated that individuals who excel in these contexts do so using MK and MS: while MK allows the individual to retrieve strategies used in similar contexts, MS enable the individual to implement and evaluate these strategies (Chein & Schneider, 2012). This aligns with neuroimaging work, indicating that in novel contexts, there is heightened neural activation in areas related to metacognitive control, such as the anterior prefrontal cortex, which diminishes after a few trials when the situation is no longer novel (Cole et al., 2010).

4.3. Future directions

An important area for future research involves expanding upon the findings presented in this thesis. This entails investigating various types of learning or aspects related to learning, where their relationship to metacognition may show some level of complexity. Recent publications show that the facets of metacognition are not necessarily correlated with each other (Lehmann et al., 2022). Furthermore, some authors highlight the relevance that different facets of metacognition have on different types of learning (Jang et al., 2020; Stanton et al., 2021; Veenman & Beshuizen, 2004). Subjecting these relationships and metacognition interventions designed for educational contexts to experimental scrutiny is relevant for policymakers, educators, and students. Determining, for example, whether monitoring and control are equally relevant for collaborative learning or experiential learning would allow for the design of more effective intervention programs.

Much of the literature studying the relationship between metacognition and learning - including this thesis - has used correlational studies. Due to its relevance to practice, an obvious next step would be to conduct experimental studies investigating how training to improve some facet of metacognition can improve learning or learning outcomes. However, there is a preliminary step, as the evidence on the trainability of metacognition is mixed: while the education literature acknowledges that metacognition is a trainable skill (Azevedo, 2020; Desoete & De Craene, 2019; Perry et al., 2018), the cognitive science literature still seems to be seeking ways to train it (Rahnev et al., 2022; but see also Carpenter et al., 2019, and Rouy et al., 2022). As mentioned in the introduction, both areas of the literature define, operationalise, and assess metacognition in different ways (Kuhn & Dean, 2004; Son, 2007), with a focus on different facets of metacognition (Fleur et al., 2021), so this disagreement could be due to differences in the trainability of each facet of metacognition. Considering this, future research should actively explore the feasibility of training metacognitive knowledge, experiences, and skills in educational contexts.

The trainability of metacognition immediately brings to mind the external factors such as stress and anxiety, which can unintentionally influence metacognition. Although the possibility of training the accuracy of metacognitive judgments is not yet confirmed, several studies show that metacognition, particularly ME, can be influenced positively and negatively by stress (Culot et al., 2021; Massoni et al., 2014; Reyes et al., 2020), and are also related to stress reactivity (Barrientos et al., 2020; Reyes et al., 2015), and students' feelings of anxiety (Barrientos et al., 2022; Silaj et al., 2021). However, the effect of stress and anxiety on students does not seem to be the same for everyone. Some studies have shown that students with high metacognition may be less affected by these factors (Legg & Locker, 2009). The varied impact of stress and anxiety on students remains a crucial area for exploration. Future lines of research could delve into the specific dynamics at play, examining how different levels of metacognitive ability shape individual responses to stressors. Through this, we can gain deeper knowledge about the potential protective role of metacognition in the face of external pressures, offering important implications for educational programs and students' well-being.

As we gain a better understanding of the role of metacognition in the learning process, it becomes apparent that there is a need for further research that helps us uncover the mechanisms underlying this relationship and to bridge the gap between the accumulated theoretical knowledge and the practical application in educational contexts. In this vein, metacognition research can benefit from using methodologies incorporating several instruments designed to assess different facets of this construct. As we have seen, if we want to study the effect of metacognition on other processes, studies with a single measure of metacognition cannot show us the whole picture (Saraç & Karakelle, 2012). If we want to understand how metacognition operates, we must consider the different aspects of metacognition at play during any cognitive enterprise. For this and given the evidence from several meta-analyses on the topic (Dent & Koenka, 2016; Muncer et al., 2022; Ohtani & Hisasaka, 2018), it is not enough to use different instruments, but it is also important that these measurements are both online and offline. Online measures, such as accuracy ratings, provide information about experience-based judgements that occur during and shape the learning process (Craig et al., 2020; Koriat, 2007). On the other hand, offline measures, such as self-report questionnaires, offer insights into past experiences, perceptions, and contextual factors that prelude the learning process and shape the expectations and motivation with which we approach it (Martins Siqueira et al., 2020). A more authentic representation of how metacognition and its components operate in learning environments would offer practical insights for educators and learners alike.

However, introducing new tools in the assessment of metacognition demands extra effort, as these instruments will serve no purpose unless we clearly understand what aspects of metacognition they measure. In 2008, Dinsmore et al. found that only 32% of articles studying metacognition in educational contexts defined and operationalised metacognition. Today, the situation does not seem to have improved (Azevedo, 2020; Wacker & Roebers, 2023; Zepeda & Nokes-Malach, 2023). The first step in solving this problem does not involve either grand consensus or new taxonomies, but rather making explicit what we mean by metacognition, what aspects of it we are studying, and how the instruments we choose will allow us to assess those aspects. This may seem utopian, but the solution to the conceptual and methodological challenges that have plagued the study of metacognition since its beginning should start with the commitment of the authors themselves, who are troubled by this fuzziness. This recommendation applies not only to research in educational contexts, but also to research in experimental, clinical, and other contexts that face similar problems to those described in the introduction of this manuscript.

4.4. Conclusions

In the 1980s, Ann Brown described metacognition as "a many-headed monster" (Brown et al., 1983, p. 137) due to its pervasive presence in the psychology literature of the time. This apparent omnipresence of metacognition led the discipline to theoretical and methodological challenges that remain (Azevedo, 2020; Fleur et al., 2021; Veenman et al., 2006), making certain problems more difficult to answer. The role of metacognition in learning seems to be one of these problems. Although the positive role of metacognition in learning and related educational processes has been described since the 1980s (Babbs & Moe, 1983; Baird, 1986; Baker, 1982; Wang et al., 1990), today, there are still doubts about how the different facets of metacognition behave in these relationships.

The results reported here support the thesis that different aspects of the learning process differentially recruit different facets of metacognition (Chapter 2). While complex aspects such as academic performance may depend directly on multiple facets, more basic aspects, such as associative learning, depend on only one. However, this does not imply that the other facets do not continue to operate in the background. As observed, MK indirectly affects associative learning through ME, while the use of MS influences the relationship between ME and associative learning. Although further studies are needed to confirm these results in other aspects of the learning process, they contribute to constructing a more comprehensive understanding of metacognition's involvement in the learning process. Additionally, the results also suggest that the relationship between these variables may be affected by external factors such as the anxiety students experienced during the COVID-19 pandemic quarantines (Chapter 3). Our results show that students who are better at monitoring their cognitive processes and who were more affected by their context behaved contrary to expectations and reported less willingness to collaborate. Further investigation into how these attitudinal changes impact academic performance is warranted; however, research suggests that students with high metacognitive skills adapt successfully despite the new demands of the environment (Legg & Locker, 2009).

In conclusion, it is possible to affirm that the role of the facets of metacognition in the learning process is both intricate and context-dependent. The collective interplay between

MK, ME, and MS influences learning outcomes, but this relationship is nuanced and influenced by factors such as task characteristics and students' emotional states. Future metacognition research needs to continue investigating this question in more detail, concentrating on the differential roles of the facets of metacognition. Further, metacognition researchers need to start directing their efforts at solving the challenges this area of study has faced since its inception. Although the idea of a single conceptual framework for all areas of psychology that use this construct is impossible, our ultimate goal should be to develop a comprehensive view of metacognition, facilitating effective communication and eliminating the fuzziness of its study.

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