Children's Aha-Experiences:

How Children Experience and Understand Sudden Insight

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General Summary

Children undergo a formidable conceptual development in early childhood and are known to be curious and active learners. While much of children's conceptual learning involves the gradual construction of knowledge, occasionally they may make a leap; they may have an *aha-experience*. How do such leaps in understanding influence the child's subsequent learning? We know from research with adults that aha-experiences can benefit learning, by facilitating increased motivation (Liljedahl, 2005; Skaar & Reber, 2020, 2021) and more accurate memory (Danek et al., 2013; Kizilirmak et al., 2016). We also know that children have aha-experiences from an early age (Haugen et al., in press; Marchant et al., 2022; B. Sobel, 1939). Yet, to date, very little systematic research has investigated children's aha-experiences. The overarching aim of this dissertation is to build a foundation for research on aha moments in childhood. It provides theoretical, empirical, and methodological contributions to the study of children's aha-experiences.

The theoretical contribution of the current project consists of both the first paper and this dissertation. Paper 1 is a theoretical book chapter which provides a review of the cognitive psychology of aha moments and places aha moments in a wider developmental context. The chapter discusses momentary changes in cognition and affect which make up an aha moment, and more long-term changes in motivation and development that may follow an aha moment. In this dissertation, the section Theoretical Background picks up the thread from the book chapter and elaborates in more detail on how children's aha-experiences may be related to their overarching cognitive and metacognitive development. Children's aha-experiences are conceptualized as metacognitive experiences that accompany and guide children's conceptual development from early childhood.

The empirical contribution of the current project provides the initial data on how children experience and understand aha moments. Two empirical studies are reported in Paper 2 and Paper 3. The first study investigates children's understanding of the affective valence of aha-experiences. Children aged 4 to 8 years old (N = 123) were presented with problem-solving scenarios and asked how the character in the story was feeling. We found that in all age groups, children understood that having an aha-experience was associated with positive affect. However, there were age-related differences in children's affect judgements when a problem was solved through trial and error. The 4-year-olds expected a story character to feel less sad after a series of failed solution attempts, compared with the older age groups. To follow up the tentative finding that children understand the affective valence associated with aha-experiences, the second study assessed children's understanding of aha-experiences beyond affective valence.

The second empirical study investigated children's experiences and understanding of aha moments. Children aged 4 to 8 years old (N = 160) solved a picture clues task designed to elicit aha-

experiences as well as a broad set of tasks that assessed their understanding of aha-experiences. Our results indicate that there is a developmental lag between the occurrence of aha-experiences and children's understanding of aha-experiences. Based on experimenter observation, children had the same number of aha-experiences on the picture clues task in all age groups. However, understanding of aha-experiences improved with age. With age, there were improvements in children's ability to self-report their own aha-experiences, to distinguish between scenarios where a story character did or did not have an aha-experience, and to correctly identify statements that describe a typical aha-experience. The second study also provided tentative evidence that children's aha-experiences, like those of adults, are associated with motivation and solution accuracy. Higher numbers of observed aha-experiences were associated with increased motivation to continue working on a similar task rather than switching to something new, and trials with observed aha-experiences had higher accuracy compared to trials without observed aha.

The methodological contribution of the current dissertation consists of several new tasks suitable for children in the age-range 4 to 8 years old. First, a visual remote associate task was developed to elicit children's aha-experiences in an experimental setting. Second, a range of new tasks were developed to assess children's understanding of aha-experiences. The tasks have been made accessible on the Open Science Framework and can be used in future research on children's aha-experiences.

Many new lines of research can be drawn from the current work, with implications for education, for the cognitive science of insight, and for developmental research on metacognition and emotion understanding. The current work encourages educators to consider how metacognitive experiences shape students' progress and motivation. When it comes to the cognitive psychology of insight, gaining a better understanding of how aha-experiences develop can advance the field by broadening the scope of the field and drawing on methods and knowledge from developmental science. In developmental research, the aha-experience forms an interesting case of how metacognitive experiences influence cognitive development, and how children develop an understanding of their own thoughts and feelings. As for the development of emotion understanding, the close connections between a cognitive shift in understanding and the characteristic affective profile of the aha-experience can provide new knowledge about how children develop an explicit understanding of the relationship between thoughts and feelings.

List of Papers

Paper 1

Prenevost, M. H., & Reber, R. (in press). The aha moment: Changes in cognition, affect, motivation, and development. In K. Taku & T. K. Shackelford (Eds.), *The Routledge International Handbook of Changes in Human Perceptions and Behaviors*. Routledge.

Paper 2

Prenevost, M. H., Haugen, J., Nilsen, I. B. R., Bølstad, E., Pons, F., & Reber, R. (in review). *Young children's understanding of affective implications of insight.* [Submitted for publication].

Paper 3

Prenevost, M. H., Nilsen, I. B. R., Bølstad, E., Pons, F., Harris, P. L., & Reber, R. (in review). *Young children's experience and understanding of aha-experiences.* [Submitted for publication].

It may even seem that affective, dynamic factors provide the key to all mental development and that in the last analysis it is the need to grow, to assert oneself, to love, and to be admired that constitutes the motive force of intelligence, as well as of behavior in its totality and in its increasing complexity. (Piaget & Inhelder, 1969, pp. 157–158)

Introduction

Children undergo a formidable conceptual development during the preschool and early school years. They are known to be curious and active learners with a strong motivation to explore and learn about the world that surrounds them. Yet the dynamics of this motivation to learn is not well understood. Imagine a child who is learning to read. At first, they are learning about the individual letters. Perhaps they even begin to combine the letters into simple words; "hat"; "cat"; "sat". They gradually get better at recognizing the letters and sounding them out to spell words. Along the way, they may feel excitement to be learning something new, mastery and pride when they succeed, but also frustration and boredom in the face of repetitive practice exercises and increasingly difficult words. Like most learning processes, literacy learning is accompanied by a diverse set of emotions, and these emotions in turn influence the child's persistence and motivation to continue practicing. Most of the learning process will be gradual, with repeated practice, trial-and-error. Yet once in a while, the child might make a leap. They may, for instance, suddenly grasp that long words can be broken down into smaller units, which can more easily be decoded and understood. With this new understanding, they can now search for smaller, recognizable units when faced with daunting long and unfamiliar words, rather than trying to sound out the whole word letter by letter. Such a sudden leap in understanding is called an aha-experience.

How might this leap in understanding influence the child's future learning efforts? We know from research with adults that aha-experiences can benefit learning, by facilitating increased motivation (Liljedahl, 2005; Skaar & Reber, 2020, 2021) and more accurate memory (Danek et al., 2013; Kizilirmak et al., 2016). We also know that children have aha-experiences from an early age (Haugen et al., in press; Marchant et al., 2022; B. Sobel, 1939). Yet, to date, there is very little systematic research investigating children's aha-experiences. As a consequence, there are many open questions when it comes to how children experience aha moments, how these moments influence subsequent learning processes, and how children's understanding of these experiences develops with age. The overarching aim of this dissertation is to build a foundation for research on aha-experiences in childhood. This is done, first, through a theoretical contribution that places momentary aha-experiences in a developmental context, and second, through an empirical contribution that focuses on how children experience and understand aha moments.

The current work has implications for education, for the cognitive science of insight, and for developmental research on metacognition and emotion understanding. Previous research has indicated that children have aha-experiences in learning situations (Haugen et al., in press; Marchant et al., 2022). Thus, there is a need for a better understanding of how aha-experiences relate to the overall learning process and how teachers and caregivers can facilitate children's aha-experiences. However, before moving to the classroom it is important to know more about what children's aha-experiences are like, and whether they are indeed related to indicators of learning such as accuracy and motivation. When it comes to the cognitive psychology of insight, understanding how aha-experiences develop across childhood can advance the field by broadening its scope and by drawing on methods and knowledge from developmental science. In developmental research, the aha-experience forms an interesting case of how metacognitive experiences influence cognitive development, and how children develop an understanding of their own thoughts and feelings. The momentary nature of aha-experiences can perhaps make them easier to observe and measure compared to more state-like metacognitive experiences such as curiosity and uncertainty, once methods to elicit and record aha-experiences are in place. As for the development of emotion understanding, the close connections between a cognitive shift in understanding and the characteristic affective profile of the aha-experience can provide new knowledge about how children develop an explicit understanding of the relationship between thoughts and feelings.

This doctoral work consists of this text (referred to as the dissertation) and three papers. The dissertation provides an extension of the theoretical work from the first paper, and a synthesis of the theoretical and empirical contributions of all three papers. The text is divided into three sections. First, under the headline Theoretical Background, the theoretical contribution from the first paper of the dissertation project is presented and the theoretical connections to developmental research are further elaborated. Then, under the headline Empirical Studies, the two empirical papers are summarized, followed by an elaboration of some methodological considerations pertaining to the methodological approach, the development of the experimental tasks, and the handling of transparency and ethical concerns. In the final section, under the headline General Discussion, the contributions from the theoretical and empirical sections are synthesized and future directions are drawn.

Theoretical Background

Aha-experiences and sudden insight have fascinated researchers for over a century, and recent methodological advancements have led to renewed interest in this phenomena within cognitive psychology (for reviews, see Kounios & Beeman, 2009; Laukkonen et al., 2023; Topolinski & Reber, 2010; Tulver et al., 2023). However, although developmental studies were a part of the early research program on insight (Alpert, 1950; B. Sobel, 1939), children's insights and aha-experiences

have received little attention from developmental research. The current dissertation makes a two-fold contribution to the study of children's aha-experiences and includes both the theoretical work presented in this section and the empirical work presented in the next section. A theoretical foundation for the study of aha-experiences in childhood is built through: a review of the cognitive psychology of insight that places moments of insight in a larger developmental context (Paper 1, briefly outlined below); and an elaboration of how aha-experiences relate to current developmental research on children's metacognitive development (the section Aha-Experiences and Cognitive Development).

Defining the Aha-Experience

Defining aha-experiences has proven an elusive task. Researchers have suggested various definitions, often depending on specific research areas or research goals. Definitions of aha-experiences vary in the degree to which they emphasize cognitive processes, phenomenology, solution of specific kinds of problems, the value attributed to the discovered idea, and the role of incubation and impasse. Historically, cognitive psychologists in the tradition of the Gestalt psychology of the early 20th century have tended to focus on specific cognitive processes that can distinguish insightful reasoning, which may involve an aha-experience, from analytic reasoning, which is thought to be a more stepwise approach to solve a task (Ohlsson, 1984). Several branches of research can be traced back to these early insight studies. In cognitive psychology, the neurological (Kounios & Beeman, 2014) as well as the phenomenological (Danek et al., 2014a; Skaar & Reber, 2020) correlates of insight have received the most attention. Other traditions have studied how insights may have a deep personal meaning in, for instance, psychotherapy or meditation (see Tulver et al., 2023 for a review).

So far, I have used the terms *insight* and *aha-experience*. These are two related but distinct concepts. However, different traditions make different distinctions between them. Some researchers distinguish between the terms insight and aha-experience, using the term insight to refer specifically to cognitive processes, and reserving the term aha-experience to denote the more phenomenological or affective aspects of an aha moment (Kounios & Beeman, 2014). Others use the term insight to refer to both cognitive and affective features (Danek & Kizilirmak, 2021; Gick & Lockhart, 1995). Insight is also often used to describe a more general self-understanding (in psychotherapy, see Caspar & Berger, 2007) or to signify an important or innovative idea (in studies of creativity, e.g., Csikszentmihalyi & Sawyer, 1995).

The term aha-experience is used in this dissertation to emphasize the phenomenological approach of the project, which aims to study children's *experiences* and *understanding* of sudden insight, rather than the cognitive or creative processes underlying these moments. As discussed in more detail in Paper 1, on-going debates in the insight literature pertain to whether or not the

cognitive processes underlying insight are distinct from the cognitive processes underlying analytic thinking, whether or not insight must be preceded by a phase of impasse, and whether or not insights must involve a restructuring of mental representations. In this text, I have chosen a descriptive definition that does not take a stance on these on-going debates that pertain to specific underlying cognitive processes. An aha-experience is here defined as: a new understanding which is accompanied by a subjective experience of suddenness, certainty, ease, and positive affect (Topolinski & Reber, 2010). Although investigating the underlying cognitive, social, and creative processes that encompass children's aha-experiences would be an interesting and valuable addition to the research literature, it is beyond the scope of this project.

Cognitive, Affective, Motivational, and Developmental Change (Paper 1)

The first paper of this dissertation is a book chapter about aha-experiences to be published in *The Routledge International Handbook of Changes in Human Perceptions and Behaviors*. Because no previous research has directly addressed the development of children's aha-experiences, this theoretical chapter was included as one of the papers in the dissertation to meet the need for a theoretical link between the aha literature and the literature on cognitive development. While there are other reviews of the insight literature, no existing reviews draw on developmental theory. The book chapter is the first paper to place short-term aha-experiences in the context of long-term developmental change, and this theoretical work is an important contribution of this dissertation.

The chapter outlines four kinds of changes associated with aha-experiences: cognitive, affective, motivational, and developmental change. Aha-experiences involve *cognitive change* in the form of a sudden understanding or realization, often referred to as an *insight* (e.g., Kounios & Beeman, 2014; Ohlsson, 1992, 2011; Weisberg, 2015). This cognitive change is typically understood as a reorganization of the mental representations (or meta-representations) of a problem or phenomenon which leads to new understanding. Cognitive change thus involves a change from one belief state to another. Aha-experiences also involve the experience of an *affective change* (Danek & Kizilirmak, 2021; Gick & Lockhart, 1995; Topolinski & Reber, 2010). Several epistemic feelings and emotions have been associated with aha moments, including feelings of certainty, ease, positive affect, relief, and curiosity, but also frustration and anxiety prior to the aha-experience. Although most studies emphasize the positive valence of aha-experiences, some sources also report a small proportion of negative aha-experiences, where the new understanding acquired in the aha moment has a negative personal meaning, such as discovering one's mortality or realizing that one has made a mistake (Haugen et al., in press; Hill & Kemp, 2018; Skaar, 2019).

Beyond these momentary changes in cognition and affect, aha-experiences are associated with *motivational change*. Following an aha moment, people often find themselves motivated to make renewed efforts in the specific domain or field to which the new understanding pertains. This

increased motivation may be related to a sense of mastery or agency, and more positive expectations that effort is worthwhile (Liljedahl, 2005; Skaar & Reber, 2020, 2021), or it may be related to the identification of new problems and new ways to think about the problem area (Csikszentmihalyi & Sawyer, 1995; Hill & Kemp, 2018). Finally, we argue that aha-experiences are related to *developmental change.* There is a theoretical and tentative empirical basis for expecting children to have aha-experiences already at a young age. Moreover, research with adults has shown that aha-experiences are associated with positive learning outcomes, such as improved memory (Cui et al., 2020; Danek et al., 2013; Kizilirmak et al., 2016) and higher solution accuracy (Danek et al., 2014b; Hedne et al., 2016; Salvi et al., 2016; Skaar & Reber, 2021). Given the finding that aha-experiences are often followed by increased motivation, aha-experiences may play an important role as a driver of cognitive development.

The book chapter reviews findings from the research on the aha-experiences of adults and forms the first piece in a theoretical foundation for the study of children's aha-experiences by mapping out potential associations between developmental changes and aha-experiences. In what follows, I will elaborate on how aha-experiences may be related to cognitive development.

Aha-Experiences and Cognitive Development

How are aha-experiences related to children's cognitive and metacognitive development? In the first paper of this dissertation, we argue that aha-experiences may play an important role in cognitive development because research with adults has established an association between aha-experiences and learning outcomes. This section will pick up the thread from the first paper and examine in more depth how children learn about the world, and what role aha-experiences could play in this development. First, I will present research indicating that children are active learners who seek out opportunities to learn and elaborate on their understanding of the world around them, by interacting with both their physical and social environment. Next, I will show how this active knowledge construction is guided by children's metacognitive experiences. This paves the way for considering how aha-experiences may play a unique role in this process of knowledge construction, alongside other metacognitive experiences, such as curiosity and uncertainty.

Children Are Active Learners

Children are intrinsically motivated to explore and learn about their environment. This claim can be traced back to some of the most influential theories in developmental psychology, including Piaget's constructivist theory of cognitive development (Piaget & Inhelder, 1969), and Bowlby's attachment theory (Bowlby, 1969). Based on detailed observations and interviews with children, Piaget described children as active learners who use exploration and play to learn about their surroundings, act out newly acquired skills, and test causal relationships to construct their understanding of the world that surrounds them (e.g., Piaget, 1951, 1952). In relation to attachment

theory, Bowlby combined constructivist and psychoanalytic traditions and theorized that children were driven by two conflicting needs: the need for emotional security and the need to explore their surroundings. In attachment theory, caregivers function as a secure base from which children can go out and explore. While the emphasis of Bowlby's theory was on the processes of attachment and security, the drive to explore was seen as an important, antithetical behavioral system that acted in concert with attachment behavior (e.g., Bowlby, 1969, pp. 237–239). In Bowlby's theory, a child alternates between seeking their caregiver and exploring their surroundings, and the theory posits that once the child feels secure, exploration becomes their primary activity.

A large body of empirical work supports the claim that children learn from active exploration from an early age (e.g., Baldwin et al., 1993; Herzberg et al., 2022; Kretch & Adolph, 2017; Piaget, 1951; Pieraut-Le Bonniec, 1985; Siegel et al., 2021; D. M. Sobel et al., 2022; van Schaik et al., 2020). In a recent study, Herzberg and colleagues (2022) documented that infants spent a substantial proportion of their free play exploring objects. During two 2-hour home visits, infants would engage in frequent short bouts of object play, adding up to about 60% of the total time of the visits. The pattern of short bouts of object interactions was found across all age groups (13-, 18- and 23-month-olds), regardless of whether the infants had learned to walk, consistently across the two visits, and for the full duration of each visit. In other words, infants are persistent explorers, constantly moving on to explore something new. This raises the question of whether children's exploration is random or guided; do children haphazardly explore everything in their surroundings or are they attuned to the efficiency and potential for learning associated with their exploration?

Experimental research has found that children's exploration is carefully attuned to the specific situation the child is in. For instance, one study found that one-year-olds efficiently used visual and haptic exploration when crossing a bridge (Kretch & Adolph, 2017). Infants adjusted their exploratory behavior according to the demands of a bridge platform by spending more time visually examining the different aspects of the scene for narrower bridges compared to wider bridges. The likelihood that the infant would explore the bridge by touching it was also higher for narrower compared to wider bridges. Thus, it seems that the infants' exploratory behavior depended on the perceived difficulty in crossing the bridge. Infants also adjust their exploration according to whether or not an observed event is in alignment with their expectations. In an influential series of experiments, Feigenson and colleagues have shown that infants who witnessed an impossible event where, for instance, a toy passes through a solid wall, will explore the toy more and prefer the observed toy over a novel toy, compared to children who observed an event that was consistent with their expectations (Stahl & Feigenson, 2015). A recent follow-up study found that infant's exploration depended on whether a plausible explanation for the impossible event is provided (Perez & Feigenson, 2022). For instance, in the event where a toy passed through a solid wall, the wall was

turned to reveal either a hole large enough for the toy to pass through or a wall that also looked solid from the backside. Exploration of the toy was reduced when infants were presented with a plausible explanation for the impossible event compared to when no plausible explanation was provided. Infants also attune their visual and auditory attention towards stimuli of medium complexity, potentially providing the greatest opportunities for learning (Kidd et al., 2012, 2014).

Research with preschool- and early school-age children has also found that children's exploration is guided by the demands and affordances of the task at hand (e.g., Gopnik & Wellman, 2012; Schulz, 2012). In a series of studies, 2- to 4-year-olds were more persistent in a search task when there was more information to be gained (Ruggeri et al., 2023). Thus, children's efforts were guided by the potential to learn something new. Another series of studies found that children adjusted their exploratory play according to the difficulty level of a discriminatory task (Siegel et al., 2021). More specifically, when asked to judge between two alternative contents of a box based on the sound the box made when shaken, children would shake longer for more difficult comparisons (e.g., six vs. eight marbles) compared to easier comparisons (e.g., two vs. eight marbles). Moreover, when playing for fun, children prefer more difficult game conditions compared to when playing to win (Rule et al., 2023), and when faced with confounded evidence, they perform spontaneous experiments to determine causal relationships (e.g., C. Cook et al., 2011; Schulz & Bonawitz, 2007; see also Sim & Xu, 2017). This provides further support for the notion that children's exploratory play is guided by the potential to learn.

Although children learn from acting on and exploring their environment, a great deal of knowledge cannot be acquired through direct experience. When it comes to formal knowledge, such as word learning, scientific terms and mathematical operations, or cultural knowledge, such as myths and stories, children rely on the testimony of others (e.g., Harris et al., 2006, 2018; Harris & Koenig, 2006). Already in infancy, children seek information from their caregivers through gesticulation and communicative gazes (e.g., Goldin-Meadow, 2007; Rowe et al., 2008; Walden & Ogan, 1988), and with the onset of language they use questions to request information from knowledgeable others (Butler et al., 2020; Ronfard et al., 2018).

Note that children are selective when it comes to *when* they seek information from others and *whom* they trust as informants. Infants will seek to use the expressions and gaze patterns of others as information, but only when there is some level of uncertainty or ambiguity involved (Hembacher et al., 2020; Kim & Kwak, 2011; Stenberg & Hagekull, 2007; Vaish et al., 2011). For example, in one study, 12- and 16-month-old infants were presented with three kinds of toys: unambiguously positive toys, ambiguous toys and unambiguously negative toys (Kim & Kwak, 2011). The valence and ambiguity of the toys was determined through a pretest where a separate sample of infants were introduced to a set of toys. A selection of toys was made that consistently triggered

either positive, negative, or ambiguous reactions in the pre-test sample. The aim of the study was to see whether infants' social looks would depend on the ambiguity of the toy, and whether infants would regulate their emotional expressions and approach-avoidance behavior based on whether adults displayed a happy or fearful reaction to the toy. Indeed, infants looked more towards the adult caregivers when presented with an ambiguous toy compared to a positive or negative toy. Infants' regulatory behavior also depended on the ambiguity of the toy. Infants were more likely to adjust their expressions of affect and approach-avoidance behavior to the valence of the message from adult caregivers when the toy was ambiguous than when it was unambiguous. In other words, the infants sought information from an informant more when they were unsure of how to appraise the toy.

Children also distinguish between different informants when faced with ambiguous tasks. In one study, when presented with a novel object label task, infants looked more at a stranger who had given informative labels during a familiarization phase, compared to a stranger who had expressed ignorance during the familiarization phase (Bazhydai et al., 2020). Preschoolers also track the accuracy of an informant (e.g., Bridgers et al., 2016; Ganea et al., 2011; Hermansen et al., 2021; Koenig & Harris, 2005; Scofield & Behrend, 2008). For instance, in one study, three- and four-year-olds shifted from endorsing an informants' claim on an initial trial to not endorsing their claim on a subsequent trial when the informant had proved to be wrong on the initial trial (Hermansen et al., 2021). In addition to accuracy, children have been found to rely on cues about informants' domain expertise (e.g, Einav & Robinson, 2011; Koenig & Jaswal, 2011; Stenberg, 2013) and social identity (e.g., dominance, Bernard et al., 2016; consensus, Chen et al., 2013; moral behavior, Hetherington et al., 2014; and accent, Kinzler et al., 2011), as well as their own personal relationship with the informant (Corriveau et al., 2009; Corriveau & Harris, 2009), when deciding whom to trust (see Harris et al., 2018 for a review).

In summary, children are active learners who seek out information from their physical and social environment from an early age. Notably, children do not indiscriminately explore every aspect of their environment. Rather, from an early age children's exploratory play is attuned to the novelty, complexity, alignment with expectations, and potential for learning associated with an object or event. Similarly, when learning from the testimony of others, children do not indiscriminately trust all informants. Instead, children determine the trustworthiness of different informants based on their record of accuracy, domain expertise, and social identity.

Metacognitive Development

We have seen that childhood is characterized by an orientation towards learning. Children spend a large proportion of their time constructing and revising their mental representations of the world around them. However, what guides children's exploration of their environment? How do

children decide where to explore next or what question to ask next? Children do not indiscriminately explore every aspect of their environment, nor do they indiscriminately trust the testimony of all informants. Yet, it is unlikely that infants make deliberate, conscious decisions about when and what to explore. In this section, I will first outline research on children's metacognitive development that suggests that explicit metacognition is limited in early childhood. Then I will outline the development of children's emotion understanding and their understanding of the mind, before pointing to how metacognitive experiences[1] can explain children's early capacity to tailor their exploration and information seeking.

Development of Explicit and Implicit Metacognition. Young children's ability to reason about mental processes is limited. For instance, preschool-aged children may claim that they have always known an animal fact that they just learned (M. Taylor et al., 1994), demonstrating a limited awareness of their own knowledge acquisition. Similar limitations in young children's capacity to reason about mental processes have been found for false belief (Liu et al., 2008; Wellman et al., 2001), the relationship between thoughts and feelings (Lagattuta et al., 1997), and the impact of expectations on emotions (Asaba et al., 2019; Lara et al., 2019). However, studies that use more indirect measures of understanding have found an understanding of mental processes such as false belief in young children (e.g., Buttelmann et al., 2009; Carpenter et al., 2002; Clements & Perner, 1994; Southgate et al., 2010). Researchers in this tradition have suggested that even infants display some understanding of the minds of others (Baillargeon et al., 2016). For instance, using a violation-of-expectations paradigm, Onishi and Baillargeon (2005) found that 15-month-old infants looked longer when an actor reached for an object in a location that was inconsistent with their false belief about the object's location, compared to when the actor reached in a location that was consistent with their belief. However, while some replication studies have supported this finding (e.g., Luo & Baillargeon, 2007; Surian et al., 2007; Träuble et al., 2010), other replication-attempts have failed (Kampis et al., 2021; Poulin-Dubois & Yott, 2018; Yott & Poulin-Dubois, 2016). Similar mixed replication results have been found in several paradigms studying implicit theory of mind (Rakoczy, 2022; see also Sabbagh & Paulus, 2018). Thus, although there is evidence for a distinction between implicit and explicit understanding of mental processes, the mixed results indicate that the nature of implicit understanding within these paradigms is not yet well understood.

The puzzling discrepancy between implicit and explicit measures of children's understanding of the mind has led to a lively debate about the nature of children's metacognitive abilities (Apperly & Butterfill, 2009; Baillargeon et al., 2016; Carruthers, 2021; Lyons & Ghetti, 2010; Roessler & Perner,

[1] The term epistemic feelings is sometimes used to denote a similar construct (e.g., Arango-Muñoz, 2014; Loev, 2022).

2013; Saxe et al., 2004; Sodian et al., 2020; Southgate, 2020; D. Taylor et al., 2023). Various explanations for the observed difference in metacognitive capacity have been proposed, differing in whether they emphasize a form of dual processes (Apperly & Butterfill, 2009; Roessler & Perner, 2013; Southgate, 2020), limitations in language and executive functioning in early childhood (Baillargeon et al., 2016), or a logical distinction between conceptual and nonconceptual representations (Carruthers, 2021). Note that the distinction between two or more types of metacognition is not new. Already in the 1970s, Piaget argued that there is a developmental lag between children's ability to successfully complete a task and their ability to explicitly reason about how they proceeded (Piaget, 1977, 1978; see also Pons & Harris, 2001). When the term metacognition was introduced, Flavell (1979) distinguished between (1) metacognitive knowledge, which is conceptual knowledge about cognition; (2) metacognitive experiences, which are cognitive or affective experiences that accompany and concern mental processes; and (3) metacognitive actions and goals, which regulate and direct cognition (see Efklides, 2008, for a more recent formulation).

Development of Emotion Understanding. Evidence for a gap between experience and understanding can also be found in the research literature on the development of emotion understanding. Children undergo several important changes in their understanding of emotion during preschool and early school years (for a review, see Pons & Harris, 2019). From about 3-4 years to about 7-8 years of age, children increasingly understand how someone's thoughts, memories, and beliefs can influence their emotions (Bender et al., 2011; Flavell et al., 2001; Lagattuta et al., 1997; Lara et al., 2019; Ronfard & Harris, 2014). As an example, Flavell and colleagues (2001) presented participants with a character that had a sudden change in emotion and asked what might cause this change. They found that 5-year-old participants rarely referred to the characters' thoughts as the cause of the change in emotion (0-25 %, depending on the story), whereas most 8-year-olds (65-70 %) and nearly all adult participants (75-100 %) did. Similarly, in a study by Lara and colleagues (2019), 4- to 10-year-olds' explanations of story character's emotions were coded for whether they referred to the situation, desires, or thoughts. They found that thought explanations increased with age, whereas explanations referring to either situation or desire decreased. Thus, children's understanding of how thoughts influence emotion improves and becomes more elaborate from about 4 years of age and through the early school years.

A similar developmental pattern has been found for the influence of expectations on emotions. Asaba and colleagues (2019) presented 4- and 5-year-olds with bowling scenarios. The bowling scenarios were paused half-way through, with the trajectory of the bowling ball either clearly heading for the gutter (negative expectation) or clearly heading for the center of the bowling pins (positive expectation). When the bowling scenario continued, both scenarios had the same

outcome with 3 pins knocked down. When children were asked to rate the emotion of the story character, although both the 4- and 5-year-olds took the character's expectations into account when the videos were paused half-way through, once the outcome was known only the 5-year-olds continued to take expectations into account. The 5-year-olds, but not the 4-year-olds, indicated that the character who knocked down more pins than expected would feel better in the end compared to the character who knocked down fewer pins than expected. Similarly, Lara and colleagues (2019) found that children's understanding of how expectations influence emotions depended on both the valence of the outcome and the valence of the expectation. For instance, 6-7-year-olds but not 4-5-year-olds understood that someone with high expectations may feel worse than someone with low expectations in the face of a negative outcome. Taken together, the research on children's understanding of the relationship between thoughts and emotions indicate that a declarative, explicit understanding develops gradually from preschool age and through the early school age years.

Note that while preschool children do not have a clear understanding of the relationship between thoughts and feelings, they frequently experience emotions that are triggered or modulated by their thoughts. For example, a three-year-old would respond quite differently if they were presented with a box and believed it contained chocolates, compared to if they believed it contained pencils (Perner et al., 1987). As discussed in Paper 3, a recurrent finding from research on children's emotion understanding is that children's understanding of emotions tends to lag behind their experience of emotions (Harris, 1989). This lag is particularly notable in the development of mixed feelings where the lag between experience and understanding is especially large. Children seem to experience mixed feelings already as toddlers, yet the understanding that a person can simultaneously experience multiple emotions does not fully develop until around age 7-11 (Harris, 1989; Pons & Harris, 2019). Thus, while explicit, verbalized emotion understanding develops gradually throughout childhood (see Kramer & Lagattuta, 2022 for a review of the continued development of emotion understanding in middle childhood), young children have rich emotional experiences that are independent of this understanding.

Recently, Viana and colleagues (2022) argued for a distinction between two kinds of emotion understanding, following the tradition that distinguishes between metacognitive knowledge and metacognitive action (Efklides, 2008; Flavell, 1979). Declarative understanding refers to conceptual knowledge about emotion that can be declared verbally. Procedural understanding, on the other hand, refers to a demonstration of understanding through actions that recognize, express or control emotions. Declarative and procedural emotion understanding may have distinct developmental trajectories (see Viana et al., 2022 for a more detailed discussion). Note that the distinction between declarative and procedural emotion understanding cannot be reduced to the distinction between implicit and explicit metacognition in the previous section. Take for instance the case of false belief.

There is some evidence that children's implicit understanding of false belief develops at an earlier age than their explicit understanding of false belief (see previous section). In terms of emotion understanding, children would have to understand both that people's beliefs can be false and that beliefs can influence emotions in order to fully understand the influence of false beliefs on emotion. Indeed, a study by de Rosnay and colleagues (2004) found that there was a developmental lag between children's understanding of false belief and their understanding of the influence of false belief on emotion. In other words, the younger children in this study had an explicit, declarative understanding of false belief, but did not yet have an explicit, declarative understanding of how false belief influenced emotions. Thus, the development of declarative emotion understanding cannot be expected to perfectly overlap with the development of explicit metacognition. Nevertheless, both lines of research imply that some types of understanding or metacognition can guide actions without being accessible to conscious or verbal elaboration. This takes us back to the question of what drives children's cognitive development. If young children do not have conscious, deliberate access to their own mental processes, how can we explain the active and targeted pursuit of new opportunities for learning in early childhood?

Metacognitive Experiences Guide Cognitive Development. A plausible answer to the question of what drives children's exploration is that children are guided by their metacognitive experiences. For instance, consider the toddler presented with an unfamiliar toy in the social referencing study by Kim and Kwak (2011). The study showed that the toddler adjusted their social referencing behavior according to the level of ambiguity associated with the toy. Their approach or avoidance of the toy, and their emotional reaction to the toy, was more influenced by information from their caregivers when there was some uncertainty or ambiguity associated with the toy. The toddlers may not have deliberately reasoned about whether the toy was ambiguous, but rather relied on a feeling of uncertainty that prompted them to seek more information. Ghetti and colleagues (2013) have argued that uncertainty monitoring guides cognitive development, at least during the preschool years (see also Baer & Kidd, 2022). They point to evidence that children from about 3 years of age can report on their own feelings of uncertainty (e.g., Lyons & Ghetti, 2010), and that they rely on uncertainty monitoring when asked to choose whether or not to provide an answer in a perceptual identification task (Lyons & Ghetti, 2013), and whether or not to ask for help (Coughlin et al., 2015; see also Goupil et al., 2016).

As another example, recall the finding that preschoolers are more persistent in a search task when there is a higher potential for information gain (Ruggeri et al., 2023). It is an open question whether the 2- to 4-year-olds in the study deliberately reasoned about the potential for information gain. A plausible explanation that does not require conscious deliberation, is that their persistence was guided by an experience of interest or curiosity, which was triggered by the potential for

information gain without the child's explicit, declarative awareness. This view is in line with Goupil and Proust (2023), who recently argued for a conceptualization of curiosity as a metacognitive feeling. According to this conceptualization, curiosity is a reaction to a detected information gap which arises from metacognitive monitoring of prior knowledge states, and which motivates information seeking behaviors (see also Golman & Loewenstein, 2018; Loewenstein, 1994). In line with this view, the children in the study by Ruggeri and colleagues were more persistent in the search task when there was higher potential for information gain because the feeling of curiosity motivated continued search behavior. Importantly, this conceptualization of metacognition does not imply that children have conscious access to the metacognitive monitoring processes that precede the feeling of curiosity. Metacognitive monitoring can take place without propositional or declarative knowledge (Baer & Kidd, 2022; Efklides, 2008; Goupil & Proust, 2023). That is, the children in the study may have merely had a feeling of curiosity which motivated their search, and not a conscious awareness of their own monitoring of potential information gaps.

So far, curiosity and uncertainty have been presented as examples of metacognitive feelings that guide children's conceptual development in early childhood, arguably from infancy. Curiosity and uncertainty are perhaps the two metacognitive experiences that have received the most attention in developmental research to date. Other metacognitive experiences include feelings of knowing, fluency, familiarity, interest, confusion and difficulty (Efklides, 2008; Goupil & Proust, 2023). It is an open empirical question to what extent children rely on these metacognitive experiences, and how different metacognitive experiences uniquely and in combination contribute to guide children's knowledge construction in early childhood. The current project focuses specifically on the aha-experience (referred to as "Eureka feelings" by Goupil & Proust, 2023).

Do Young Children Have Aha-Experiences?

The aha-experience is a metacognitive experience that has received little attention in developmental research. Before discussing how aha-experiences may play a part in cognitive development, it is important to first establish whether young children have aha-experiences. To date, very few studies address this question. During the course of this doctoral work, only five studies of insight with child participants were identified, two of which date back to the first half of the 1900s. The studies focus on insightful problem solving and do not explicitly address children's subjective aha-experience. Yet, because insights often trigger aha-experiences, and the use of the term often includes both cognitive processes and subjective experience, they are highly relevant to answer the question of whether children have aha-experiences.

Two early studies on children's insight were inspired by Köhler's work with chimpanzees (1925) and studied the performance of preschoolers in practical problem-solving scenarios. In the first study, Alpert (1950; a partial reprint of her 1928 dissertation) presented children aged 1.5 to 4

years with situations where the child had to retrieve a toy suspended from the ceiling, for instance standing on a block. Alpert found that most children reacted to the situations by exploring different potential solutions and finally arriving at an insightful solution. She argued that the successful solution to the problems was an indicator of the presence of insight because the problems required some intentional and specific action, and therefore the child had to have some understanding of the solution before implementation. Following up the work of Alpert, Matheson (1931) did a series of experiments where children aged 2 to 4.5 years solved practical puzzles to retrieve a cookie, for instance by pulling a string to bring a basket with the cookie within reach or releasing a string used to hold a basket in suspension so that the basket would drop within reach. In these studies, insightful solutions were those which found a "round-about way of solution" (Matheson, 1931, p. 243), and insight was inferred if the child successfully solved the task. In line with Alpert, Matheson found evidence of insightful problem solving in preschool children. Moreover, Matheson found that with increasing age, children were increasingly successful at solving the problems. Taken together, these studies suggest that children begin to have insights sometime between the age of 1.5 and 4 years. However, note that the difficulty of some of these tasks, such as detaching a string to drop down the cookie basket, may be more important to determine the success or failure of the children than their capacity to have aha-experiences.

The third study focused on the debate in the insight literature about whether there were unconscious processes leading up to insights. Siegler and Stern (1998) presented second-graders (mean age = 8.75 years) with inversion problems that could be solved either through stepwise calculation or through an insightful shortcut. They analyzed the strategies used by the children in successive trials of inversion problems, and distinguished between unconscious implementation of the shortcut rule, as indicated by short solution times, and children's explicit acknowledgement of having used the shortcut. They found that children tended to use an unconscious version of the insightful shortcut before the explicit conscious implementation of the shortcut rule, and that the implementation of different versions of the shortcut were more likely after the first unconscious use of the shortcut. The results were interpreted as an indication that unconscious solution generation occurred before conscious awareness of the insightful solution. In other words, the moment of sudden realization, so characteristic of insightful problem solving, may not coincide with the moment the solution was generated on a more implicit level. These findings are informative for the debate around the nature of insight and echo the Piagetian distinction between success and understanding (Piaget, 1978). However, the authors do not discuss the *development* of insight. The age of the participants is not discussed, and the findings are not connected to any discussion of age-related changes. Regardless, the children in the study did demonstrate a capacity for insightful problem-solving around 8 years of age.

In the fourth study, Howe and colleagues (2011) presented children aged 7 to 11 years old with the compound remote associate task (Bowden & Jung-Beeman, 2003), a task commonly used to study insight in adults (e.g., Jung-Beeman et al., 2004; Kounios et al., 2006; Subramaniam et al., 2009). The task consists of sets of three cue words and one solution word that can make a compound word with each of the cues. For example, the three cues might be AGE/MILE/SAND with the solution word STONE which makes the compound words STONEAGE/MILESTONE/SANDSTONE. Howe et al. (2011) aimed to investigate the effect of false memories on subsequent insight problem-solving, and therefore did not directly address the question of whether or not children have aha-experiences. Unfortunately, the compound remote associate task proved difficult for the younger participants in the study. The 7-year-olds had an average solution rate of 20.95% across 20 items, with eight of 20 items not solved by any child at 7 years of age. This ultimately led Howe and colleagues to exclude the 7-year-old age group in subsequent experiments. The low solution rate among the 7-year-olds could be used to argue that younger children do not have the capacity for insightful problem solving, and therefore do not have aha-experiences. However, given the findings of the studies reviewed above it is more likely that the 7-year-olds' low solution rates were related to the difficulty of the task rather than the capacity to have aha-experiences.

In the fifth study, Marchant and colleagues (2022) reported on the insights of 41 elementary school students (ages ranged from 7 to 10 years, no mean age reported) engaged in a collaborative group assignment in a naturalistic classroom setting. Their focus was on documenting the gestural and linguistic patterns of the students and their interactions with their peers and their teacher around moments of insight. They identified 12 cases of insight during 10 video-taped sessions. Ten of the 12 cases were classified as *full insights*, defined as the realization of a correct solution or solution procedure. The remaining two were *partial insights* in which a child realized a mistake in their own work. Of the 12 cases of insight, four occurred during interactions with the teacher, five occurred during peer interactions (three full insights + two partial insights), and three were classified as individual insights that did not depend on interactions with peers. The relatively small number of participants and the descriptive nature of the study makes it difficult to draw clear conclusions about children's aha-experiences in general based on this study. Moreover, because all the recorded sessions consisted of collaborative group-work it is unclear whether the proportions of interactive (peer and teacher) versus individual insights would be different in other learning contexts. Still, the study demonstrates that school-aged children did have moments of sudden insight in a naturalistic classroom setting.

In addition to the five identified studies, a recent study from our lab also addressed the question of whether children have aha-experiences (Haugen et al., in press). Using parents' reports of their children's aha-experiences, a total of 606 descriptions of children's aha-experiences were

collected. Parents described aha-experiences throughout childhood. Indeed, the youngest child described as having an aha-experience was only a few weeks old. Moreover, parents described aha-experiences related to various activities, including object manipulation, sports, mathematics, and literacy, and situations that included everyday activities, free play, and structured learning. In most cases (85.5 %), children's aha-experiences involved positive affect, and social interactions were involved in the aha-experience about half of the time (53.3 %). The use of parent reports makes it difficult to verify the descriptions of children's aha-experience, and the exact criteria for whether something is reported as an aha-experience or not may vary between parents even if they received the same description and definition of an aha-experience. Nevertheless, the study gives a unique window into children's everyday aha-experiences and implies that aha-experiences are relatively common in childhood.

Based on the reviewed studies, it seems likely that children do have aha experiences from an early age (Alpert, 1950; Haugen et al., in press; Howe et al., 2011; Marchant et al., 2022; Siegler & Stern, 1998; B. Sobel, 1939). It may even be that children have aha-experiences more frequently than adults. Two points support this suggestion. First, children undergo massive conceptual development from infancy through the school years, and especially in early childhood. That means that it is likely that children engage in more updating and changing of their concepts compared to adults, and thus there are more opportunities for children to have aha-experiences. Second, research with adults has found that aha-experiences are more likely to occur when participants are in diffuse attention states, that is, a relaxed state where thoughts are allowed to wander (Kounios et al., 2008; Wegbreit et al., 2012). It has been argued that such diffuse attention states facilitate aha-experiences because the relaxed cognitive control found in diffuse attention allows for more remote associations to form (e.g., Tulver et al., 2023). From the point of view of developmental science, Gopnik (2007) has argued that based on neurological and physiological measurements, the cognition of infants and young children tends to resemble these diffuse attention states. Combining these findings would suggest that young children may have aha-experiences more frequently than adults. However, this is an empirical question that awaits testing.

The Proposed Relationship Between Aha-Experiences and Development

How may aha-experiences play a role in guiding children's cognitive and metacognitive development? Alongside other metacognitive experiences such as curiosity and uncertainty, aha-experiences may hold a distinct position in cognitive development. The feeling of suddenness involved in the aha-experience may signal to the child that a new idea they had is worth attending to. In other words, the surprise associated with an aha-experience may function in a similar way as the surprise involved in the violation-of-expectation paradigm (Onishi & Baillargeon, 2005; Stahl & Feigenson, 2015) in directing the child's attention towards opportunities for learning. It has been

suggested that aha-experiences function as a heuristic that indicates when a new idea is consistent with either a problem-solving context or some subconscious conceptual framework (Laukkonen et al., 2023). If this is the case, children's aha-experiences may influence which new ideas are taken up and incorporated into their representational framework. Evidence of better recall for solutions that were accompanied by an aha-experience, compared to solutions generated without an aha-experience, provides support for the notion that aha-experiences facilitate encoding of new information related to the solution (Danek et al., 2013; Kizilirmak et al., 2016).

Moreover, the feelings of confidence and positive affect which typically characterize the aha-experience can create a sense of mastery and lead to sustained motivation for future learning efforts. In one of the first studies to highlight the relationship between aha-experiences and feelings of mastery, Liljedahl (2005) reported on university students' descriptions of their aha-experiences in a mathematics course. The students described changes in their beliefs and attitudes towards mathematics and their own capabilities associated with their aha-experiences. While they reported feeling anxious and fearful about the mathematics course before the aha-experience, after the aha-experience they had a renewed confidence in their own capacity to understand the course contents and a more optimistic attitude towards the course work. The association between aha-experiences and motivation has later been confirmed in survey and experimental designs (Skaar & Reber, 2020, 2021). Based on these findings with adult participants, an aha-experience may contribute to a child's developing interest in the topic area of the aha-experience and motivate them to pursue new chances to learn.

So far, I have pointed out how aha-experiences may have a beneficial effect on subsequent learning (aha → learning). However, it is possible to reverse the causal direction of this effect and argue that aha-experiences function as an indicator that learning has occurred. From this point of view, an aha-experience is the outcome of a learning process rather than a factor that facilitates learning (learning → aha). Classic models of insight place the aha-experience in the middle of a creative process (e.g., Ash & Wiley, 2006; Ohlsson, 1992; Wallas, 1926; Weisberg, 2015). In these conceptualizations, the aha-experience is preceded by a process of preparation and search, and it is followed by further verification and implementation of the idea that was illuminated in the aha-experience. This highlights the importance of considering not only the aha-experience in isolation, but also the processes leading up to and following the moment of insight. Furthermore, the process of implementing one idea may instigate a process that in turn triggers new aha-experiences. Thus, a spiral-shaped or transactional model may be a more helpful conceptualization of how aha-experiences relate to learning (learning → aha → learning → aha, etc.).

The proposed outline of how aha-experience may guide children's cognitive development leaves many open questions. Because the proposed influence of aha-experiences on conceptual

development and motivation is entirely based on research with adults, there is a need for research with children to investigate whether children's aha-experiences resemble those of adults. It will also be necessary to investigate whether there are any developmental changes in the proposed relationships, for instance, in the relation between aha-experiences and memory, and in motivation following aha-experiences. Other open questions pertain to the processes that initiate aha-experiences in children, for instance how the likelihood that a child will have an aha-experience while solving a task may relate to specific task demands such as difficulty level, and how the social environment may support or hinder aha-experiences. Finally, aha-experiences may provide a unique chance to study the discrepancy between implicit and explicit metacognition. Aha-experiences are events that occur within more narrow time-constraints, in mere moments, compared to other metacognitive experiences which are more state-like, such as curiosity and uncertainty. This momentary characteristic provides the potential to observe and count aha-moments which can be compared with children's self-report of aha-experiences. Answering these open questions will depend on the development of methods to measure and classify children's aha-experiences. The empirical part of this dissertation is therefore focused on how children understand and experience moments of insight.

Empirical Studies

Given the scarcity of research on children's aha-experiences, there are many open empirical questions about this phenomenon. The research reviewed in the previous section indicates that children likely have aha-experiences from a young age, but how children experience and understand these moments of insight is not well understood. Moreover, there is a need for new methods to study children's aha-experiences in a systematic way. Two empirical studies were conducted as the first attempt to bridge these research gaps. The studies took inspiration from research on emotion understanding, which has a long tradition of studying the relationship between children's experience and conceptual understanding (for reviews, see Harris, 1989; Pons & Harris, 2019). The first study used a scenario approach to study children's understanding of the affective valence associated with insightful problem solving. A broader methodological approach was taken in Study 2 because there was limited evidence of any developmental effects for the insight scenarios in Study 1. More specifically, Study 2 included a task designed to elicit direct experience of aha moments in addition to tasks assessing more general understanding of the aha-concept. Taken together, the two studies give a first impression of how children experience and understand aha moments, and provide new experimental tasks designed to study children's aha-experiences.

In what follows, I will first provide a summary of the two studies, focusing on the aims and results of each and how the results of the two studies are related. Then some key considerations are provided around the methodological approach taken in the current project, how the novel

experimental tasks were designed, and how ethical and open science practices were handled. For further details on the procedure and design of the two studies, see Paper 2 and Paper 3. The target age in the empirical studies ranged from 4 to 8 years. This age-range was chosen because previous research has indicated that children undergo developmental changes in their conceptual understanding of emotions and metacognition during this age (see Theoretical Background). A relatively wide age range was chosen to ensure that we would be able to document any developmental changes, given that no previous research has investigated children's understanding of aha-experiences.

Summary of Study 1 (Paper 2)

The starting-point for the empirical work of this dissertation was the aim to study children's understanding of aha-experiences and sudden insight. Mapping the development of children's understanding of insight is an important first step in the study of children's aha-experiences because knowledge about children's understanding of this phenomenon is a prerequisite for methodological decisions about how to measure and study children's aha moments. Research paradigms that study insight in adults tend to rely heavily on self-report and retrospective descriptions, so it is important to gather systematic evidence of the development of children's understanding of this phenomenon to support methodological decisions in future studies.

Moreover, knowledge about the development of children's understanding of aha-experiences can inform theory on children's emotion understanding. It is known from prior research that children first grasp external characteristics of emotions such as facial expressions of emotion categories and how different situations are typically associated with different emotions (e.g., receiving a gift is associated with happiness; losing a toy is associated with sadness). During the preschool and early school-years, children gradually develop an understanding that mental processes also influence emotion (Pons & Harris, 2019). First, around two to three years of age, children typically understand that desire influences emotion. Then, around ages 4 to 6, children understand that beliefs and expectations influence emotion. More reflexive and social emotions, such as shame and guilt, are typically understood later (see also Kramer & Lagattuta, 2022 for a review of emotion understanding in middle childhood). Because aha-experiences typically relate to both external problem-solving situations and internal expectations and beliefs, Study 1 aimed to investigate the development of children's understanding of aha-experiences in the transition from preschool to school-age.

More specifically, Study 1 investigated young children's understanding of the valence associated with insightful problem-solving. The study looked specifically at the link between aha-experiences and positive affect because this association is well-established in the insight literature. We used a scenario-approach. Children (N = 123, 58 girls, age: 4-8 years, community sample) saw

short, illustrated stories of children in problem-solving scenarios, and were asked how the story character was feeling at different time-points throughout the stories. The stories varied with respect to whether or not the problem was successfully solved, and whether the problem was solved with an aha-experience or through trial-and-error. We expected that children as young as 4 years of age would understand that successfully solving the problem would lead to positive affect (H1), but that there would be age differences in children's affect judgment following an aha-experience (H2). Given the limitations in children's understanding of the link between thoughts and feelings, we did not expect the younger children in our sample to understand the relationship between having an aha-experience and affective valence.

Our hypotheses pertained predominantly to the positively valenced story versions (the aha-moment, and the successful outcome) because these were the aspects of the story that most saliently related to the prototypical description of an aha-experience. However, counter to our hypotheses, our results indicated no age-related differences in affect judgements at the aha-moment and a small age-related difference after a successful outcome (see Table 1). On average, children at all ages indicated that the character would feel somewhere between *a little happy* and *very happy* after both an aha-moment and a successful solution. In contrast, there was evidence for age-related differences in the negatively valenced story versions (failed attempt in a series of trial and error, and the failed outcome). These were intended as control conditions, and we had no specific hypotheses for these story versions. The results indicated that although children at all ages expected the story character to feel sad after a negatively valenced event, the 4-year-olds expected the story character to feel less sad than the 5- to 8-year-olds did.

Table 1
Mean Affect Judgements by Story and Age

Age	Aha moment		Outcome moment	
	Aha	Trial-error*	Success**	Failure*
4	3.58	2.02	3.64	2.14
5	3.61	1.53	3.88	1.58
6	3.58	1.29	3.98	1.33
7	3.38	1.29	3.94	1.52
8	3.61	1.29	3.87	1.34
All	3.55	1.50	3.86	1.60

Note. Affect judgements: 1 = *very sad*; 2 = *a little sad*; 3 = *a little happy*; 4 = *very happy.*
* In these columns, the 4-year-olds gave significantly higher affect judgements than all other age-groups. See Paper 2 for more details on the analyses.
** In this column, the 4-year-olds gave significantly lower affect judgements than the 6-year-olds. All other comparisons were non-significant.

The results of Study 1 indicate that there were no age-related changes in children's understanding of the association between aha-experiences and positive affect. Already at 4 years of age, children understood that aha-experiences lead to positive affect. The findings for the negatively-valenced story versions can perhaps be explained by a general optimism or positivity bias in early childhood (e.g., Bamford & Lagattuta, 2020; Boseovski, 2010). Perhaps the younger children expected the character to be close to finding a successful solution given the duration of the stories, even if they had encountered a failure. The study of young children's understanding of the emotional implications of failure is an interesting field in its own right. However, it is outside the scope of the current dissertation and will not be discussed further here.

How can we interpret the lack of evidence for any developmental change in the understanding of aha-experiences in Study 1? One alternative is to argue that children are familiar with aha-experiences from a young age and therefore have a clear understanding of this phenomenon already as preschoolers. This possibility remains open; however, it would be a misguided interpretation on Study 1 because the study focused only on the association between aha-experiences and positive affect. While young children might have a clear grasp of the notion that having an idea for a problem solution in an aha-experience is a positively valenced event, it could be that other aspects of the aha-experience, such as the tentative character of the idea from an aha-experience, are less clear to young children. This possibility is followed up in Study 2, which involved a wider assessment of children's understanding of aha-experiences alongside a task designed to elicit children's first-hand aha-experiences.

Summary of Study 2 (Paper 3)

The overarching aim of the empirical work in this dissertation was to provide initial knowledge about how children understand aha-experiences. Study 1 approached this question by applying a narrow focus on the association between aha-experiences and affective valence. In contrast, a broader approach was taken in Study 2, which aimed to collect a wide range of assessments of children's understanding of aha moments, including the aha moments of a story character, their own aha moments and the aha moment as an abstract concept. Children (N = 160, 75 girls, age: 4-8 years, community sample) solved a scenario task, a statements task, and an illustrated puzzle task. The puzzle task was accompanied by observed and self-report measures of aha-experience, and self-report of confidence (see a more detailed description in the section Experimental Tasks and in Paper 3). We expected that the older children in our sample would have a better understanding of the aha concept overall, compared to the younger children (H1). Moreover, as a secondary aim, Study 2 included measures of children's confidence and motivation following aha moments, to investigate whether the phenomenology of children's aha-experiences resembles that of adults' aha-experiences. Based on the adult insight-literature, we expected a positive association

between trials where a child has an aha-experience and their solution accuracy and subsequent ratings of confidence (H2a). We also expected higher numbers of elicited aha-experiences to predict greater motivation to continue working on a similar task rather than switching to a new task (H2b).

The results of Study 2 can be summarized in four points: (1) we find a developmental gap between the occurrence of observed aha-experiences and children's explicit understanding of aha-experiences; (2) the finding from Study 1 that children from 4 years of age understand that aha-experiences are related to positive affect was replicated in Study 2; (3) observed aha-experiences were related to higher accuracy and confidence ratings, but the association between aha-experiences and confidence was non-significant when controlling for accuracy; (4) the number of aha-experiences was associated with higher motivation for observed, but not self-reported, aha-experiences.

Developmental Gap Between Experience and Understanding

Children had an average of 1.4 observed aha-experiences across 8 trials of the AhaClues task, and the number of aha-experiences remained stable with increasing age (see Table 2).

Table 2
Children's Experience and Understanding of Aha Moments by Age

Age	AhaClues			Scenarios	Statements
	Observed aha	*Self-reported aha*	*Control task*		
4	1.30	5.59	0.22	2.08	3.34
5	1.35	6.00	0.23	2.40	3.43
6	1.55	4.58	0.42	2.97	4.12
7	1.55	4.21	0.61	3.21	4.94
8	1.27	3.15	0.81	3.38	5.12
All	1.41	4.78	0.44	2.81	4.19

Note. Self-reported aha and observed aha: min. = 0, max. = 8. Control task: proportion correct on a task that assessed children's understanding of the self-report question for aha-experiences. Scenarios: min. = 0, max. = 4. Statements: min. = 0, max. = 6.

In contrast, there were age-related changes in four tasks which reflected children's understanding of aha-experiences. First, younger children reported having more aha-experiences than older children on the self-report measure of aha-experiences on the AhaClues task. Second, with increasing age, children were more likely to pass a control task intended to assess whether children had understood the self-report question for aha-experiences. In the control task, children were first presented with a simple identification task where they had to identify the object in a cartoon image of a car. The task was presumed to not trigger aha-experiences because there was no problem-solving involved. Children were then asked whether or not they had an aha-experience

while solving the identification task. To pass the task, children had to answer no to the self-report question. The relatively high frequency of self-reported aha-experiences among the younger children, combined with the performance rate on the control task indicated that the younger children could not reliably answer the self-report question about their own aha-experiences. Third, in a scenario-task, children's ability to distinguish between scenarios where a story character did and did not have an aha-experience increased with age. Fourth, with increasing age, children performed better on a forced-choice statement task assessing children's understanding of six separate characteristics of an aha-experience. Overall, these findings indicate that children's understanding of aha-experiences increased with age.

Understanding of Affective Valence in Aha-Experiences

The Statements task assessed children's understanding of six characteristic features of aha-experiences. While the likelihood of choosing the correct statement significantly improved with age for most of the items, there was no significant age-differences for the affective valence item (see Table 3). For this item, children in all age groups tended to choose the correct statement which indicated that aha-experiences are associated with positive affect. Notably, although the Statements task was very different from the scenario-paradigm employed in Study 1, the findings pertaining to affective valence in Study 2 converged with the findings from Study 1. Both studies indicated that already at the age of 4, children understood the link between aha-experiences and positive affect.

Table 3
Performance on Individual Statements-Task Items by Age

Age	Positive affect	Confidence	New idea	Impasse	Feeling-of-suddenness	Feeling-of-truth
4	0.92	0.51	0.61	0.61	0.56	0.37
5	0.80	0.63	0.57	0.57	0.63	0.40
6	0.97	0.67	0.76	0.76	0.73	0.49
7	1.00	0.73	0.94	0.94	0.85	0.58
8	1.00	0.85	0.92	0.92	0.92	0.54
All	0.94	0.67	0.75	0.59	0.73	0.47

Note. Performance is indicated by the proportion of participants who chose the correct statement.

Accuracy, Confidence, and Aha-Experiences

In addition to the main findings pertaining to children's experience and understanding of aha moments, we also analyzed the relationship between children's aha-experiences and their solution accuracy and solution confidence on the AhaClues task. These analyses were designed to mirror findings from research with adults that indicate that aha-experiences predict higher accuracy and confidence on problem-solving trials, compared to trials with no aha-experience. Details on the analyses can be found in Paper 3, here I will present a brief summary of the findings.

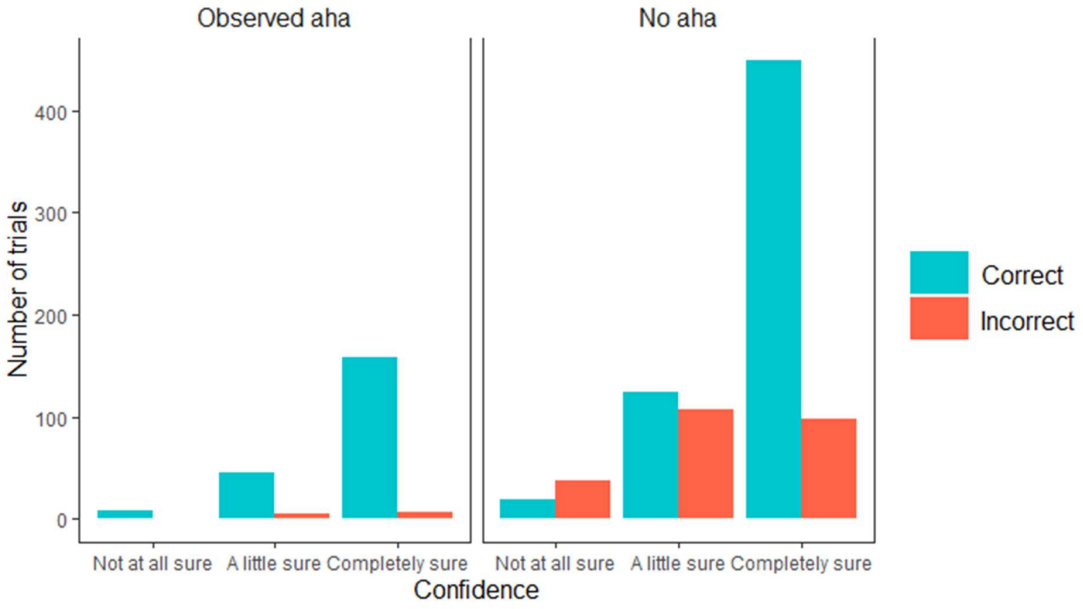
First, we found that children's answers on the AhaClues task were indeed more likely to be correct when an aha-experience had been observed, compared to when no aha-experience was observed (OR = 10.63, 95% CI [5.48, 20.64], $p < .001$). Moreover, while there was a direct relationship between accuracy and age (accuracy increased with increasing age, OR = 1.89, 95% CI [1.53, 2.33], $p < .001$), there was no evidence of an interaction between accuracy and age (OR = 0.83, 95% CI [0.40, 1.70], $p = 605$). Thus, the relationship between observed aha-experience and accuracy did not depend on the age of the child.

Second, when it came to confidence ratings, our results painted a more complex picture. In a simple regression model[2] with confidence as the dependent variable and aha-experience as the only predictor, we found a significant effect (OR = 1.86, 95% CI [1.23, 2.81], $p = .003$). However, a one-way model also indicated that confidence ratings were related to accuracy (OR = 8.77, 95% CI [5.80, 13.28], $p < .001$). When accuracy and aha-experiences were included in the same model predicting confidence ratings, higher accuracy was significantly related to higher confidence (OR = 8.20, 95% CI [5.26, 12.79], $p < .001$), but the effect of aha-experience was no longer significant (OR = 1.46, 95% CI [0.88, 2.42], $p = .197$). Thus, when controlling for accuracy, aha-experiences no longer predicted higher confidence ratings. See Paper 3 for more detailed results. Note that only a few trials where an aha-experience was observed also had incorrect answers (n = 12, see Figure 1). That means that there may not have been enough data on aha-experiences with incorrect answers to clearly differentiate between the influence of aha-experiences and accuracy on children's confidence ratings.

[2] Generalized Linear Mixed Models (GLMM) were used to take into account: (1) the non-normal nature of the outcome variables (ordinal logistic regression); (2) the dependencies in the data (each participant completed 8 trials, thus, a random slope for participant was included in the model).

Figure 1

Confidence by Observed Aha and Solution Accuracy



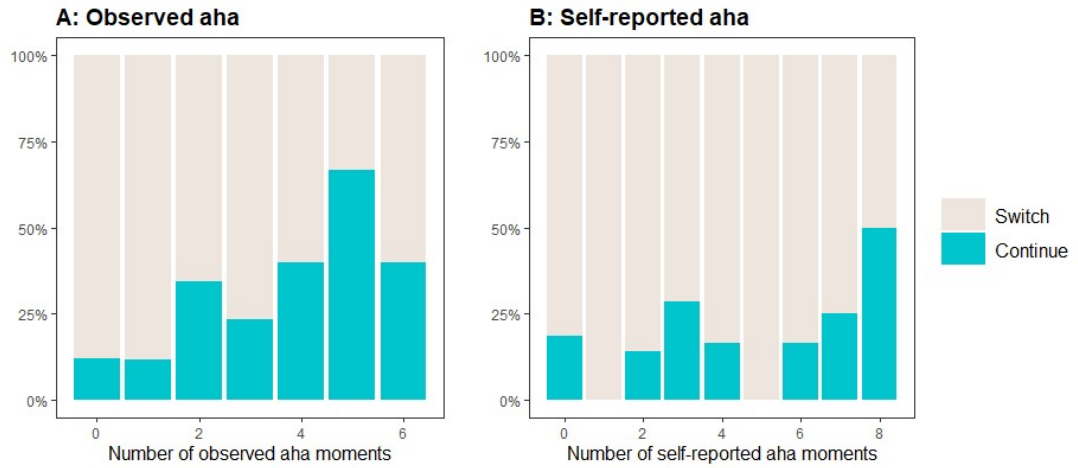
Note. Total number of trials = 1063. Trials in which children answered "Don't know" are not included. Number of trials with observed aha = 225, number of trials without observed aha = 838.

Motivation and Aha-Experiences

To assess whether children's motivation to work on the AhaClues task was influenced by the number of aha moments they experienced, we included a bonus task at the end of the AhaClues task. In the bonus task, children chose to either continue with another trial of AhaClues or switch to a new task. Most children (80 %) chose to switch to a new task, which is not surprising given the evidence for children's tendency to explore, reviewed in the section Children Are Active Learners. What we wanted to find out was whether children who had more aha-experiences would be more likely to continue with the same task rather than switch to a new task. The results were mixed. When we used the observational measure of aha-experiences, there was indeed a positive association between the number of aha-experiences and the motivation to continue with the same task. However, when the self-report measure of aha-experiences was used the association was not significant. Note that the trend for the number of self-reported aha-experiences matched that of the observed aha-experiences (see Figure 2), and that the second analysis, which used the self-report measure of aha-experiences, had reduced power. Participants who had failed a control task assessing children's understanding of the self-report measure were excluded from this analysis. Thus, it could be that the null finding in the second analysis was related to statistical power. This possibility will need to be addressed in future research.

Figure 2

Proportion Who Chose to Switch Tasks vs. Continue by Number of Aha-Experiences



Note. Figure 2A: N = 160; Figure 2B: N = 70. Number of children in Figure A and B differ because only children who passed a control task assessing understanding of the self-report measure were included in Figure 2B.

Methodological Considerations

To provide background for the results of the two empirical studies, the current section provides methodological considerations concerning: (1) how research on aha-experiences and insight have approached the systematic study of this fleeting phenomenon, and the suitability of these approaches to developmental research; (2) the experimental tasks developed for the current project to study children's aha-experiences; (3) ethical reflections pertaining the recruitment and data collection; (4) how open science practices were implemented in the current project. For further details on the method of the two empirical studies, such as statistical procedures and precise study design, readers are referred to Paper 2 and Paper 3.

How Can Aha-Experiences Be Studied?

At the onset of the current project, very few studies had investigated children's aha-experiences. That means that there was little to no precedence for the choice of methodological approach. There were no validated experimental tasks suitable for children, no guidelines or criteria for observational studies and no questionnaires or interview protocols available for this specific phenomenon. Moreover, aha-experiences are characterized by their fleeting nature, and this makes them challenging to study in a systematic way. In this section, I will outline three different approaches that have been taken in the study of aha-experiences in adults and discuss the applicability of each approach for developmental studies targeting young children. These considerations form the background of the methodological approach taken in the empirical studies of this project.

Expert Creative Reasoning. One line of research has studied the reasoning and insights of people in innovative or creative careers such as artists or elite researchers (referred to as "the Great-Minds Approach" by Sternberg & Davidson, 1995). This approach has typically used a combination of ethnography, in-depth interviews, and document analysis. For instance, Csikszentmihalyi and Sawyer (1995) reported on in-depth interviews with people who had made a creative contribution to their field. The exploratory and in-depth methodology of this approach to the study of insight allows for the discovery of novel frameworks. For instance, while most of the literature on insight has been conducted in the context of problem-solving, Csikszentmihalyi and Sawyer presented a framework that included both *problem-solving* and *problem-finding* insights. A problem-finding insight is a discovery of a new problem or a gap in a current method or framework. Such problem-finding insights may prove difficult to study in the lab, given that they may be more closely connected to long-term reasoning processes and therefore more difficult to elicit compared to problem-solving insights that can be elicited with puzzles or experimental tasks. Despite this strength, the approach is not well-suited to answer questions about children's aha moments. In-depth interviews that probe cognitive processes in detail will be limited by children's metacognitive awareness and capacity for

self-reflection (e.g., D. M. Sobel & Letourneau, 2015; Tang & Bartsch, 2012). Moreover, the approach defines insight in a way that hinges on the value of the discovery, by focusing on ideas that are proven successful, innovative, or ground-breaking. A child's insight may be new and ground-breaking for the child's mind. Take for instance a toddler who discovers how to stack blocks to make a tower or a preschooler who learns to recognize the letter of their name and now discovers this letter everywhere they go. These discoveries may represent a paradigm-shift in the children's understanding of blocks and letters even if they do not have the same significance for anyone else. Therefore, an investigation of the development of insight requires a broader, everyday definition of insight compared to the one used by this approach.

Retrospective Studies of Everyday Aha-Experiences. A second approach has been to ask participants to recall and describe an aha-experience they have had in the past (Hill & Kemp, 2018; Skaar & Reber, 2020). Such a retrospective approach has a privileged access to the breadth and depth of everyday aha-experiences that would not be possible with experimental studies (see next section). If children can remember their own aha-experiences, this could be a fruitful approach to study children's experiences and understanding of insight. However, it is unclear whether and when children would be able to give such accounts of their own aha-experiences, especially considering that many adults do not recall such moments. For instance, in a large-scale survey of the aha-experiences of adults and adolescents, about 51 % of the participants could remember and describe an aha-experience (Skaar, 2019, p. 29). The proportion of remembered aha-experiences would probably be smaller with child participants because they may not have formed clear accounts of such experiences that can be recalled when asked by a researcher, even if they have experienced them in the past. It is likely that the terms "aha-experience" and "insight" are unfamiliar to children. Anecdotally, few of the children interviewed in the empirical studies of the current project indicated that they were familiar with the aha-concept on an informal question at the beginning of the study.

If few children are able to recall and describe past aha-experiences, then using a retrospective approach to study the development of insight would require a large sample size to obtain a sufficient number of accounts. Given the scarcity of research on the development of children's experiences and understanding of aha moments, a different approach was taken in the current project. However, the results of the empirical studies presented in this dissertation about children's understanding of aha-experiences can provide some indication for when children may be able to discuss these events in retrospective studies. We found that children around 7-8 years of age were able to distinguish between scenarios with and without aha-experiences, showed a good understanding of the aha-concept and were able to self-report on their own aha-experiences on the AhaClues task. Thus, retrospective studies could recruit children from 7 years and older. Younger children in our study, particularly 4- and 5-year-olds, showed a limited explicit understanding of the

aha-experience in the current work and may not be able to report on their own past aha-experiences. However, it remains an open empirical question at what age and to what extent children can recall and describe their own past aha-experiences.

Experimental Studies. A third line of research has presented participants with puzzles and experimental tasks designed to elicit aha-experiences (see for instance Chu & MacGregor, 2011 for a review). A variety of different tasks has been used to elicit aha-experiences, including verbal puzzles (e.g., Metcalfe, 1986), visual-perceptual puzzles (e.g., "droodles", Nishimoto et al., 2010; the "triangle of coins", Vallée-Tourangeau et al., 2021; "Mooney images", Van de Cruys et al., 2021), matchstick arithmetic tasks (Knoblich et al., 1999; Skaar & Reber, 2021), magic tricks (Danek et al., 2014b), anagrams (Laukkonen et al., 2020), and remote associate tasks (C-RAT, Bowden & Jung-Beeman, 2003; RAT, Mednick, 1962). Using laboratory and puzzle tasks has been a fruitful approach that has led to a large body of new knowledge when it comes to the cognitive, affective, and neurological correlates of aha-experiences over the past few decades (Kounios & Beeman, 2009; Laukkonen et al., 2023). It can be debated to what extent aha-experiences generated in an experimental setting resemble those that occur in more naturalistic settings (Hill & Kemp, 2018). Despite this issue, an experimental approach to the study of aha-experiences provides an opportunity to study children's aha-experiences that does not depend on their ability to recall and describe aha-experiences. Given the variety of tasks used with adults, it was considered likely that it would be possible to design an age-adjusted task that could elicit children's aha-experiences. Moreover, pursuing an experimental approach provided an opportunity to investigate children's understanding of aha-experiences by taking inspiration from experimental studies that investigate children's emotion understanding (e.g., Harris, 1989; Lagattuta et al., 1997, see next section). This forms the background for the methodological approach chosen in the current project.

Experimental Tasks

While the main contributions of the current work are theoretical and empirical, a secondary contribution consists of the development of new tasks that can be used in the systematic study of children's aha moments. This section presents and describes three new tasks, that is, the Scenarios task, the Statements task, and the AhaClues task.

The Scenarios Task. Both Study 1 and Study 2 included a version of the Scenarios task. This task was developed to investigate children's understanding of the aha-experiences of a story character, to answer questions about children's understanding of the aha-experiences of others. The use of scenarios has a long tradition in research on children's understanding of the mind. Already in 1971, Helen Borke presented children with illustrated scenarios and asked questions about how the protagonist in the story was feeling (Borke, 1971). Since then, scenarios have also been used to study many aspects of children's emotion understanding, including the influence of desires and beliefs on

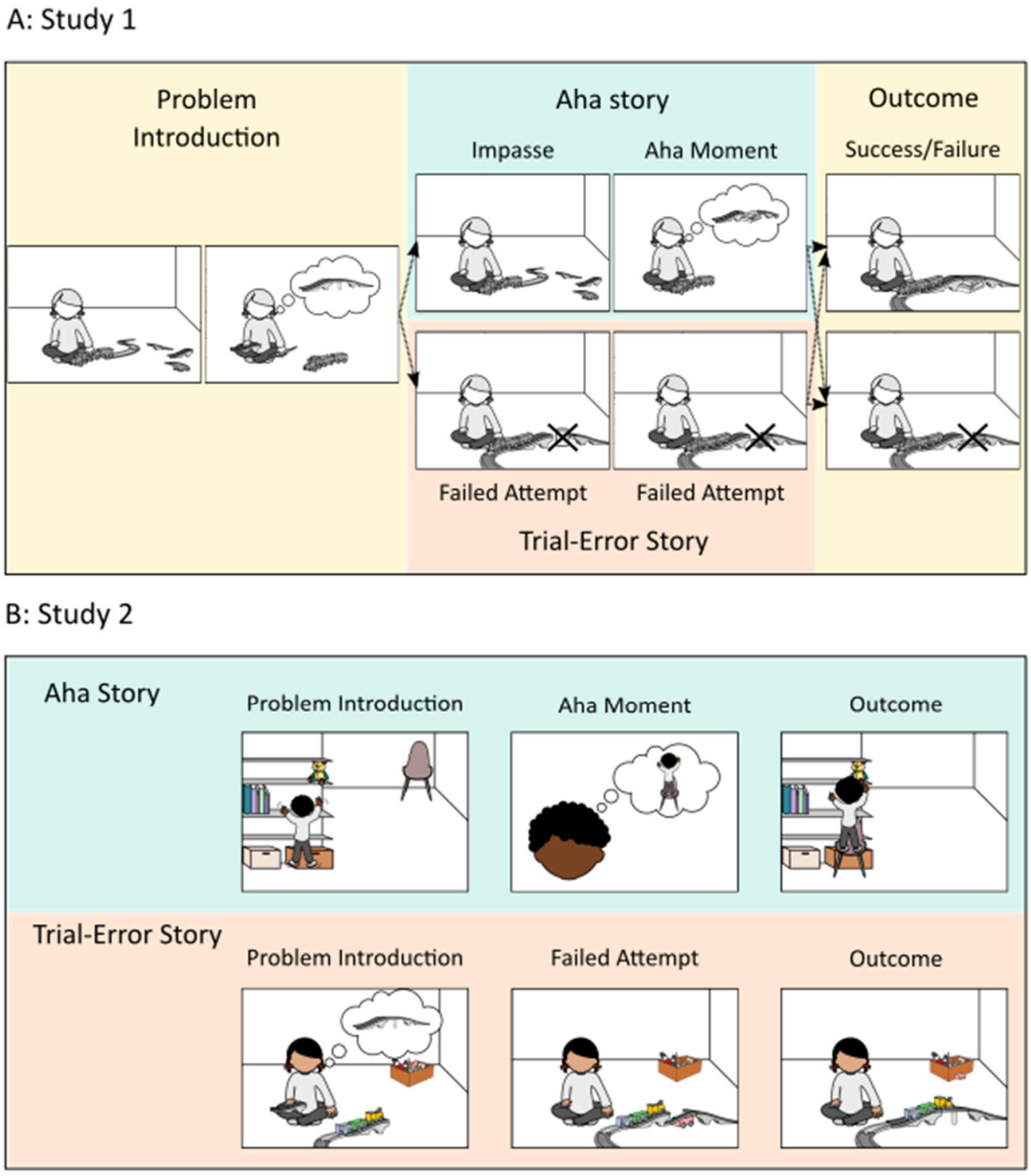
emotions, mixed and hidden emotions, and the relationship between thoughts and feelings (Flavell et al., 1993, 2001; Harris, 1989; Lagattuta et al., 1997; Pons et al., 2004). More recent examples include studies that investigate impact of expectations on emotions (Asaba et al., 2019; Lara et al., 2019), counterfactuals (Nyhout et al., 2019), and optimism and wishful thinking (Bamford & Lagattuta, 2020). Because of this long tradition, employing a scenario-approach to investigate children's understanding of aha moments was deemed a good place to start to answer the overarching question about how children understand aha-experiences.

Study 1. The Scenarios task was the main experimental task in Study 1. Children were presented with four problem-solving scenarios (see Figure 3A for an example). The scenarios varied in the type of problem solving that was employed by the story character (trial-and-error vs. insight), and in terms of the outcome (success vs. failure). Each child saw one of each combination of problem-solving strategy and outcome.

Each scenario consisted of 5 frames. The insight stories were based on the *insight-sequence* often described by insight researchers (e.g., Ash & Wiley, 2006; Wallas, 1926; Weisberg, 2015). In the first frame, a problem was introduced. Next, in the second frame, the child tried but failed to solve the problem. In the third frame, the child reached an impasse where the problem remained unsolved, and the child was no longer actively trying to solve the problem. The fourth frame was the aha moment, the moment of insight. Here, the child had an idea of how to solve the problem. Finally, in the fifth frame, the child verified the idea and either succeeded or failed to solve the problem. The trial-error scenarios resembled the insight scenarios, except for frames three (impasse) and four (insight). In these frames, the trial-error scenarios depicted two more failed attempts at solving the problem, so that the trial-error scenarios consisted of a set of three failed attempts in frames two to four, before the outcome was revealed in frame five. For both styles of problem solving, the scenario could end with either a successful outcome or a failed outcome.

Figure 3

Illustration of the Scenarios Task in Study 1 (Figure 3A) and Study 2 (Figure 3B)



The focus of Study 1 was children's understanding of the affective valence of aha-experiences. Thus, for each scenario, the children were asked to assess how the story character was feeling. Children answered on a four-point scale ranging from "very happy" to "very sad". The results of Study 1 indicated that there were limited developmental changes pertaining to the understanding of affect associated with the aha-moment. However, the task has the potential for adjustments that may target other research questions pertaining to children's understanding of aha-experiences. The questions asked when interviewing the child may be altered. For instance, children may be asked to identify an aha-experience by pointing to the frame of the story where the child has an aha-experience, or they may be asked open-ended questions about their reasoning. Another alternative for future development of the Scenarios task could be to manipulate different aspects of the depicted aha moments, for instance by varying the quality of the idea the story character has at the aha moment.

Study 2. The second empirical study took a broader approach by including several different tasks that assessed children's understanding of aha-experiences. Thus, the Scenarios task played a smaller role in Study 2, where it was included as an introductory task. For this purpose, a simplified version of the scenarios used in Study 1 was created. Children were presented with two aha-scenarios and two trial-error scenarios. They were asked whether or not the story character had had an aha-experience after the presentation of each scenario and could receive a total score of 4 points if they answered "yes" on the aha-scenarios and "no" on the trial-error scenarios.

Several adjustments were made to the scenarios to meet the goals of Study 2. To reduce the presentation time, the scenarios were shortened to three frames, compared to the five frames in Study 1. The two frames that were removed were one of two introductory frames and the impasse moment (see Figure 3B). Moreover, in Study 2, we did not vary the outcome of the scenarios; all problems were successfully solved. Another adjustment was that the scenarios in Study 2 had color, whereas in Study 1, the scenarios were in gray scale. Finally, we also made some adjustments to the trial-error stories to emphasize that the story character simply happened upon the solution and did not first have an idea for a solution. For instance, the toy box was added in Study 2, and the story character found the pieces for both the failed attempt and the successful solution by searching in the toy box. In contrast, in Study 1, the story character found different objects (a cup, a train car, and some books) and tried to use them to solve the problem. More details and complete scenario transcripts can be found in Paper 2 and Paper 3, and on OSF (see Transparency and Open Science).

Table 4
Mean Scores on the Scenarios Task in Study 2 by Age and Story Type

Age	Aha stories	Trial-error stories
4	1.81	0.27
5	1.83	0.61
6	1.88	1.09
7	1.91	1.30
8	1.92	1.46

Note. Min. = 0, max. = 2.

The version of the Scenarios task that was used in Study 2 indicated improvements with age in children's ability to distinguish between the scenarios with and without an aha-experience. While the 4- and 5-year-olds performed at or near chance levels, the 6- to 8-year-olds were reliably above chance. On a closer examination of the two different story types (aha and trial-error), the younger children made more mistakes on the trial-error stories compared to the aha stories (see Table 4). Note that the correct answer for the trial-error stories was that the story character *did not* have an aha-experience, whereas the correct answer for the aha stories was that the story character *did* have an aha-experience. Thus, the results could be related to a positivity bias in early childhood, as the younger children appeared to answer yes without taking into account the story that was presented. In anticipation of this tendency, Study 2 also included the Statements Task, which assessed children's understanding of the aha-experience without depending on yes/no answers.

The Statements Task. The Statements task was designed to assess children's understanding of specific features which characterize an aha-experience. In addition, the Statements task was designed to avoid some potential issues with the Scenarios task, such as the confound of a potential positivity bias. The Statements task consisted of six forced-choice items referring to six aspects of a typical aha-experience (see Table 5). The items consisted of pairs of statements, one which accurately described a typical aha-experience and one which was intended to be the inverse of the correct statement. For each item, the child was asked to choose which of the two statements best fit with an aha-experience. Both a sum score for the number of correct answers (maximum 6) and individual scores for each item (correct/incorrect) were investigated to assess children's understanding of aha-experiences. Compared to the Scenarios task, the Statements task provided more information about which aspects of an aha-experience was easily understood in all age groups (i.e., positive affect), and for which aspects understanding improved with age (i.e., new idea, impasse, feeling-of-suddenness, and feeling-of-confidence). As for the final item (feeling-of-truth), children performed around chance-levels in all age groups (see Table 3). This could indicate that this

aspect of aha-experiences was more difficult to understand than the other aspects, for instance because the concept of a feeling-of-truth was unfamiliar. Alternatively, the results could relate to the phrasing of this statement. Note that the two alternative statements were very similar for this item (see Table 5). Future research could test other ways of phrasing the statement to better describe the feeling of truth associated with an aha-experience.

Table 5
All Items for the Statements Task

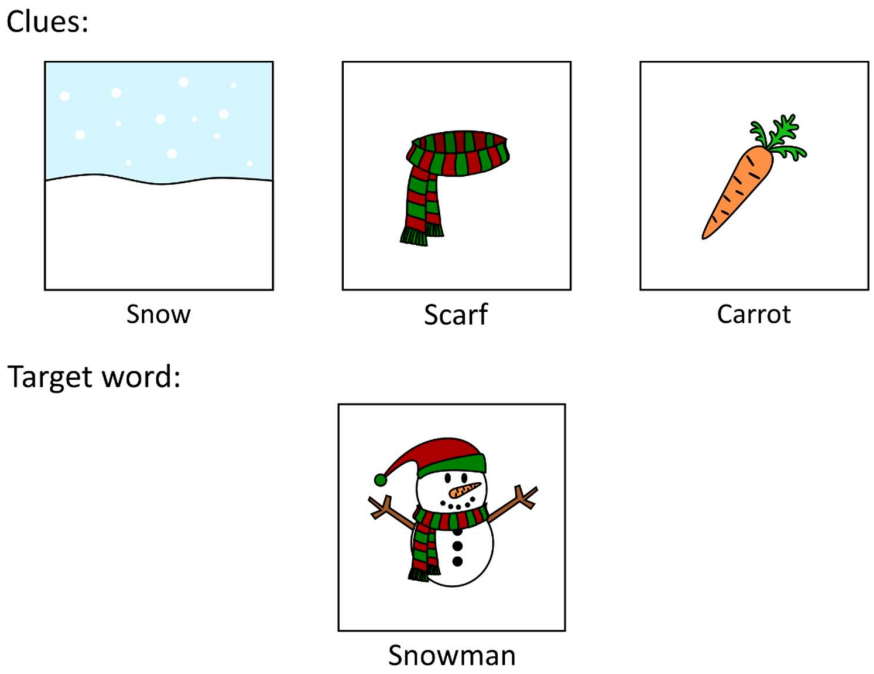
Concept	Correct statement	Incorrect statement
Positive affect	Having this idea makes you feel happy.	Having this idea makes you feel sad.
New idea	You have a new idea.	You have an idea that you often had before.
Impasse	You couldn't think of the right answer when you first saw the task.	You thought of the right answer straightaway.
Feeling-of-suddenness	The idea suddenly pops into your mind.	The idea comes into your mind very slowly.
Feeling-of-confidence	You feel sure this idea is right.	You feel unsure of whether this idea is right.
Feeling-of-truth	The answer feels right.	The answer is right.

Note. These are English translations; statements were presented in Norwegian.

The AhaClues Task. The AhaClues task was the main experimental task in Study 2. This task was inspired by the Remote Associates Test (RAT, Mednick, 1962), which involves presenting participants with three cue words, and asking them to find a solution word that is associated with the three cues (e.g., SURPRISE, LINE, BIRTHDAY, solution: PARTY). The task was created by Mednick to be a test of creativity. The test was based on an associative theory of creative thinking, which postulated that creative thinking consisted of new combinations of associative elements in a way that either was useful or met some specified requirements (Mednick, 1962, p. 221). In recent decades, the RAT has been used to study intuition and creativity (Bolte & Goschke, 2005; Bowers et al., 1990; Topolinski & Strack, 2008; Wu et al., 2020), and a version of the Remote Associates Test, that is, the Compound Remote Associate Task (C-RAT, Bowden & Jung-Beeman, 2003), has been used extensively to study insight in adults (see Kounios & Beeman, 2014 for a review). However, the items of the C-RAT are two difficult for young children to solve. Remember that only 20.95% of the presented C-RAT items were successfully solved by 7-year-olds in the study by Howe and colleagues, and almost half of the items were not solved by any 7-year-old (Howe et al., 2011). In Study 2, we wanted to study the aha-experiences of children aged 4- to 8-years-old, so there was a need for a new task that could be solved by younger children.

Figure 4

Illustration of the AhaClues Task



We used the logic of the RAT to develop the AhaClues task. In the AhaClues task, children were presented with three illustrated clues, and were asked to find a solution word that was associated with each of the three clues (see Figure 4). The three clue words were semantically associated with the solution word, but the clues and solution words did not need to make up new compound words when combined. This was in line with the original RAT, but unlike the C-RAT, which has the added constraint that the solution word forms compound words with the cue words. As mentioned, previous work has indicated that the C-RAT was difficult to solve for children at 7 years of age. Thus, forming compound words was not a requirement in the AhaClues task. We designed the AhaClues task to be appealing to young children by visualizing the clues with cartoon images and choosing topics that are familiar to children.

The AhaClues task did elicit children's aha-experiences. All of the items elicited at least one observed aha-experience and each elicited aha-experiences in between 16 and 26 percent of the participants. The items of the AhaClues task were designed to vary in difficulty. We had three a-priori categories of difficulty; easy (e.g., PAWS, TAIL, SAYS: "WOOF WOOF"; solution: DOG), medium (e.g., SUITCASE, RAILS, STATION; solution: TRAIN) and difficult (e.g., YELLOW, SOUR, OVAL; solution:

LEMON). The actual difficulty of the items, assessed by ranking the items based on children's accuracy scores, were well matched with the a-priori difficulty categories so that the items that ranked 1st and 2nd were in the easy category, the items ranked 3rd - 5th were in the medium category and the items ranked 6th – 8th were in the difficult category. More details on the performance of the different items are provided in the Supplementary Material for Paper 3. Difficulty level and age interacted in predicting whether an item would elicit an aha-experience. We were more likely to observe aha-experiences for the easier items with younger children, and with more difficult items for the older children. Overall, the variation in difficulty of the AhaClues task items may have increased the likelihood that children in the selected age range would have at least one aha-experience during the eight trials presented to them.

Observation and Self-Report of Aha-Experiences. The purpose of the AhaClues task was to elicit children's aha-experiences. Whether or not a child had an aha-experience while solving a trial of the AhaClues task was measured in two ways. First, the experimenter that was interviewing the child made an observational note of either observed aha or no aha for each trial. An observed aha-experience was recorded if the experimenter observed at least one of the following criteria: (a) after being seemingly stuck for a while, the child suddenly produced the answer; (b) the child gasped or suddenly drew in their breath immediately before saying the answer; (c) the child suddenly shouted the answer or said the answer in a notably energetic way. Second, after each trial, the child was asked a self-report question about whether or not they had had an aha-experience. Prior to the AhaClues trials, the child was introduced to the concept of an aha-experience in the following way. The experimenter explained that: "An aha-experience is when you have a new idea that suddenly pops into your mind". Then children saw a short video of a girl acting as if she had an aha-experience while working on a school problem. In the video, the girl first thought for a while and then exclaimed "Aha, now I've got it!". The children also solved the Scenarios task prior to the AhaClues task. The order of presentation of the tasks (1. Introduction, 2. Scenarios, 3. AhaClues, 4. Statements) was selected to give the children a chance to become familiar with the aha-concept before they were asked to self-report on their own aha-experiences.

In sum, this section has presented three new experimental tasks that were developed for the current dissertation. The task materials have been made openly available on OSF to facilitate the use of the tasks in future research.

Transparency and Open Science

Efforts were made to follow open science practices in the current work, including preregistration, open publication of study materials, and preprints. For both empirical studies, the aims, hypotheses, materials, and analysis plan were preregistered through the website www.AsPredicted.org (Study 1: #69780; Study 2: #111201). Any deviations from the preregistrations

are reported and justified in Paper 2 and Paper 3 respectively. Moreover, for both studies, research materials have been made openly available on the Open Science Framework (Study 1: https://osf.io/nfx5z/?view_only=94005230bd474f2daea1c66d65f89aa1; Study 2: https://osf.io/5w486/?view_only=a5d5ed20e1b54376aab0efad1d9b21e5). This material includes the images and protocols of the experimental tasks, anonymous data files, and analysis scripts. The publication of the research material was done to ensure transparency, enable reproduction of the reported analyses, and facilitate replication studies. Importantly, in addition to enabling replication studies, the open availability of the novel experimental tasks developed for the current work may be adapted by future research into children's aha-experiences. Given the scarcity of research on this topic, the open sharing of tasks is important to encourage new research on this topic and thereby make the methodological contribution of the current work more accessible to the wider research community. A final open science practice that has been implemented in the current project is the use of preprints for the empirical papers. So far, Paper 2 has been made publicly available in the form of a preprint (https://doi.org/10.31234/osf.io/u48sb). The same will be done for Paper 3 once the current review process is completed. As for Paper 1, it is included in a copyrighted handbook and the copyright agreement unfortunately does not permit the release of the chapter in the form of a preprint.

Ethical Considerations

Ethical issues pertaining to the data collection in the current project pertained to the diversity of the sample of participants, ensuring that participation was voluntary, ensuring that participation was not stressful for the participating children, and employing a reward-structure that would benefit the participating schools and kindergartens in a fair way. In this section, I will elaborate on how each of these issues was handled. As for formal ethical permits, the empirical studies were approved by both the Norwegian Centre for Research Data (NSD, ref. 103789) and the internal ethics review board at the Department of Psychology at the University of Oslo (Study 1: ref. 8375942; Study 2: ref. 20322771).

Efforts were made to collect a sample that would reflect the diversity of a typical community in Eastern Norway. Specifically, we collected two community samples through schools and kindergartens in three municipalities. Information and consent forms were sent out to all parents of children within the relevant age range, which meant that the children in the neighborhoods served by the participating schools, all children had access to participate in the study. Information was sent out digitally through the regular communication channels of the participating schools and kindergartens. Because children participated in the study during their regular time at kindergarten or the afterschool program, participation did not require any planning or scheduling on the part of the parents. This made participation accessible to children with diverse family situations. To ensure

voluntary and informed participation, we collected active parental consent through either online or paper-pencil forms ahead of the data collection. Information about the project was sent out before the data collection visits, and parents had the opportunity to ask questions about the project before completing the consent form. In addition, it was voluntary for the children to participate on the data collection days even if their parents had given their consent. Teachers at the kindergartens and afterschool programs, who were familiar to the children, invited those children who had their parents' consent to join the interviews. The children could choose not to join.

The children were interviewed by either the PhD candidate or a research assistant in a quiet and familiar room at the schools and kindergartens. One concern was that some of the children, especially the youngest participants, would feel stressed or anxious about the interview situation. To accommodate this issue, for some of the younger children, a familiar teacher sat in the room during the interview to ensure that the children felt comfortable. Considerations of which children would need the presence of a familiar teacher were made in collaboration with the teachers who knew the children well.

Participating schools and kindergartens received a gift as compensation for their help with facilitating the data collection. It was important that the gifts would be relevant and benefit all the children in the schools, and not only the participating children. To ensure this, schools and kindergartens could request specific gifts. Many schools wanted to receive books, games, or toys, and one school asked for reflective vests that could be used when the children go on excursions. The value of the gift was in proportion to the number of children recruited from each school or kindergarten. The participating children also received stickers as a reward for their participation.

To sum up, ethical concerns in the current project pertained to the diversity of the recruited sample, to ensure informed and voluntary participation, and to ensure that participation in the studies would not be stressful for the participating children and would benefit the children in the participating schools and kindergartens.

Summary of Empirical Contribution

Overall, the contributions of the empirical work of this dissertation project consists of initial empirical findings pertaining to children's experience and understanding of aha moments. More specifically, we found that (1) children aged 4 to 8 associated aha-experiences with positive affect; (2) there was a developmental lag between children's experience and understanding of aha-experiences; (3) children's aha-experiences were associated with higher accuracy and confidence compared to trials without aha-experience, but the association with confidence was not significant when controlling for accuracy; and (4) the number of observed, but not self-reported, aha moments predicted higher motivation to continue with a similar task rather than switching to a new task. This

section has also outlined the methodological contribution of this dissertation project, which consists of several new tasks that can be used to investigate aha moments in children aged 4 to 8 years old.

General Discussion

The overarching aim of the current dissertation was to investigate children's experience and understanding of aha moments. The dissertation makes both theoretical and empirical contributions to this investigation. In the theoretical part of the dissertation, momentary aha-experiences are placed in a wider developmental context. I ask how children's aha-experiences may contribute to cognitive development, and point to how aha-experiences, alongside other metacognitive experiences, such as curiosity and uncertainty, may guide children's knowledge construction. The empirical part of the dissertation focuses on children's understanding of aha-experiences. Drawing from work on children's emotion understanding and metacognitive awareness, the empirical studies ask to what extent preschool- and early school-age children understand the interplay of thoughts and emotion involved in aha-experiences. In this section, I will synthesize the theoretical and empirical contributions of the current work by discussing the empirical findings in light of the proposed theory. I begin by considering children's experience of aha moments before discussing the findings pertaining to children's understanding of aha-experiences. Next, some central methodological limitations in the current work are discussed, including the lack of open-ended questions and video recordings of children's responses. Finally, several new lines of research which can be derived from the current work are outlined. Taken as a whole, the theoretical and empirical work presented in this dissertation builds a foundation for new research on aha moments in childhood.

Children's Experience of Aha Moments

To support the notion that aha-experiences are metacognitive experiences that guide children's learning in early childhood, as proposed in the theoretical section of this dissertation, a prerequisite would be evidence that young children have aha-experiences in the first place. Indeed, Study 2 found that children at the age of 4 to 8 years had aha-experiences while working on the AhaClues task. To date, only a handful of studies, spanning almost a century, have systematically studied children's insights (Alpert, 1950; Haugen et al., in press; Howe et al., 2011; Marchant et al., 2022; Siegler & Stern, 1998; B. Sobel, 1939), and none have specifically addressed children's aha-experiences in an experimental setting. Our results provide further empirical support for the notion that children have aha-experiences and is the first to indicate that children's aha-experiences can be triggered in a relatively short timeframe in an experimental design. This opens many potential new directions for future research into children's aha-experiences, as outlined in the section Future Directions.

We also found that at least some of children's aha-experiences could be observed and coded by a third party. In Study 2, we observed an average of 1.4 aha-experiences per session. That is, for

each child, about 18 % of the trials triggered observable aha-experiences. Children were also asked to self-report whether or not they had an aha-experience for each trial. In the full sample, children self-reported having an average of 4.8 aha-experiences per session, that is on 60 % of the trials. It is likely that the self-report measure in the full sample overestimates the number of aha-experiences because some children misunderstood or were uncapable of answering the self-report question. In a reduced sample that only contained children who successfully completed a control task[3], children reported having on average 3 aha-experiences per session, that is on 38 % of the trials. Note that in both cases, the average number of self-reported aha-experiences was higher than the number of observed aha-experiences. Provided that children in the reduced sample could indeed provide accurate self-report of aha-experiences, this suggests that some but not all of children's aha-experiences could be observed by a third-party experimenter. In other words, although it was possible to observe children's outward expressions of aha moments, children had some privileged access to their own experience that could not be directly observed by their expressions. This notion is in line with the conceptualization of aha-experiences as metacognitive experiences that guide learning, which requires aha-experiences to be directly available to children's awareness but does not require any particular outward expression.

If children's aha-experiences play a role in knowledge construction, we would also expect to see associations between children's aha-experiences and problem-solving variables such as motivation and accuracy. The current work provides tentative evidence that children's aha-experiences lead to increased motivation to persist with pursuing a task rather than switch to something new. There was also a positive association between children's aha-experiences and the accuracy of their answers. In line with research on the aha-experiences of adults (e.g., Danek & Salvi, 2018), children's answers were more likely to be correct on trials where an aha-experience had been observed compared to trials where no aha-experience was observed. However, the results should be interpreted with caution because the effects could only be found for the observational measure of aha-experiences, and not for the self-report measure of aha-experiences.

There are several potential explanations for the lack of convergence between the observed and self-reported aha-experiences in the results for motivation and accuracy. First, the lack of convergence could be related to issues with the self-report measure. Given the developmental changes in children's understanding of aha-experiences documented in the current work, children may not have understood or not have been capable of answering the self-report question. We

[3] Recall that in the control task, children first answered a simple identification question and then were asked whether or not they had had an aha-experience. The identification question was presumed to not trigger aha-experiences because there was no problem-solving involved. To pass the task, children had to answer "no" to the aha-question.

included a control task to account for this possibility, but it could be debated whether the control task functioned as intended. A second possibility is that the lack of convergence was due to the reduced statistical power in the analyses for the self-report measures. A reduced sample with N=70 children was used in the self-report analysis. This was done to account for the first possibility that children would not understand the self-report question. However, given that such a large proportion of the participants failed the control task, using the reduced sample took a large toll on the statistical power of the analyses. A third possibility is that the lack of convergence was related to an interaction between the intensity of aha-experiences and their influence on motivation and accuracy. It could be that the observational measure, which relies on the outward expression of an aha-experience, only captures more intense aha-experiences. The self-report measure has the potential of capturing aha-experiences of a larger variety of intensity compared to the observed measure of aha-experiences because it could include aha-experiences that are so mild that they don't produce any outward expression. If the intensity of the aha-experience moderates the influence of aha-experiences on accuracy and motivation, this could lead to the observed lack of convergence. More data is needed to determine which of these three possible explanations is correct.

The proposed theoretical conceptualization places the influence of aha-experiences on cognitive development alongside other metacognitive experiences such as curiosity and uncertainty. This raises the question of how different metacognitive experiences interact. The current work sheds some light on the relationship between confidence and aha-experiences in relation to accuracy. Our results suggest that accuracy is directly related to both confidence and aha-experiences. It is difficult to pin down the directionality of the relationship between metacognitive experiences and accuracy. In the experimental design of Study 2, measures of aha-experience and confidence were made before the correct solution was revealed. Thus, from the point of view of the child, the metacognitive feelings occurred before knowledge about the accuracy of the answer. However, if metacognitive experiences function as signals about subconscious cues of the accuracy of an idea or solution, accuracy arguably comes before (and triggers) the metacognitive experiences. Future research should specifically address this issue of directionality.

In sum, the current work finds that children can have aha-experiences in experimental studies and provides tentative empirical support for the notion that children's aha-experiences are related to increased motivation and higher solution accuracy. However, the issues regarding convergence between self-reported and observed aha-experiences points to the importance of knowledge about young children's understanding of aha-experiences and the aha-concept.

Children's Understanding of Aha-Experiences

A central debate regarding the development of metacognition in recent decades concerns the distinction between implicit (or procedural) metacognition on the one hand, and explicit (or

declarative) metacognition on the other. Aha-experiences may provide a unique opportunity to shed light on this debate. Children have aha-experiences from a young age. Moreover, aha-experiences are relatively concise, vivid, and time-bound experiences, which could make them easy to recognize and monitor. Yet, unlike other metacognitive experiences, such as uncertainty, it is probably not common for caregivers to provide verbal labels and talk about aha-experiences with children. The current work provides data on children's understanding of aha-experiences with limited training and exposure to the aha-concept. Future research could manipulate the amount of training to investigate whether young children's declarative understanding of the aha-experience increases with more exposure and training, both when it comes to monitoring and recognizing their own aha-experiences and understanding the aha-concept in general.

The results of both Study 1 and Study 2 indicate that children from 4 years of age associate aha-experiences with positive affect. In two different experimental tasks, there were no significant age-differences in the understanding that aha-experiences lead to positive affect. Children in all age groups expected either a story character (Study 1) or themselves (Study 2) to feel happy rather than sad in an aha moment. However, in Study 2, three different tasks designed to assess children's understanding of the aha-experience indicated clear improvements with age. First, with age, children were more likely to pass a control task intended to assess their understanding of the self-report question for aha-experiences. The control task consisted of a simple identification task that did not require any problem-solving, and therefore should not trigger any aha-experiences, followed by a question about whether or not the child had had an aha-experience. With increasing age, children were more likely to correctly answer no to this question. Second, on a scenario task, children were more likely to correctly distinguish between scenarios that did and did not include an aha-experience. Third, on the statements task, children were more likely to choose the correct description of aha-experiences with increasing age for four out of six features (feeling of confidence, new idea, impasse, and feeling-of-suddenness; see Table 3; and Paper 3, Figure 5). The two items which did not indicate significant changes with age were the affect-item, on which children were well above chance at all ages, and the item for feeling-of-truth, on which children at all ages answered at or close to chance. Thus, overall, the current work indicates that children's explicit understanding of aha-experiences showed marked improvement with age in the age range 4-8-years.

Why did we find different developmental trajectories for children's understanding of the positive valence of aha-experiences and their more general understanding of the aha-concept? One possibility is that children did not distinguish between having an idea for a solution, in an aha-experience, and having successfully solved the problem. From this point of view, children's association between aha-experiences and positive affect could be due to an understanding that successfully solving a problem makes you happy. Prior research has shown that young children

understand how a variety of situational outcomes may influence emotions (e.g., Pons & Harris, 2019). For instance, Asaba and colleagues (2019) found that 4- to 5-year-olds understood that both expectations and outcomes influenced how a story character would feel in a bowling game. However, only the 5-year-olds reliably took prior expectations into account once the outcome was known. If children confuse aha-experiences and successful solutions, this could explain their tendency to associate aha-experiences with positive affect.

How can the limited understanding of the more general aspects of aha-experiences of younger children in our sample be explained? Language development is one of several potential mechanisms that have been suggested for the delayed development of explicit metacognition (e.g., Pons & Harris, 2019; Rakoczy, 2022). Language can facilitate explicit understanding of mental processes by providing both syntax and concepts which supports children's reasoning. By providing verbal labels for different categories, language can facilitate the formation of mental representations for phenomena and concepts (e.g., "think", "feel", "want", "believe") which can enable children's reasoning about mental processes. In our study, if the younger children failed the understanding task because they did not have the required verbal labels and/or mental representations for aha-experiences, then familiarizing children with concepts such as "idea", "aha-experience" or "insight", with clear categorical examples, should facilitate younger children's performance. Note that in the current work, children were presented with a brief explanation of the term "aha-experience" at the beginning of the study but received no targeted training.

Beyond conceptual labels, language can also facilitate children's understanding through syntax. For instance, so-called that-complementation has been pointed out as a syntactic feature that may facilitate reasoning about beliefs (Rakoczy, 2022, p. 229). In this context, that-complementation is a sentence structure in which the word "that" connects an actor and a mental capacity (e.g., "believes" or "thinks") to a propositional statement (e.g., "the car is blue"). An example of a complete sentence is "[Izzy thinks] that [the car is blue]". This kind of syntax may facilitate children's capacity to reason about the content of other's thoughts and beliefs. When it comes to the statements-task to assess children's understanding of aha-experiences in Study 2, such mastery of this kind of syntax may have contributed to making the task more difficult for the younger children. However, the differential performance across items, and especially the high performance of the younger children on the item about positive affect, suggests that syntax did not play an important role in the children's answers on this task. The development of other cognitive determinants, such as working memory capacity, may also explain the delay of explicit metacognition. However, a detailed discussion of this issue is beyond the scope of this text because working memory capacity did not play a role in our theory, and we did not measure it.

In sum, the current work provides evidence of a gradual development of children's explicit understanding of aha-experiences in the age-range 4 to 8 years. This finding is in line with research on children's emotion understanding and explicit metacognition at this age. Interestingly, one feature of the aha-experience, namely their positive valence, appears to be an exception from this general developmental trend. The early understanding of the association between aha-experiences and positive affect may indicate either that children confuse the idea for a solution with a successful outcome, or that the valence of metacognitive experiences is more salient to young children than other features which distinguish the different experiences.

Limitations

Several limitations in the current work are worth pointing out as they can limit the interpretation of the presented results. For Study 1, we included trial-error stories which were intended as control scenarios to compare with the insight scenarios. However, we found unpredicted age-related differences in children's responses to the trial-error stories. The trial-error stories were also quite different from the target insight scenarios in ways that could influence children's affect judgements. While the insight stories involved several distinct moments that depicted a prototypical aha moment, the trial-error stories consisted of a repeated sequence of failed solution attempts. The two story-types were based on the descriptions of insightful and analytical problem-solving in the insight literature. In retrospect, other control scenarios or a greater variability in the presented scenario types, such as scenarios that vary in the quality of the idea that is generated at the aha-moment, could prove better equipped to detect children's understanding of aha-experiences. A second limitation in Study 1 is that we did not include any open-response questions that could allow children to demonstrate their reasoning about their answers on the affect judgement tasks. Open-response questions could have provided more nuanced answers that could have showed potential development in children's understanding of aha-experiences and should be implemented in future research.

As for Study 2, a central limitation was that the study did not include video recordings of children's responses to the AhaClues task. Instead, children's expressions of aha-experiences were observed and coded in vivo by the experimenter interviewing the child. This means that it was not possible to verify the observed aha-experiences after the data collection. At the outset of Study 2, it was unclear whether the AhaClues task would successfully elicit aha-experiences, and whether it would be possible for a third-party observer to reliably observe children's expressions of aha-moments. Given the resources required to collect and code video recordings, and the person identifiable, non-anonymous nature of video data that would require additional permits and data handling procedures, it was decided to not include video data in this initial test of the experimental paradigm. However, because our experience while carrying out the study was that at least some of

children's aha-experiences (on average 1-2 per session) could be observed and coded, future research should include video recordings. Video recordings would allow researchers to assess the reliability of the observations, and to potentially discover new observation criteria that can be employed to detect children's expressions of aha-experiences.

A related limitation is that the observations of aha-experiences were made by a single experimenter, as opposed to two independent coders. This meant that we could not assess the reliability of the observations across coders. In retrospect, including two coders would have improved the validity of the observational measure. The decision to only have one single observer was made because of limited resources. If both experimenters were to meet with each child, the data collection would have taken twice as long. Thus, parallel coding was unfortunately not possible in the current project. Note that the two experimenters who conducted the data collection, that is, the PhD candidate and one research assistant, discussed and agreed on the criteria for what should be considered indications that the child had aha-experience before the data collection started. See the section Observed and Self-Reported Aha-Experiments under the section Experimental Tasks. These criteria were based on the experimenters' informal observations in a pilot study. The experimenters relied predominantly on the timing of the children's answers (indicated in criterion (a): after being seemingly stuck for a while, the child suddenly produced the answer), the children's sudden vocalization (e.g., "Oh!"; indicated in criterion (b): the child gasped or suddenly drew in their breath immediately before saying the answer), and their abrupt announcement of the solution word, combined with a triumphant or enthusiastic tone of voice in making that announcement (indicated in criterion (c): the child suddenly shouted the answer or said the answer in a notably energetic way). Future research should use either video recordings or parallel coders to formally test the reliability of observations of children's aha-experiences.

Future Directions

Many new lines of research can be drawn from the current work. First, a future line of research could follow up and elaborate on the findings that pertain to children's explicit understanding of aha-experiences. The current work found age-related improvements in children's general understanding of aha-experiences and their ability to recognize their own aha-experiences from 4 to 8 years of age. Future research could conduct further mapping of which features of aha-experiences are relatively easier/more difficult for younger children to grasp. Moreover, future work could examine different mechanisms that may explain the limitations in younger children's understanding of aha-experiences. This could include investigations into how understanding may be facilitated, for instance through training or teaching. More extensive familiarization with the aha-concept ahead of the understanding-tasks could be one way to facilitate the younger children's understanding. For example, an approach to provide more chances to learn about the aha-concept

ahead of the understanding tasks could be to conduct book-reading sessions, where children read stories designed to teach children about aha-experiences together with an adult. Book-reading sessions have previously been used to improve preschoolers' emotion understanding (Bergman Deitcher et al., 2021) and ability to reason about ambiguous evidence (Bonawitz et al., 2012). Other approaches to facilitate young children's understanding could be to provide feedback on children's responses, or to watch video recordings of children's own aha-experiences with the children and talk with them about the characterizing features of aha-experiences. Another line of research could follow up on the finding that children's understanding of positive affect associated with aha-experiences appeared to follow a different developmental trajectory compared to the more general understanding of the aha-concept. For instance, future research could investigate understanding of the valence of aha-experiences with children younger than 4 years old.

Second, the current work indicated that children's aha-experiences can be observed and detected based on their outward expressions. The observation criteria used in Study 2 were based on informal observations during a pilot study, and focused on the timing of children's answers, combined with their sudden vocalizations and announcements of their answer. Future work could explore whether other indicators, such as changes in hand gestures, posture, or facial expressions, could be used to record children's aha-experiences. Such work could initially target older children who can be expected to provide reliable self-reports of aha-experiences, which could be compared with observations based on different indicators (e.g., timing, vocalizations, gestures, posture, or facial expressions). Based on the data on children's understanding of aha-experiences collected in this dissertation, children aged 7-8 years and older can be expected to provide self-report measures of aha-experiences after a brief introduction to the concept of an aha-experience. Given the extensive use of either self-report or retrospective interviews to document aha-experiences in research with adults, there is a need for new methods to study the aha-experiences of pre-verbal children and children with limited verbal capacities. A mapping of an expressive profile associated with aha-experiences, as outlined here, could facilitate research of aha-experiences that does not depend on verbal abilities.

Third, future research could address how different task-related and contextual features may facilitate or hinder children's aha-experiences. There is no reason to think that the potential to elicit aha-experiences is reserved for the AhaClues task. Rather, given the diversity of tasks used in laboratory studies of adults' aha-experiences, our findings should be seen as an indicator that other tasks can be devised to systematically study children's aha-experiences. Future tasks could involve experimental manipulation of task features to study how different task demands may influence children's aha-experiences. In Study 2, there was evidence that the difficulty level interacted with age to influence the likelihood that children would have an aha-experience for a given task. While

younger children were more likely to have aha-experiences for trials of lower difficulty, older children were more likely to have aha-experiences in more difficult trials. Previous research has found that infants prefer stimuli that is of medium complexity (Kidd et al., 2012, 2014). Moreover, a recent study found that school-aged children preferred more challenging game conditions when playing for fun, compared to when playing to win (Rule et al., 2023). In other words, when they chose the easier conditions, this was to ensure that they would score points, but was not necessarily experienced as enjoyable. If they were encouraged to choose the game settings they would enjoy more, they chose conditions that would provide more challenge. Both of these lines of research can be considered recent evidence that children thrive in a zone of proximal learning (Metcalfe et al., 2020; Vygotsky et al., 2012), where a task is difficult enough to provide some challenge, but not so difficult that the solution is beyond reach. In light of this research, our finding that difficulty interacted with age in predicting whether or not a task would elicit an aha-experience may indicate that children are more prone to have aha-experiences in tasks within their zone of proximal learning. Future research could device tasks and experimental designs that explicitly address this hypothesis.

In addition to task-specific features, future research could address how contextual features may influence children's aha-experiences. In the current work, children solved the experimental tasks individually. Previous work has suggested that children have aha-experiences while collaborating with peers in the classroom (Marchant et al., 2022), and that children's naturalistic aha-experiences involve other people about half of the time (Haugen et al., in press). Future research could explore whether collaboration with peers would influence children's aha-experiences, for instance, by comparing aha-experiences of children working with peers or individually on the same tasks. Are children equally likely to have aha-experiences in both conditions? And how do collaborative and individual aha-experiences compare in terms of their phenomenology and their influence on learning outcomes, such as motivation and recall? The influence of social context on aha-experiences remains largely unknown, both when it comes to children and adults.

Finally, future research could take an applied approach by investigating children's aha-experiences in educational settings. Previous work has indicated that aha-experiences play an important role in the learning process for both university (Liljedahl, 2005) and middle-school students (Marchant et al., 2022), and that children's aha-experiences predominantly pertain to formal knowledge acquisition from about 4-5 years of age (Haugen et al., in press). There is a need for more knowledge about how children's aha-experiences influence learning in educational settings, and how educators can facilitate children's aha-experiences in the classroom.

Concluding Remarks

This dissertation makes theoretical, empirical, and methodological contributions to the study of children's aha-experiences. In terms of theory, the current work has built a foundation for

research on children's aha-experiences by combining cognitive psychological research on the aha-experiences of adults on one hand, and developmental research on children's capacity to learn and reflect on cognition on the other. Children's aha-experiences can be understood as a metacognitive experience that accompanies and guides children's conceptual development from early childhood. The empirical contribution consists of the first data on children's experience and understanding of aha moments. Our results indicate a developmental lag between the occurrence of aha-experiences and children's understanding of aha-experiences. Moreover, our results suggest that children's aha-experiences are related to motivation and accuracy. Finally, the methodological contribution of the current dissertation consists of several new tasks suitable for children from the age of 4 years old, to elicit aha-experiences in an experimental setting and to study the development of children's understanding of aha-experiences. Many new lines of research can be drawn from the current work, with implications for the conceptualization of aha-experiences, the influence of metacognitive experiences on learning, and the development of children's understanding of mental phenomena. More broadly, the current work encourages educators to consider how metacognitive experiences shape students' progress and motivation. My hope is that the current work can inspire renewed interest in children's learning experiences.

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