MOMENTS OF BRILLIANCE

Understanding the Aha-experience through Bayesian Statistics

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"We all have our moments of brilliance and glory, and this was mine."

~ Roald Dahl (1984, p. 35)

Five years is a long, long time. Since I first began this project in 2014, I have experienced the passing of my father and several cherished friends, but I have also gained a wife (2016) and a son (2017). Five years is equally a long time to spend on a single project and I hope I have spent the time wisely.

First, and foremost, I would like to thank my supervisor, Professor Rolf Reber, who made the journey from University of Bergen to University of Oslo possible. Without his prior research, his guidance and essential contributions, this project would not have been possible. When I wrote the acknowledgements for my master's thesis in 2013, I stated that the most important aspect for me was to explore the rudiments of quantitative methodology. This statements still holds, and in the interim, I have continued exploring statistical, mathematical and computational methods. In 2013, I thanked Professor Andy Field, and I still encourage all to read his wonderful book, *An Adventure in Statistics*. However, this time around I will have to thank Professor John K. Kruschke for his educational workshop at the ICPSR16, and his excellent book, *Doing Bayesian Data Analysis*. It opened my eyes to Bayesian statistics, and I will settle for one representative sample (Kruschke, 2015, p. 143). Furthermore, I would also like to thank Professor Svein Olav Glesaaen Nyberg at University of Agder for his feedback on the methods section.

I am especially grateful for the support from my little family, thank you for tolerating this little absentminded man. Wife, Firstborn, I shall return to you shortly, whimsical and all.

Lastly, but not least, I would like to thank the respondents for their contribution, the foundation of this thesis. I am in your debt.

Øystein Olav Skaar
Hamar, April 2019

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General Summary

Regarded as the product of prolonged and sustained efforts, creativity is still often associated with the rare moments when a solution to a problem suddenly bursts into consciousness: the hallmark of sudden insight. The present thesis aims to provide evidence for a better understanding of the phenomenology connected with these moments, colloquially termed as the *Aha-experience*. Founded on an integrative fluency account, linking sudden insight to the ease with which information is processed, positive affect and subjective certainty in the newfound solution, the thesis delves into different aspects of educational, cognitive, personality and social psychology, providing diverse and new understanding of motivation and creativity associated with the Aha-experience. *Paper I* utilized the integrative fluency account to understand metacognitive feelings in relation to change in motivation and coping from Aha-experiences. *Paper II* applied social role theory to help explain gender similarities and differences in Aha-experiences. *Paper III* examined elapsed time since last memorable Aha-experience to explore the relationship between Openness to Experience and the frequency of Aha-experiences.

Based on a large, retrospective survey, utilizing multiple independent samples, the strength of the project is the overall coherence between the individual studies. The design allows drawing conclusions across the three papers, which is the main purpose of this dissertation. All three studies applied *bfw,* a Bayesian framework, developed in tandem with the ongoing PhD project. The framework provided several modules to conduct linear and non-linear, hierarchical analyses, and allowed the use of custom Bayesian models specifically devolved for the project. The goal of the framework was to easily estimate parameter values and the stability of estimates and conduct convergence diagnostics. In other words, to assess the certainty, and uncertainty, associated with the presented results. Thus, the development of *bfw* aided the process of gaining a deeper understanding of the phenomenology of insight. An important aspect of this thesis is to present the methodological considerations of the Bayesian approach.

Paper I aimed to test the integrative fluency account and examine the relationship between Aha-experiences and motivation within a given domain. Results indicated that fluency, positive affect and subjective certainty are underlying facets of metacognitive feelings elicited by sudden insight. The study strengthens the hypothesis that fluency is marked hedonically and

epistemically, and therefore generally conforms to the proposed fluency account. Moreover, the study links the Aha-experience with an increase of motivation and coping.

Paper II explored the situational aspects of Aha-experiences. Prior research indicates that boys show more interest in science, technology, engineering and mathematics (STEM) than girls, where traditional STEM education is marked as highly competitive and individual-oriented. We applied a social role theory perspective to explain the role of gender in interest. Social role theory argues that society's division of labor between men and women forms social roles and gender stereotypes, and that an interaction of biological and social processes influences sex-differentiated dispositions and behaviors. Results indicated that men, compared to women, were more likely to be alone during the Aha-experience. The effect was most credible for participants who reported increased interest in personal and STEM domains. The study is consistent with previous findings that women, relative to men, find more interest from cooperation. The study concludes that biosocial influences have led, in part, women to adopt more communal roles and men more agentic roles.

Paper III examined the relationship between personality traits and the frequency of Aha-experiences. Openness to Experience appears to be the strongest predictor of creativity and creative self-efficacy, and the Aha-experience is a phenomenon associated with creativity. Results linked Openness to Experience to recollecting autobiographical memories, and it is argued that feelings in the fringe of consciousness serve as a retrieval function, mainly through metacognitive feelings associated with a specific insight. Furthermore, the relationship between Openness to Experience and frequency of Aha-experiences was dependent on elapsed time since the last memorable Aha-experience, indicating that the relationship depends on creative achievement in the form of Aha-experiences and not just creative aptitude. Paper III concludes that to understand the relationship between Openness to Experience and Aha-experiences, and creativity in general, it is essential to consider the effect of motivational processes.

Drawn together, the current thesis suggests that understanding situational aspects, phenomenological dimensions and individual differences are crucial in order to understand the Aha-experience itself. The thesis discusses these implications and draws inferences based on the overall perception of the independent studies. In sum, the work presented herein states that the Aha-experiences are multifaceted and without the context in which the sudden insight occurred, the Aha-experience will remain a mythical phenomenon.

List of Papers

I Skaar, Ø. O., & Reber, R. (2019). The phenomenology of Aha-experiences. *Motivation Science*. https://doi.org/10.1037/mot0000138

II Skaar, Ø. O., & Reber, R. (2019). *Unravelling the Aha-experience: Gender Differences and Similarities Predicted by Social Context, Domain and Interest*.

III Skaar, Ø. O., & Reber, R. (2019). *Fringe Consciousness and Openness to Aha-experiences*.

List of Abbreviations

ANOVA	Analysis of variance
bfw	Bayesian framework for computational modeling
DMN	Default-mode network
ESS	Effective sample size
GLM	Generalized linear models
GLMM	Generalized linear mixed models
HDI	Highest density interval
MCMC	Markov chain Monte Carlo
JAGS	Just another Gibbs sampler
NHST	Null hypothesis significance testing
ppp	Posterior predictive p-values
ROPE	Region of practical equivalence
SEM	Structural equation model
STEM	Science, technology, engineering, and mathematics

Introduction

Bühler (1907) coined the term Aha-experience, which is a peculiar, yet pleasurable experience that accompanies sudden insight[1]. The present thesis aims to provide evidence for a better understanding of the peculiar Aha-experience. The introductory section will present the main theoretical underpinnings of the project, naturally, with an emphasis on the Aha-experience (cf., Paper I). Furthermore, an important aspect of this project has been to unravel the situational settings of Aha-experiences, particularly with a focus on Aha-experiences and gender differences within fields of science, technology, engineering, and mathematics (STEM). To achieve this, we applied social role theory (Eagly & Wood, 1999) to better identify gender differences and similarities, and the second part of this introductory section will provide a brief outline of this theory (cf., Paper II). Finally, the Aha-experience, or the *moment of insight*, is associated with creativity (Sternberg & Davidson, 1995), and in our project we have linked Aha-experiences with creativity through the personality trait Openness to Experience, or simply *Openness*. Consequently, the introduction will end with a section on the relationship between the Aha-experience, creativity and Openness (cf., Paper III). After the introduction follows a section on methodological considerations and a presentation of the Bayesian framework used in the studies. Subsequently, the three papers are summarized, followed by a section presenting extended results based on hypotheses derived from the papers. The thesis concludes with a general discussion on the projects' contribution to the research field of insight and Aha-experiences, drawing inferences from all three papers. The three papers printed in full, follows the references at the end of the thesis.

The Aha-experience

Since the days of Köhler (1927), the term *Einsicht* (insight) has been used to differentiate sudden understanding of a problem from incremental problem-solving (Gilhooly & Murphy, 2005; Shen et al., 2016). Wallas (1926) proposed an influential four-stage model of the creative process (Davidson, 2003; Gilhooly, 2016; see Shen et al., 2018 for a meta-analysis). *First*, an

[1] "Ein eigenartiges im Denkverlauf auftretendes lustbetontes Erlebnis, das sich bei plötzlicher Einsicht […] einstellt" (Bühler, 1907, p. 315f).

individual addresses a problem, task or query through conscious preparation, for instance, by defining the issue and gathering relevant information. *Second*, unconscious processes aid the individual during incubation periods where the issue is set aside. *Third*, the individual experiences an illumination, or insight, providing a sudden answer to the issue at hand. *Fourth*, the individual scrutinizes the provided answer, in order to validate or invalidate the result.

The Aha-experience is the subjective experience that accompanies the third stage, the sudden insight (Topolinski & Reber, 2010a; Webb, Little, & Cropper, 2016). Until recently our knowledge of Aha-experiences mainly stemmed from historical and anecdotal data (Ash, Cushen, & Wiley, 2009; Ovington, Saliba, Moran, Goldring, & MacDonald, 2018; Sprugnoli et al., 2017). However, recent advances in cognitive and neurocognitive research suggests that sudden insights are the product of unconscious cognitive processes, rather than spontaneous solutions (Bowers, Farvolden, & Mermigis, 1995; Kounios & Beeman, 2014; Sheth, Sandkühler, & Bhattacharya, 2009). Thus, the underlying processes of creative insights are likely to be similar to incremental problem-solving (Chuderski & Jastrzębski, 2018), and the insights themselves the product of prolonged and sustained efforts (Runco, 2004; Sawyer, 2013). Consequently, there are no mental shortcuts to groundbreaking ideas (Finke, Ward, & Smith, 1992; Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998). However, as evident by the pioneering work of Metcalfe (1986a, 1986b), insight *feels* different from conscious, analytical problem-solving. This is the Aha-experience, and the phenomenology of insight is the subject of study in Paper II.

The phenomenology of insight. Einstein once wrote, “I was sitting on a chair in my patent office in Bern. Suddenly a thought struck me: If a man falls freely, he would not feel his weight. I was taken aback. This simple thought experiment made a deep impression on me. This led me to the theory of gravity” (as cited in Irvine, 2015, p. 129). There are numerous examples that remarkable scientific and artistic breakthroughs have appeared as *rushes of insight* (Gick & Lockhart, 1995), breakthroughs that in essence have been simply stated in concise verbal form (Hutchinson, 2014). For example, acclaimed screenwriter and comic book writer Straczynski was on location shooting a TV series, when the story for a Spider Man comic beamed into his head like automatic writing (Straczynski, 2019a). He later described the experience as a frequency he did not know existed before, and in accordance with Hutchinson, the sentences came out fully formed with no editing afterwards (Straczynski, 2019b). Straczynski claimed the

insight felt more like remembering the story than creating it. Similarly, Poincaré (1914, p. 54) was walking when an idea came to him with the "characteristics of conciseness, suddenness, and immediate certainty". However, he acknowledged that even if sudden insights seldom led him astray, they were not always correct. The tale of Johannes Kepler is an excellent example of the lure of Aha-experiences. Kepler spent his entire life pursuing the notion that platonic solids accounted for the intervals of space between the planets (Caspar, 1993; Voelkel, 1999). The idea came to him while demonstrating the geometrical relationship between two circles on July 19, 1595 (Voelkel, 1999, p. 29). Kepler's insight was incorrect, but please note the date and year, and revel at the notion that we today, more than four hundred years later, can know that the Aha-experience made Kepler weep "tears of joy". This is the potential transformational power of Aha-experiences, erroneous or not. Kepler's pursuit of finding evidence for his sudden insight led him to develop the three laws of planetary motion, which later proved crucial for Isaac Newton to formulate the law of gravitation. Drawn together the anecdotal evidence encompass what Topolinski and Reber (2010a) proposed as components of the processing fluency account of Aha-experiences: (1) a sudden insight leads to change in (2) processing fluency that increase (3) positive affect and (4) certainty that the insight is true. The following sections elaborate on the integral components of the Aha-experience.

Sudden fluency. The depiction of Aha-experiences is often the proverbial light bulb, illustrating the sudden transition from ignorance to understanding (Danek & Wiley, 2017; Shen, Yuan, Liu, & Luo, 2015). Such insights are experienced as both sudden and surprising (Gick & Lockhart, 1995). Metcalfe and Wiebe (1987) conducted experiments comparing classic insight problems to non-insight and algebra problems. The results exhibited that participants were able to predict performance on non-insight problems but not insight problems. Importantly, Metcalfe and Wiebe (1987) used patterns-of-warmth ratings, measuring the participants' subjective feeling of whether they approached a solution. The ratings indicated that participants solving non-insight problems experienced an incremental increase in warmth, that is, an incremental increase in subjective certainty that they approached a solution. Conversely, participants solving insight problems reported low levels of warmth, until they abruptly found a solution. Similarly, Bowden (1997) examined the effects of unreportable hints in anagram-solving, that is, hints that do not reach consciousness hence the individual is not subjectively aware of their existence. Bowden found that unreportable solutions and semantically related hints, compared with unrelated hints,

produced more insights. Kounios and Beeman (2014) claimed the results indicated that insights are the product of unconscious cognitive processes and not just spontaneous solutions. For example, Bowden and Jung-Beeman (2003) developed a series of compound remote associate problems, where participants were asked to identify a single solution word (e.g., “bag”) that forms a compound word, or familiar phrase, derived from three problem words (e.g., “sleeping”, ”bean” and “trash”). Such tasks encompass unconscious processing that leads to the sudden conscious understanding of each word and, if the task is successfully completed, the sudden understanding of the solution word. However, as evident from the patterns-of-warmth ratings, individuals experience the solutions as spontaneously generated. This is the rush of insight (Gick & Lockhart, 1995) and pertains to processing fluency (or simply fluency), meaning the ease and speed with which the solution is understood (Reber, Schwarz, & Winkielman, 2004).

To some researchers, suddenness and fluency constitutes the essential moment of insight, and are by themselves sufficient to form the definition of an Aha-experience (Gick & Lockhart, 1995; Metcalfe & Wiebe, 1987). However, Topolinski and Reber (2010a) argued that fluency generally elicits a positive emotional response (Reber, Winkielman, & Schwarz, 1998; Winkielman & Cacioppo, 2001) and an increased subjective truth of the solution (Reber & Schwarz, 1999; Reber et al., 2004). Corresponding to Kepler’s tears of joy (Voelkel, 1999, p. 32) and Poincaré’s absolute certainty (Poincaré, 1914, p. 53), the integrative fluency account unifies the four attributes as separate features of the same experience, the Aha-experience. In Hutchinson’s account on the nature of insight, an unnamed scientist described sudden insight as “usually simple, and in its simplicity lies its beauty” (Hutchinson, 2014, p. 227). The scientist ended on the note that he always felt elated after suddenly finding an answer. The following section will discuss this relationship between aesthetic emotion and subjective certainty.

Beauty and truth. There is ample empirical evidence that links sudden insight with positive emotions (Cosmelli & Preiss, 2014; Friedlander & Fine, 2018; Gruber, 1995; Kounios & Beeman, 2014). Reber et al. (2004) proposed the hedonic fluency hypothesis and argued that fluency is hedonically marked as high fluency elicited positive affect and, moreover, that fluency plays a crucial role for aesthetic pleasure and aesthetic judgements (Leder, Belke, Oeberst, & Augustin, 2004; Winkielman, Schwarz, Fazendeiro, & Reber, 2003). According to Bornstein and D’Agostino (1992, 1994), stimulus repetition enables retrieval from long-term memory, which

increases fluency and consequently positive affect (see Jacoby & Dallas, 1981). Similarly, Alter and Oppenheimer (2009) reviewed the literature on fluency and concluded that through manipulating conceptual, perceptual or linguistic fluency it is possible to facilitate aesthetic judgements and positive affect. Evidently, easily processed information is generally preferred over information that is more difficult to process (Topolinski, Likowski, Weyers, & Strack, 2009; Winkielman & Cacioppo, 2001). Thus, fluency prompts positive affect that leads to an experience of beauty (Topolinski, Erle, & Reber, 2015). However, Aha-experiences are not only aesthetically pleasing, according to Poincaré (1914, p. 60) sudden insights appeared to him as beautiful, useful and, importantly, *truthful.*

Experimental studies have established that participants consider symmetric patterns more beautiful (Makin, Pecchinenda, & Bertamini, 2012) and more correct (Reber, Brun, & Mitterndorfer, 2008) than asymmetric patterns. Reber and Schwarz (1999) showed that participants were more likely to endorse statements (e.g., "Osorno is in Chile") when presented in high, compared to low visual contrast (see Unkelbach, 2007). Furthermore, Topolinski and Reber (2010b) manipulated the interval between anagrams and their subsequent solutions. The study suggested that solutions, regardless of actual truth, presented after shorter delay (50 ms) were more likely to be endorsed than those presented after longer intervals (150 ms). In two experiments, Parks and Toth (2006) found that effect sizes were even larger with semantic rather than perceptual fluency. Importantly, Hansen, Dechêne and Wänke (2008) found that the effect of fluency on subjective certainty was strongest when the experienced fluency was surprising (see Webb et al., 2016). Corresponding studies showed that repeated exposure to statements increases fluency (Begg, Anas, & Farinacci, 1992; Dechêne, Stahl, Hansen, & Wänke, 2010) which, in turn, affected subjective certainty (Hedne, Norman, & Metcalfe, 2016). Reber et al. (2006) found that individuals use retrieval fluency to judge their own performance, and Ackerman and Zalmanov (2012) demonstrated that individuals have more confidence in solutions that are easy to retrieve. In sum, the studies imply that discrepancies in fluency and temporal contiguity are essential for the link between fluency and subjective certainty, and strengthens the assumption that sudden insights appear both truthful and beautiful.

Fluency and sense of agency. Sense of agency encompasses conscious awareness that one is initiating, executing, and controlling ones own actions or thoughts (Balconi, 2010; David, Obhi, & Moore, 2015). According to Wegner and Wheatley (1999), feelings of sense of agency

are strongest when an individual believes that a thought (1) precedes, (2) corresponds to and (3) causes an action. Olson et al. (2016) introduced a simulated thought insertion paradigm, where participants were told that a neuroimaging machine could either read or influence their thoughts. Results from their study indicated that participants felt less voluntary control of their decisions, and made slower decisions, in a Mind-Influencing compared to Mind-Reading condition. The authors argued that slower decision time indicated reduced fluency (cf., Chambon, Sidarus, & Haggard, 2014). In light of Aha-experiences, sudden insight precedes fluency within the domain of the insight, and it is therefore plausible that the sudden insight increases sense of agency. However, similar to Plato's notion that the poet can only create when the Muse dictates, Aha-experiences are often credited to someone or something else (Sternberg & Lubart, 1998). Consequently, sudden insight might decrease sense of agency.

The reviewed earlier empirical studies provide seminal work on the Aha-experience. However, the studies provide only individual links between the four attributes of the Aha-experience, and to date there are no quantitative studies that have tried to incorporate all four attributes in one single study. Furthermore, to our knowledge, there are no studies examining the relationship between sense of agency and Aha-experiences. However, the following section cites a qualitative study by Liljedahl (2004) that proved to be crucial for the development of the present project.

An integrative approach to Aha-experiences. Positive affect is the component of the Aha-experience associated with the feeling-related component of interest (see Schiefele, 1991). Yet, few studies have examined the link between Aha-experiences and interest, and primary focus in our project was to examine the potential of Aha-experiences to change people's attitude towards STEM-topics. Decline in interest within the so-called hard sciences is a major challenge during middle school years, and continues to be a source of concern for any developed society (Hidi & Harackiewicz, 2000; Krapp & Prenzel, 2011; M.-T. Wang & Degol, 2013). The topic is understudied, however, Liljedahl (2004, 2013) described change in negative beliefs and attitudes toward mathematics as a result of Aha-experiences. Based on the anecdotal reflections of undergraduate students, the anecdotal reflections of prominent mathematicians, and the mathematics diaries of preservice teachers, Liljedahl (2004, p. 78) claimed that the Aha-experience presupposes accomplishment, and moreover, that Aha-experiences elicit more positive emotions than analytical problem-solving. According to this view, the affective response

to a sudden insight is what differentiates the Aha-experience from other types of mathematical experiences, whereas the cognitive component is inconsequential (Liljedahl, 2004, p. 197). Thus, the Aha-experience can drastically change otherwise stable affective traits and foster a sense of self-improvement and mathematical progression in the face of adversity. Liljedahl (2004) wrote:

> The positive emotions that it [the Aha-experience] invokes has [*sic*] the power to change negative beliefs and attitudes about ones ability to do mathematics as well as negative beliefs and attitudes about the subject of mathematics itself. For these reasons, the impact that an AHA! experience can have on students learning is not to be ignored. (pp. 80-81)

Liljedahl provided the first evidence of an integrative approach to Aha-experiences, linking sudden insights with surprising fluency and a resultant sense of certainty. Furthermore, Liljedahl not only observed fleeting moments of positive affect, but rather strong transformational effects in attitudes towards mathematics. Consequently, the objective of Paper I was not only to test the integrative fluency account as proposed by Topolinski and Reber (2010a), but also to assess the relationship between the Aha-experience and motivation and coping.

Furthermore, in Liljedahl's study (2004, p. 205), ongoing and frequent peer interaction was an important aspect in facilitating Aha-experiences. In contrast, isolation is a common theme in the anecdotes on Aha-experiences collected by Irvine (2015) and Hutchinson (2014). Csikszentmihalyi's (1996) work on creativity has strengthened the stereotype of the *solitary genius*. Still, these insights often emerge within a domain where there are few, maybe none, that exhibit the same level of prior knowledge and expertise as those who have the Aha-experience. Consequently, the question arises whether solitude is a common feature of the general Aha-experience, or if it is merely a consequence of being a world-leading, groundbreaking expert. Moreover, the anecdotes stem mainly from men, whereas more than 80 percent of participants in Liljedahl's study were women (personal communication, 2017, February 15). Therefore, in Paper II, we were interested in examining the social context of Aha-experiences and assess whether solitude or interaction prior to the Aha-experience differed between men and women.

Social Role Theory

Eagly and Wood (Eagly & Wood, 1999, 2012, 2016) proposed a social role theory, and argued that biosocial interactions, meaning the joint effect of biological and social processes,

forms sex-differentiated dispositions and behaviors (Eagly & Wood, 2013). Social role theory states that social roles and gender stereotypes are formed by society's division of labor between men and women (Eagly & Wood, 1999, 2012; Wood & Eagly, 2002, 2012). As seen from Figure 1, division of labor derives from biological factors, principally men's physical strength and women's ability to bear children, in interaction with the requirements of the socioeconomic and ecological environment. Though some societies emphasize physical specialization of the sexes, for instance, promoting men as providers and women as nurtures, others may encourage more fluid gender roles (Wood & Eagly, 2002, 2012).

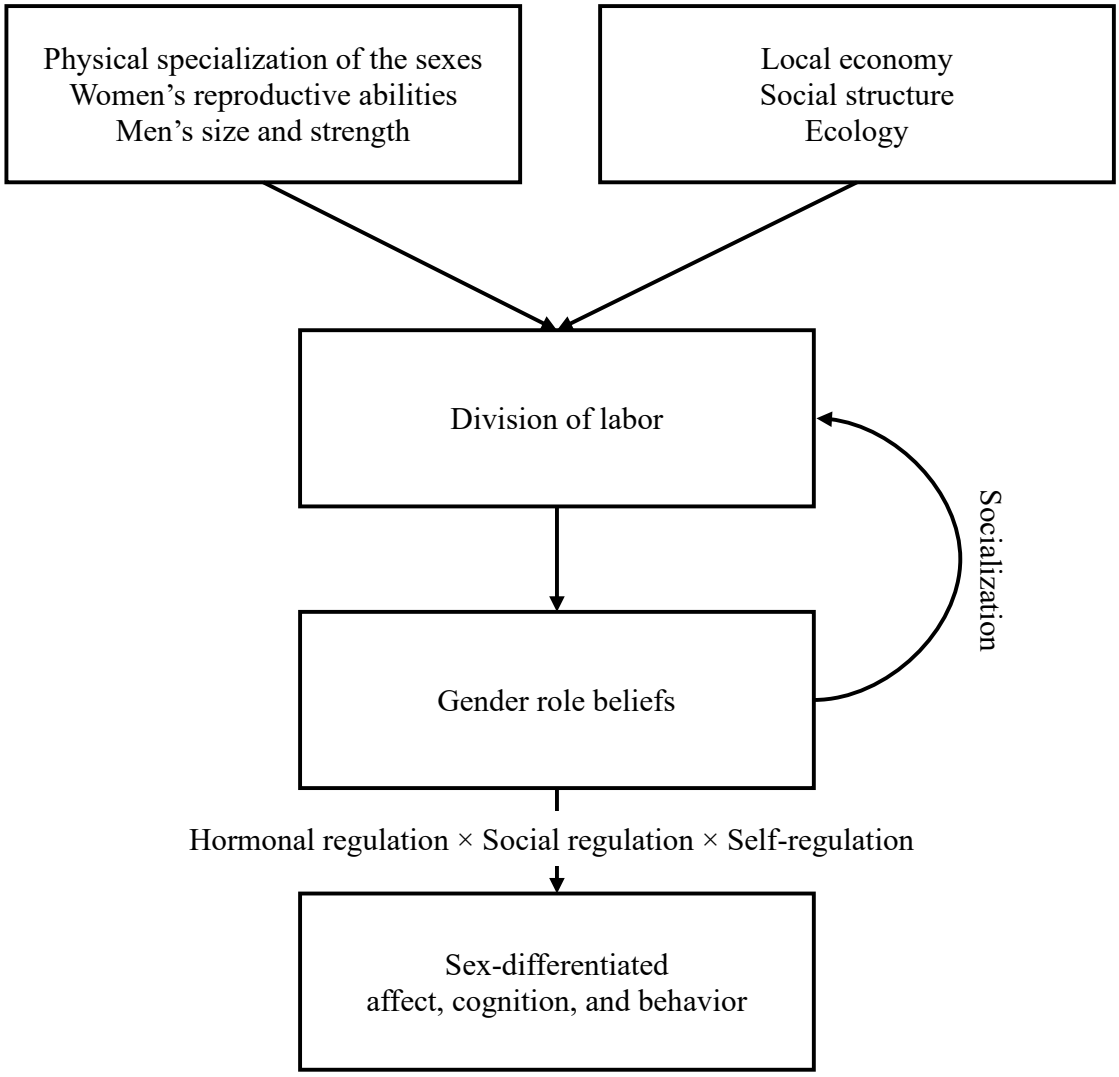


Figure 1. Gender roles guide sex differences and similarities through biosocial processes (adapted from Eagly & Wood, 2012, p. 465).

Thus, biological traits, in addition to historical and social structures, facilitate the development of social roles, which in turn foster gender role beliefs (Wood & Eagly, 2010). Societies that advocate distinct sex-differentiation in distribution of labor also promote distinct gender roles. In turn, gender stereotypes offer restrictions and opportunities that drive gender differences and similarities in career choices, partner preferences, domestic behaviors and other domains (Koenig & Eagly, 2014; Wood & Eagly, 2010; Zentner & Eagly, 2015). Throughout childhood and adolescence, individuals tend to adopt their assigned gender roles, thus, in turn strengthens the existing social roles (Eagly, Wood, & Diekman, 2000; Wood & Eagly, 2010). Eagly and Wood (2012) claimed the theory is in line with the *correspondent inference principle*, that is, to draw generalized conclusions about a person, group or gender based on observed behavior. Consequently, if the division of labor has a clear gender gap, with some professions reserved for men and others for women, the correspondent inference principle implies these professions are considered as either masculine or feminine. In an experiment, Weisgram, Bigler and Liben (2010) manipulated the gender composition of novel jobs, where the results indicated that participants preferred jobs with coworkers of the same sex over identical jobs with the opposite sex. Consequently, gender role beliefs may lead people to take jobs they are less interested in rather than working in what is considered gender-atypical professions (Gianettoni & Guilley, 2016).

Social role theory identifies biological factors and requirements of the socioeconomic and ecological environment as distal causes of gender differences and similarities. However, the theory also defines three proximal determinants: (1) hormonal processes, (2) gender identities and (3) expectations of others (Eagly & Wood, 2012). *Hormonal changes*, predominantly oxytocin and testosterone, influence behavior (Wood & Eagly, 2010). Oxytocin is closely associated with bonding and affiliation, and is culturally regarded as a mechanism supporting feminine behavior (Campbell, 2008). Testosterone, on the other hand, is generally associated with risk-taking, competition and dominance, and is culturally considered to support masculinity (Booth, Granger, Mazur, & Kivlighan, 2006). Importantly, hormones are inherently neither male nor female, but rather appropriate, yet selective, neurochemical processes initiated to serve task-specific actions (Wood & Eagly, 2010). Moreover, gender identities and social expectations are important determinants of what is deemed an appropriate response in a given context (Eagly, Karau, & Makhijani, 1995; Witt & Wood, 2010). *Gender identities* develop as the individual

internalizes smaller or larger fragments of their gender role beliefs (Wood & Eagly, 2009). Individuals with high levels of gender identification may exhibit more gender-stereotypic behavior, and as a consequence, may be more exposed to negative effects of stereotyping (Kiefer & Sekaquaptewa, 2007; Schmader, 2002). *The expectations of others* also regulate behavior, generally through negative sanctions when individuals deviate from gender roles (Eagly, Makhijani, & Klonsky, 1992). In part, children and adolescents conform to gender role beliefs in order to fit in and avoid nonconformity in fear of social sanctions (Wood & Eagly, 2010).

The division of labor in traditional societies tended to be clearly divided between a male provider and a female homemaker (Wood & Eagly, 2002). Though many postindustrial societies deviate from this fixed pattern, men still earn more than women, and women do more domestic work (Koenig & Eagly, 2014). Based on the social role theory, we inferred that biosocial influences have led women to adopt more communal roles and men more agentic roles (Eagly, 1987; Eagly & Steffen, 1984), and that these gender stereotypes are similar in most human societies (Saewyc, 2017). The communal role emphasizes polite, relational, cooperative and nurturing behavior, whereas the agentic role accentuates assertive, competitive and dominant behavior (cf., "the male-warrior hypothesis", Vugt, Cremer, & Janssen, 2007). From this perspective, women tend to be personal and communal, while men are more impersonal and individual (Meyers-Levy & Loken, 2015). This corresponds to what Gilligan (1993) describes as attachment and separation:

> In their portrayal of relationships, women replace the bias of men toward separation with a representation of the interdependence of self and other, both in love and in work. By changing the lens of developmental observation from individual achievement to relationships of care, women depict ongoing attachment as the path that leads to maturity. (p. 170)

Biosocial interactions, that is, the complex and dynamic relationship between underlying biological factors and the sociocultural environment, influence gender roles and gender role beliefs. Research has shown that on average there are few gender differences concerning performance in mathematics (Hyde, Lindberg, Linn, Ellis, & Williams, 2008; Lindberg, Hyde, Petersen, & Linn, 2010). However, studies also reveal that boys are overrepresented in each extreme of the performance distribution (see Cimpian, Lubienski, Timmer, Makowski, & Miller,

2016). Furthermore, women are still underrepresented in STEM fields, which cannot be fully explained through ability and performance alone (Miller & Wai, 2015; Stoet & Geary, 2018). Given a social role theory perspective, the gender gap may be construed as the result of two gender role beliefs, one regarding natural abilities, the other regarding competition versus cooperation.

First, natural abilities. Traditionally, male providers with better developed spatial abilities were more likely to succeed in hunting prey and survive travel over longer distances (Geary, 2010, p. 395). Similarly, females with better developed verbal abilities were more likely to maintain stable relationships in their in-group and resolve conflicts with out-groups (Geary, 2010, p. 322). Thus, gender role beliefs imply that boys have developed superior talent for mathematics and girls have superior innate abilities for languages. STEM has historically been a male-dominated field. Accordingly, there are persisting gender role beliefs that boys have better natural abilities in mathematics than girls (van Dijk, Meyer, & van Engen, 2018), and that girls have to work harder to achieve the same results (Leslie, Cimpian, Meyer, & Freeland, 2015; Räty, Vänskä, Kasanen, & Kärkkäinen, 2002; Steffens, Jelenec, & Noack, 2010). Although internalization of gender role beliefs lead girls to adopt more studious approaches to learning, gender stereotyping causes them to experience more negative self-concepts of ability than boys (Gunderson, Ramirez, Levine, & Beilock, 2012; Mau & Lynn, 2000). Correspondingly, Cimpian et al. (2016) argued that the more studious methods applied by girls appeared to have a better effect at the bottom rather than top end of the distribution, explaining why girls are underrepresented both at the lower end and higher end of the distribution.

However, cross-cultural research supports the assumption that biosocial factors drive gender differences in spatial and verbal ability. Hoffman et al. (2011) conducted a large-scale experiment on spatial abilities with two tribes in Northeast India. The tribes lived from agriculture and were similar in wealth, yet, the tribes were clearly distinct in that one of the tribes was patrilineal and the other matrilineal. Compared with women, men in the patrilineal tribe had 3.67 more years of education, whereas years of education were equal for men and women in the matrilineal tribe. The results showed that women took longer than men did to solve the puzzle in the patrilineal society but not in the matrilineal society. The authors argued that societal differences play an important role in the gender gap in spatial abilities. Moreover, Feng, Spence and Pratt (2007) found that moderate spatial skills training may neutralize gender differences in

spatial attention and mental rotation ability (see Uttal et al., 2013 for a meta-analysis). Similar results were found for verbal abilities (Pansu et al., 2016).

Second, competition versus cooperation. Men have historically been in positions of competition for resources, including warfare, whereas women have cared for children and nurtured in-group relations (Eagly & Wood, 1999). The division of labor has led men to adopt more positive attitudes towards competition, which prompt competitive behavior and enhance performance in competitive environments (Charness & Rustichini, 2011; Gneezy, Niederle, & Rustichini, 2003). Thus, men are more likely than women to seek challenging and competitive tasks (LeFevre, Kulak, & Heymans, 1992; Niederle & Yestrumskas, 2008). Conversely, women more often engage in more cooperative behavior, and consequently have more positive attitudes towards cooperation than men (Charness & Rustichini, 2011; Gneezy, Leonard, & List, 2009; Martinho, Albergaria-Almeida, & Dias, 2015). Thus, women are less likely to seek competitive environments (Buser, Niederle, & Oosterbeek, 2014; Flory, Leibbrandt, & List, 2010; Gneezy et al., 2003). Niederle and Vesterlund (2010) found that women, relative to men, are more sensitive to the gender composition in competitions. Consequently, women are less likely to participate in mixed-gender competitions (Huguet & Régner, 2007). Niederle and Vesterlund argued that one of the reasons is that women feel threatened by overconfident men who are very eager to win, which in turn may explain gender differences in highly competitive tests (e.g., AP calculus test, SAT math section, see Fischer, 2017).

Derived from the two resulting gender stereotypes, we argue that boys and girls enter STEM education on uneven terms (Easterly & Ricard, 2011). The masculine stereotype is associated with activities and interest that fosters spatial ability (Wood & Eagly, 2015), and boys more often than girls adopt agentic, competitive personality qualities. The feminine stereotype is similarly associated with activities and interest that foster verbal abilities, and girls more often than boys adopt communal, cooperative personality qualities. Consequently, gender role beliefs imply that boys are more likely to perform well in mathematics, and that they are more likely to have high-level intellectual abilities (Bian, Leslie, & Cimpian, 2017). Correspondingly, girls are raised with the expectation that they will have to work harder than boys to achieve the same results (Räty et al., 2002; Yee & Eccles, 1988). Studies have shown that gender stereotypes have a negative influence on performance and, especially, interest of both boys and girls (Banjong, 2014; Galdi, Cadinu, & Tomasetto, 2014; Hartley & Sutton, 2013). As mathematics learning, to

greater extent than other subjects, often is a fast-paced, individual and competitive field of learning, the gender role beliefs leave particularly girls at a disadvantage (Boaler, 2002, 2008, 2016; Cotton, McIntyre, & Price, 2013; Fischer, 2017). Also, many low-ability boys may opt to forfeit the perceived competition, rather than adopting girls' more studious methods to learning (Jones & Myhill, 2004; Martino, 1999). The resulting behavior may strengthen the bimodal distribution seen in PISA and SAT scores (cf., Cimpian et al., 2016).

Given disparaging gender role beliefs, women are less likely to pursue an education and a career within the STEM fields. Similarly, men are less likely to pursue an education and a career within fields associated with care, such as nursing and preschool teaching. Importantly, meta-analyses have emphasized the importance of context for explaining the role of gender in social interaction (e.g., Hyde, 2014; Leaper & Robnett, 2011). Consequently, Paper I aimed to provide some context needed to understand any gender differences and similarities in Aha-experiences, with a special emphasis on STEM-related Aha-experiences. Derived from the social role theory presented in this section, we postulated the hypothesis that men would report more often that they were alone prior to the Aha-experience, whereas women more often report they were with someone who contributed to the Aha-experience. However, we were also interested in exploring individual differences, and the Aha-experience is associated with creativity, discovery, and invention (Thagard & Stewart, 2011). For Poincaré (1914, p. 286) insights were situated in these three facets of the mathematicians mind, and the following section will elaborate on the creative process.

Creativity

A straightforward definition of creativity is the quality of being novel, good and relevant (Kaufman & Sternberg, 2007; Simonton, 1999), or at least, novel and appropriative (Hennessey & Amabile, 2010). Unsurprisingly, such broad descriptions of creativity make it difficult to assess what is creative and what is not (Sternberg, Kaufman, & Pretz, 2002), and Hennessey and Watson (2016) argued that creativity research is a fragmented field. However, Csikszentmihalyi (1988, 2014) identified three interrelated dimensions of creativity. *First,* the domain that encompasses combined knowledge within a culture at any given time. *Second,* the person, an individual that produces novel, good and relevant variations within said domain. *Third,* the field, other members of the domain (i.e., "the elite") that may facilitate or impede inclusion in

organizations that serve as authorities on what is valuable and what is not. The latter means that the field acts as gatekeeper, where experts are usually quite able to determine what is creative within the respective domain (Amabile, 1982; J. Baer, Kaufman, & Gentile, 2004; Kaufman, Plucker, & Baer, 2008). Moreover, the domain necessitates that creativity is context-specific (Lu, Martin, Usova, & Galinsky, 2019), meaning that a quality considered creative in one context, in one environment, at one time, may be derivative, offensive or even illegal in others. Thus, creativity is chiefly determined by the constraints of a specified sociocultural group, and not by the individual creator (Simonton, 1999). However, the second dimension, comprising individual processes has received the most attention in psychology (Csikszentmihalyi, 2014, p. 59), and leads to the question: "why are some people more creative than others?"

Historically, as evident from the anecdotal evidence provided in the introductory section, most creativity research has been on the qualities of eminent scientists and artists (the Big-C) rather than everyday (the little-c) creative achievements (Richards, 2007; Weisberg, 1993). Montuori and Purser (1995) argued that the one-sided focus on Big-C stems from the admiration in the western culture of the lone genius, which highlights the individual over the sociocultural environment. Consequently, the main attention of creativity research has been on the creative product rather than the creative experience (Stein, 1953). To overcome the dichotomy of the Big-C and little-c, Kaufman and Beghetto (2009) proposed an expanded model on creativity to include the *mini-c*, meaning the personal learning processes inherit in creativity, and *pro-c* to distinguish between everyday creativity and professional creativity on an expertise level. Paper III emphasized the little-c and mini-c, especially: "novel and personally meaningful interpretation of experiences, actions, and events" (Beghetto & Kaufman, 2007, p. 73). Though the mini-c may not be important or novel in the grand schemes of things, these creative experiences are novel and can be very important for the individual. To explore the relationship between the mini-c and Aha-experiences, we based the study on the well-established link between creativity and Openness (Carson, Peterson, & Higgins, 2005; Silvia, 2008).

Openness and creativity. Recent advances in cognitive neuroscience have indicated that the neural link between Openness and creativity is chiefly located in *DMN*, the default-mode network (Jung & Meadows, 2017; Yasuno et al., 2017). Beaty et al. (2015; 2018; 2019) claimed individuals that score high on Openness are more imaginative and creative due to a greater ability to dynamically shift between different modes of thinking (cf., Mednick, 1962).

Consequently, consistent with Hutchinson's (2014) notion of concise verbal insights, DMN facilities the construction of dynamic mental simulations through disinhibitory neuronal processes (Jung, Mead, Carrasco, & Flores, 2013; Li et al., 2015). Cela-Conde et al. (2013) exhibited that DMN contribute to aesthetic appreciation and Ogawa et al. (2018) found that creative insights include a coupling of DMN, semantic and cerebral-cerebellum networks that contribute to the dopaminergic system and motivational states. Similarly, research has indicated that the Aha-experience might be central in the emotional response system for recognizing novel, good and relevant information (Danek, Fraps, von Müller, Grothe, & Öllinger, 2013; Friedlander & Fine, 2018; Kizilirmak, Galvao Gomes da Silva, Imamoglu, & Richardson-Klavehn, 2016; Thagard & Stewart, 2011). Therefore, the Aha-experience is a phenomenon associated with creativity (Friedman & Förster, 2005; Kounios et al., 2006), and potentially a subfield of creativity itself (Dietrich & Kanso, 2010). Openness, creativity and the Aha-experience are associated with the dopaminergic reward system that enables cognitive flexibility and monitoring processes in DMN and other networks (Dang, Donde, Madison, O'Neil, & Jagust, 2012; DeYoung, 2013; Passamonti et al., 2015; Salvi, Cristofori, Grafman, & Beeman, 2016; Silberstein, Pipingas, Farrow, Levy, & Stough, 2016). In other words, people high in Openness search for novel experiences because they to a greater extent are emotionally rewarded by them (Sutin, Beason-Held, Resnick, & Costa, 2009). Furthermore, derived from research on mindfulness, linking Openness to fringe consciousness (R. A. Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Norman, Price, & Duff, 2006), we assumed that individuals scoring high on Openness were more likely to recall and report an Aha-experience through metacognitive feelings associated with a specific insight.

Fringe consciousness. William James (1890/1983) provided the first comprehensive description of fringe experiences (Lavazza, 2017). In short, James argued that consciousness encompasses distinct sensory content called the nucleus (i.e., focus of attention) framed by more vague fringe feelings that guide consciousness from one substantive thought to another. Mangan (1991) later reintroduced the concept of fringe consciousness to cognitive psychology, where the sensory nucleus and the non-sensory fringe are seen as facets of a single phenomenological dimension on a high articulation (i.e., nucleus) low articulation (i.e., fringe) continuum. According to this account, fringe feelings vary in intensity yet escape introspection, meaning that when the fringe is brought to attention its content reflects the nucleus rather than the fringe

feelings themselves. Mangan (2003) speculated that the fringe represents context information about the nucleus, however, the information provided is highly condensed due to physical limitations of human consciousness (cf., "the conservation principle", Mangan, 2014). This means that due to consciousness' limited resources, there is a need to balance between detailed articulated information in the nucleus and the larger context represented in the fringe. Mangan (2007) claimed that *rightness/wrongness* are essential fringe feelings that aid cognitive evaluations, and that other sensory and fringe components are experienced as more integrated and meaningful when they are accompanied by strong feelings of rightness (Mangan, 2015). Furthermore, rightness is fundamental for feelings of knowing and feelings of discovery or surprise, that generally accompanies the Aha-experience (see Mangan, 2003, 2014; Mason & Hargreaves, 2001; Zander, Öllinger, & Volz, 2016). Importantly, Mangan (2001) argued that fringe consciousness functions as a mechanism for voluntary retrieval: "The cognitive purpose of focusing on a vague experience in the fringe is not to make *that* experience a stable entity in attention, but to bring a far more articulated (informative) experience into focal inspection implied by the experience" (Mangan, 2001, p. 26). In other words, by directing attention to fringe feelings it is possible to get a better understanding of the nucleus the feelings represents (Norman, 2002, 2017). In Paper III, we argued that individuals high in Openness are more likely to recall and report specific Aha-experiences due to being more aware of metacognitive feelings at the fringe of consciousness. In addition, we were interested in exploring the possibility that Openness relates to the frequency of Aha-experiences (Aha-frequencies). Research indicates a link between Openness and a motivation to explore novel and complex information (DeYoung, 2013; DeYoung, Peterson, & Higgins, 2005), and it is therefore plausible that individuals high in Openness also experience more Aha-experiences. However, to date there are no studies that examine whether the relationship between creativity and Openness depends on creative achievement—for example in form of Aha-experiences—or creative aptitude. Thus, Paper III also explored these two facets of creativity.

Creativity as a trait or a state. In their account on the myth of the lone genius, Montuori and Purser (1995) described the prevailing notion that creativity is an innate ability, a quality of individual talent and traits. From this perspective, creativity is something that you are born with and something you cannot learn. In other words, creativity is a stable and lasting personality trait (Silvia et al., 2008; Torrance, 1972). Conversely, creativity can also be viewed as a situation-

dependent state (Amabile & Mueller, 2008). The componential theory, as proposed by Amabile (1983), suggests that creativity is influenced by three intra-individual components: (1) domain-relevant skills, (2) creativity-relevant processes and (3) intrinsic task motivation, in combination with the social environment that can influence each of the intra-individual components (see Amabile & Pillemer, 2012). *Domain-relevant skills* include both domain-specific expertise and technical skills, acquired through either innate talent or training. *Creativity-relevant processes* include flexible cognitive styles, personality traits (e.g., Openness), skills in using creative-thinking heuristics and persistent work behaviors. *Intrinsic task motivation* is the internal drive to conduct a task, to solve puzzles or problems, or to create something due to the process itself being interesting, involving, personally challenging or satisfying. According to this account, "creativity should be highest when an intrinsically motivated person with high domain expertise and high skill in creative thinking works in an environment high in support [*sic*] for creativity" (Amabile, 2013, p. 135).

Based on fringe consciousness, the two conflicting perspectives of creativity and the ample empirical evidence linking Openness to creativity, we proposed two research questions in Paper III. *First*, we assumed that Openness was associated with recollecting Aha-experiences. Consequently, we should see higher Openness in those who reported an Aha-experience compared to participants who could not remember a specific episode or stated not to have had an Aha-experience. *Second*, from a situation-dependent perspective, the relationship between Aha-frequencies ought to be the outcome of *creative achievements* (i.e., creative reward) through Aha-experiences. The perspective imposes that individuals scoring high on Openness benefit more motivationally from having Aha-experiences than individuals that score low on the trait, and consequently that the former group has Aha-experiences more often than the latter group. However, the effect of incentive reward is likely to decrease with time, meaning that if it has been some time since the last Aha-experience differences in Openness are less likely to predict Aha-frequencies. Conversely, from a creative trait perspective, the relationship between Openness and Aha-frequencies ought to be the result of *creative aptitude* (i.e., creative potential). Consequently, since individuals who score high on Openness are generally more imaginative and creative than individuals who score low on the trait, they ought to have overall more Aha-experiences. The difference between the two perspectives is subtle, but from a creative achievement standpoint, the relationship between Openness and Aha-frequencies ought to be

stronger for newer and weaker for older Aha-experiences. The creative aptitude perspective, on the other hand, necessitates that the relationship is similar in strength regardless of elapsed time since the last memorable Aha-experience.

To test the assumptions described throughout this section, we developed a Bayesian framework with computational models specifically designed to analyze the data we collected. The following section will outline the fundamentals of Bayesian statistics and address methodological concerns with the project.

Methodological Considerations

The papers that constitute this thesis are based on data from multiple independent samples, gathered using an online questionnaire platform (Qualtrics, 2014). We applied generalized linear models (GLM) and generalized linear mixed models (GLMM) within a Bayesian paradigm, and analyses were conducted in *R* (R Core Team, 2019). The present section discusses broader aspects of the Bayesian approach used in the project, not covered in the individual papers. The main emphasis will rest on the fundamentals of Bayesian statistics, which we applied as the main analytical framework. The section will conclude with a separate discussion on the retrospective survey design used in the project.

Bayesian Framework for Computational Modeling

A considerable part of this project has been to write the approximately 4,000 lines of code that constitutes the *bfw* package (Skaar, 2018). Derived from the work by Kruschke (2015), the framework provides several modules to conduct linear and non-linear, hierarchical analyses, and allows the use of custom functions and complex Bayesian models specifically devolved for the project. The overall framework and the models we used in the project were tested and validated against examples provided by Kruschke, and otherwise by replicating studies that applied similar models. The purpose of *bfw* was to integrate all facets described in the following sections.

The rationale for using a Bayesian approach stems from reasons both philosophical and pragmatic. *First* and foremost, the approach facilitates implementation of hierarchical and robust models (Gelman, Hill, & Yajima, 2012). The project addressed broad and multifaceted Aha-experiences; accordingly, the phenomenology associated with the different Aha-experiences may be equally multifarious. The nature of Aha-experience makes it challenging to collect data within specific domains. For instance, though we have data from nearly 2,000 participants, gathered from three independent data collections, less than 20 per cent of data concerns a STEM-related Aha-experience. Bayesian statistics are arguably better than frequentist statistic in addressing such uncertainties by considering the probabilities and variabilities of accumulated data. *Second*, without dwelling on the null hypothesis significance testing (NHST) debate (see Häggström, 2016; Fraley & Marks, 2007; Thompson, 2014), we do not present NHST statistics nor compute *p*-values. Still, we consider the interpretation of probability, results and confidence intervals from Bayesian statistics, to be more intuitive, if not statistically superior to NHST (Hoekstra, Morey,

Rouder, & Wagenmakers, 2014; VanderPlas, 2014; Rouder, Morey, Verhagen, Province, & Wagenmakers, 2016; Nyberg, 2018). However, though Bayesian methodology is increasingly popular (Wulff & Robinson, 2014), a short introduction might be needed to fully appreciate the qualities of this approach to statistics.

Estimation. Bayesian statistics encompasses methods for describing mathematical models. To make sense of these models, we reallocate the credibility of parameter values after observing data in concordance with prior knowledge (Kruschke, Aguinis, & Joo, 2012). Unlike frequentist statistics, we do not estimate single parameter values, but rather a distribution of parameter values given the parameter space. This understanding of probabilities is closely akin to the ones we use in everyday life. For example, if we are interested in finding a misplaced wallet, we have in most cases some prior knowledge of where the wallet might be (e.g., in our house or at the office), and we start by sorting these commonplaces according to their initial probabilities. Often the wallet is not in the most likely of places, so after eliminating prospects we reallocate the probabilities to different locations. Intuitively, we are conducting a Bayesian analysis.

The formal expression of the Bayesian approach, specified as the Bayes' theorem (see Equation 1), derives a *posterior* belief ($p(\theta|D)$) from the *prior* beliefs ($p(\theta)$) by taking into account the *likelihood* of the data given the specified prior ($p(D|\theta)$). In some instances, using few parameters and a prior that is conjugate with the likelihood function, it is possible to solve the integral (see Equation 2) constituting the *evidence* ($p(D)$), thus, analytically derive the posterior. However, in realistic, complex scenarios using multiple parameters it is impossible, difficult or just impractical.

$$p(\theta|D) = \frac{p(D|\theta)\, p(\theta)}{p(D)} \quad (1)$$

where

$$p(D) = \int d\theta\, p(D|\theta)\, p(\theta) \quad (2)$$

Luckily, modern computers have made it possible to circumvent this obstacle (Lee & Wagenmakers, 2014). Markov chain Monte Carlo (MCMC) is a popular class of algorithms for approximating the posterior distribution (van Ravenzwaaij, Cassey, & Brown, 2018). MCMC is a composite of Markov chain and Monte Carlo (Kruschke, 2015, p. 144). A *Markov chain* is a stochastic process in which future states are independent of past states given the present state. In other words, the Markov chain has a memoryless property where the probability of a future value depends only on the present value and not past values. *Monte Carlo* is the algorithms used to approximate the posterior distribution by randomly generating parameter values. MCMC samplers approximate the posterior distribution using various types of sequential processing, called *random walks* in parameter space (Gelman et al., 2013, p. 275). The random walk in MCMC is a two-step procedure repeated a specified number of iterations. *First*, a random parameter value from the target distribution is proposed. *Second*, the proposal is then either accepted or rejected. The criterion for acceptance is either a value considered more likely than the present state or acceptance of any value that lies within the boundaries of probabilistic space, even if the proposed value is less likely than the present state. An accepted proposal constitutes a new present state in the chain, whereas a rejection repeats the current state.

As an example of a random walk, consider three grocery stores (A, B and C) competing for customers. In this example, we collect the day-to-day visits of 100 customers that are representative of all customers in the area. The customers shop daily, and each customer visits an initial store, thus, when we collect data at the end of the first day we have a vector containing 100 data points (e.g., *visited stores* = [x_1 = A, x_2 = C … x_{100} = B]). The vector values will change from day to day according to the probabilities of a transition matrix (see Figure 2).

$$P = \begin{bmatrix} & A & B & C \\ A & 0.7 & 0.2 & 0.1 \\ B & 0.1 & 0.6 & 0.3 \\ C & 0.4 & 0.2 & 0.4 \end{bmatrix}$$

Figure 2. Transition matrix representing the probabilities of customers visiting one of three competing grocery stores.

In this example, each row sums up to one and represents the probabilities of whether a customer remains at the present store or moves on to another. For instance, we can see that if a customer

initially visits store A, the probabilities of using the same store the following day is 70 %, whereas a move to store B or C is 20 % and 10 % respectively. However, irrespective of the initial store, a sufficiently long MCMC chain will eventually reach a steady state where we can find the probabilities of a random customer visiting one of the competing stores. Naturally, this example is quite simple, and we can solve it analytically: The transition matrix will reach a steady state at day 43 and the probabilities of a random customer visiting one of the stores are 42.86 % (store A), 33.33 % (store B) and 23.81 % (store C).

The example above illustrates the Markov chain part of MCMC. However, in realistic scenarios we do not know the probabilities and therefore use Monte Carlo algorithms to randomly sample from the target distribution using a likelihood function. The overall purpose of MCMC is to acquire a progressively more likely realization of the posterior distribution through an equilibrium probability distribution. The total number of links, or steps, in the MCMC constitutes the approximated posterior distribution, from which we can estimate the central tendency (i.e., most probable parameter values). Thus, by using MCMC, we do not need to compute the integral in Equation 2, rather the posterior distribution is seen as proportional to the likelihood of the observed data given the prior as a factor of the a-priori probability (as in Equation 3).

$$p(\theta|D) \propto p(D|\theta)\, p(\theta) \qquad (3)$$

Given enough time and computational power, all MCMC samplers will converge to the same limit, which is the posterior distribution they are set up to approximate. However, some samplers are better adapted to specific scenarios, where they will give a better approximation in a shorter time. In the current project, we used Just another Gibbs sampler ("JAGS", Plummer, 2003) with four chains, which is suited for multivariate probability distributions. The use of multiple chains, with different initial values, is fruitful in order to assess the convergence of the chains, and affirm whether the model is an adequate representative of the respective underlying posterior distribution (Kruschke & Vanpaemel, 2015). Initial values, compared to later iterations, are likely to lie within a lower probability region and are therefore less representative of the posterior distribution. Therefore, initial steps of the chain are removed (known as the warm-up period) to increase the likelihood for a chain to enter an equilibrium probability distribution, and to

improve the convergence rate of the chains (Gelman et al., 2013, p. 282; Hobert & Jones, 2004). We conducted diagnostic testing using both graphical and numerical measures, with the *effective sample size* (ESS) statistics being considered the most valued measure of adequacy of the sampling procedure (Kruschke, 2015; Brooks & Gelman, 1998; Gelman & Rubin, 1992; Kass, Carlin, Gelman, & Neal, 1998; Gelman & Shalizi, 2013). ESS is a heuristic commonly used to evaluate the independence of steps in the MCMC chain (Kruschke & Vanpaemel, 2015). Consider a MCMC with four chains of $k = 2{,}500$, totaling 10,000 steps, if the chain has zero autocorrelation ESS would equal the total number of steps. However, even if the mathematical model is sound, there is bound to be some degree of autocorrelation, reducing the independency of each step in the chain. Thus, lower ESS signifies higher autocorrelation and less independent information in each step of the chain. Kruschke (2015, p. 184) suggests that an ESS of 10,000 is sufficient to assess the accuracy of the 95% *highest density interval* (HDI), whereas a smaller ESS is needed to inspect the central tendency of the posterior. The 95% HDI contains the values with the highest probability density, such that the (posterior) probability that it contains the true parameter values is 95%.

Hierarchical models. Mathematical models, like life in general, often include multiple parameters where the probabilities of some parameters depend on the values of other parameters (Kruschke & Vanpaemel, 2015). For instance, a hierarchical model may include parameters on subject-level (i.e., lower-level parameters) controlled for by *hyperparameters* on overarching group-levels (i.e., higher-level parameters), where the estimate on an individual level is informed by all subjects belonging to a specified group or groups (Gelman & Hill, 2006). Thus, in order for a hierarchical model to be meaningful, the hierarchy has to be meaningful (Kruschke & Vanpaemel, 2015). The main benefit of such models is to counterbalance between-group heterogeneity, where different subsets of groups have different variabilities from others (Tuerlinckx, Rijmen, Verbeke, & Boeck, 2006). The resulting effect, generally called *shrinkage* of estimates, often leads to a closer gathering of values at lower-level parameters due to the influence of higher-level parameter values (Kruschke & Vanpaemel, 2015). Consequently, outliers have less influence on parameter estimates. An additional benefit is that hierarchical models may reduce redundant analyses (Gelman et al., 2012). Thus, as inferences are derived from a single posterior distribution, there is no need to correct for multiple comparisons, a problem often encountered in frequentist statistics (Gelman & Hill, 2006; Kruschke &

Vanpaemel, 2015).

In Paper II, we explored the relationship between gender and social context, to assess whether participants were more likely to be alone or together with someone that contributed to the Aha-experience. Derived from social role theory (Eagly & Wood, 2016) we assumed that both domain and interest would influence the relationship between gender and social context. Furthermore, as data encompassed three independent samples, we were interested in reducing potential between-group heterogeneity. Consequently, the hierarchical model specified that group-level distribution of gender and social context were informed by interest, which in turn were informed by domain, which in turn were informed by the three different samples. Consequently, using a single analysis, we could infer in Paper II that women, compared with men, were more likely to be together with someone relevant for the Aha-experience, but only for Aha-experiences that prompted triggered or maintained interested within a STEM or personal domain.

Model fit. Diagnostics testing may uncover intrinsic flaws in the mathematical model. However, the procedures are only the initial part of assessing the model. Depending on the nature of the project, there are two subsequent steps: addressing relative or absolute model fit. Relative model fit includes methods to compare relative fit between competing models and are used in model selection (e.g., C.-P. Wang & Ghosh, 2011). Absolute model fit encompasses methods for assessing the adequacy of the model using posterior predictive checks to compare observed and predicted data (Gelman & Hill, 2006). The latter approach was used in In Paper II, where we applied a Bayesian structural equation model adapted from Evermann and Tate (2014). To assess the model, we computed a *posterior predictive p-value* (PPP) of fit, based on a fit statistics (f) from a likelihood-ratio (χ^2) test of the posterior results against unrestricted simulated data (Muthén & Asparouhov, 2012). In other words, adequacy was determined on whether the model was able to account for both observed (i.e., actual) data and predicted (i.e., simulated) data. As an extension, the methods used for absolute model fit can be applied to determine power and replication probability (Kruschke, 2010, 2013). We used the latter approach in Paper III to conduct a prospective power analysis.

Inference. Bayesian statistics is for many researchers an attempt to step away from the pitfalls of NHST (e.g., Cohen, 1994). Though Bayesian approaches may be less likely to fall

victim for dichotomization of evidence intrinsic to the NHST paradigm (McShane & Gal, 2017), there are still unresolved controversies associated with Bayesian inference (Gelman, 2008; Gelman et al., 2012). Naturally, it is not within the scope of this thesis to address this overarching debate but is nonetheless appropriate to discuss differences between Bayesian and frequentist school of thought. A Bayesian understands probabilities as degrees of beliefs and it models uncertainty by the probability distribution over hypotheses. Inferences are drawn on observed data that are conditional on the confidence in the selected prior and the likelihood function. The question raised is, given the observed data, what is the probability of the hypothesis being true. Importantly, alternate prior distributions may lead to considerably different findings. The main criticism of Bayesian statistics stems from the use of such *subjective* priors. Conversely, a frequentist understands probabilities as a fixed frequency, meaning the ratio of occurrences of an event over occurrences of all events. Frequentist statistics do not need a prior and does not use probabilities to describe hypotheses. Moreover, the frequentist approach indicates that the likelihood depends on both observed and unobserved data, and inferences are drawn from a finite sample that contains random products of the fixed frequency. The question raised is, given a (null) hypothesis, what is the probability of observing the sampled data. Consequently, a frequentist uses *p*-values to determine an acceptable error-rate by finding a balance between two reciprocal errors due to randomness. Type I errors signify that there is an acceptable percentage of times, usually 1-5%, where the observed data *does not support* a (null) hypothesis that is false. Type II errors, on the other hand, signify how often the observed data *support* a (null) hypothesis that is false. In the current project, due to the exploratory nature of our study, we applied priors that were broad and noncommittal. In other words, priors had minimal influence on the results (Berger, 2006). Accordingly, considering the sample size, posterior distributions would approximate maximum likelihood functions (Beerli, 2006; Kruschke et al., 2012). In other words, a researcher using the best of frequentist techniques would most likely arrive at the same conclusions as we did. So, our choice of a Bayesian framework may be seen as a philosophical one, though we would emphasize that the utility of having a single overarching model the way hierarchical Bayes offered, has been a great aid to both thinking and analyzing.

Furthermore, it is necessary to differentiate between the two major schools of Bayesian inference: *Bayes factor* (Morey, Romeijn, & Rouder, 2016; Wetzels & Wagenmakers, 2012) and

parameter estimation (Gelman et al., 2013; Kruschke, 2015). Considered a Bayesian continuation of testing null hypotheses, the purpose of Bayes factor is to compare a model that expresses the null hypothesis against a model expressing alternative parameter values (Kruschke, 2013). However, the current project opted to use the approach of parameter estimation, where inferences derive from examining the posterior distribution. Thus, by assessing the HDI of parameter values from the posterior distribution, we measured the uncertainty associated with each parameter. Furthermore, by applying a *region of practical equivalence* (ROPE), we assessed whether the probable values of the parameter were equivalent to zero (Kruschke & Liddell, 2017). Similar to equivalence testing in frequentist statistics (e.g., Lakens, 2017), the purpose of ROPE is to act as an decision rule to determine if an observed effect is different from a landmark value, usually null (Kruschke & Vanpaemel, 2015). By defining lower and upper boundaries for the landmark value, it is possible to infer whether the parameter value is equivalent or credibly different from the landmark value.

To appreciate the logic behind inference from parameter estimation, please consider the following example of the parameter values of a regression coefficient. Figure 3 represents a density plot of the posterior distribution of the parameter values accumulated from four MCMC chains (k = 250,000, where k is the number of total steps). The dark grey area is the 95 % HDI, and we see that the probability density outside the HDI (as marked in light grey) is lower than the densities inside the HDI. The solid white line is the mean and the solid black line is the mode of the parameter value. In this example, the posterior is approximately normally distributed, hence the close gathering of lines, that also masks a white dashed line indicating the median. The dotted dark grey line identifies zero, whereas two black dashed lines signifies ROPE defined as ±0.05. Here, ROPE is chosen arbitrarily, however ROPE should be defined according to some clinical or community standard. From the figure, we can observe that 27.86% of the simulated parameter values lie within the boundaries of the ROPE around zero, indicating no effect. Furthermore, we can see that zero falls within the boundaries of the HDI, and it is therefore inappropriate to claim that the posterior distribution indicates a credible null, positive or negative effect. The Bayesian term *credible* is similar but not identical to the more familiar frequentist term *significant*; as a rule of thumb, readers may equate credibility with significance. However, as seen from the horizontal dashed line at the bottom, 70.43% of the simulated parameter values were lower than, or equal to, the lower boundaries of the ROPE, meaning that it is more likely that the

effect is negative. Presented as the mode of parameter values and the upper and lower bounds of the HDI, the results look like this: β = -0.08, 95% HDI [-0.21, 0.03].

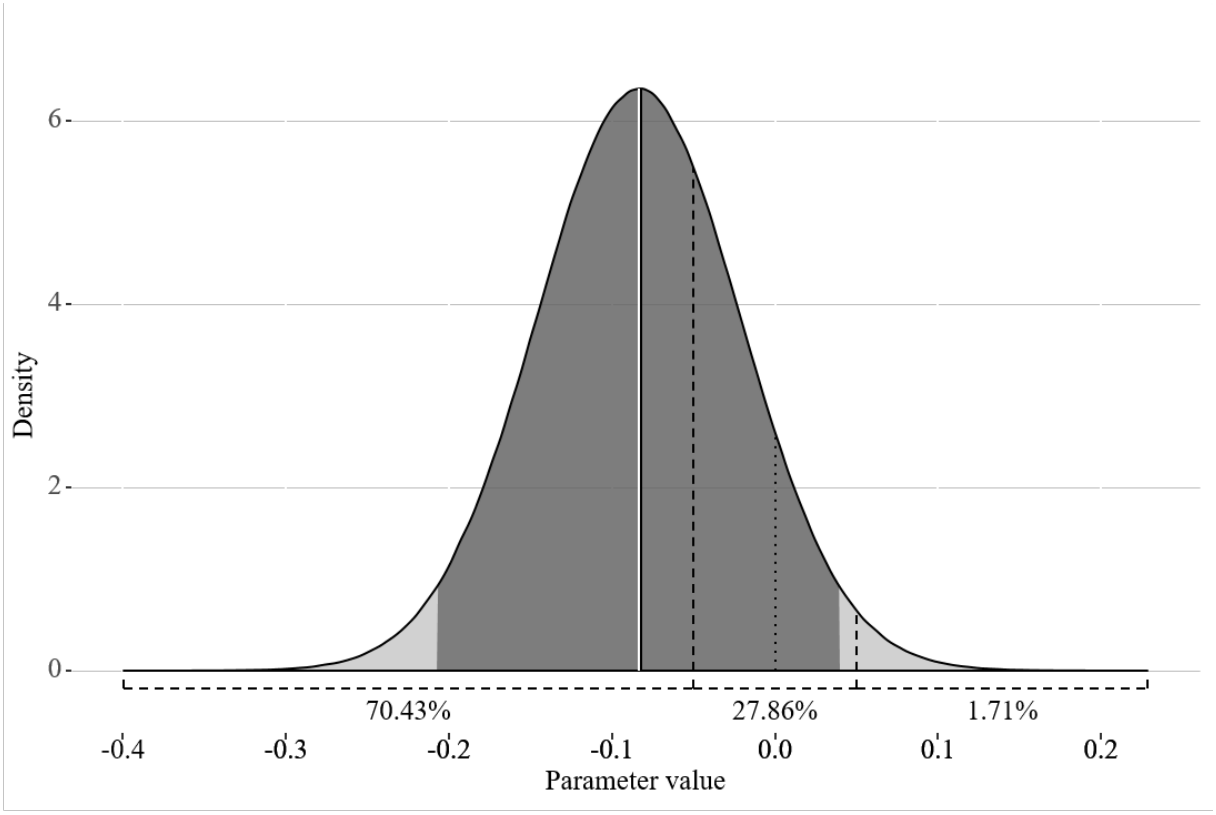


Figure 3. Example of the posterior distribution of a regression coefficient.

The Retrospective Design

Dietrich and Kanso claimed, "insight is so capricious, such a slippery thing to catch *in flagrante*, that it appears almost deliberately designed to defy empirical inquiry" (Dietrich & Kanso, 2010, p. 822). In other words, the nature of Aha-experiences makes it rather difficult to observe in experimental settings. Several paradigms exist to elicit insight, like compound remote associate problems (Bowden & Jung-Beeman, 2003), magic tricks (Danek, Fraps, von Müller, Grothe, & Öllinger, 2014b; Hedne et al., 2016) and different kinds of puzzles (e.g., Friedlander & Fine, 2018; MacGregor & Cunningham, 2008; Weisberg, 1995). However, it is uncertain whether induced insights share a similar phenomenology to those found in an naturalistic setting (Klein & Jarosz, 2011). Furthermore, induced insights are inherently bound to problem-solving domains, which make them unfeasible to compare insight within different domains. For instance,

is solving a mathematical equation through insight comparable to suddenly finding God? To approach such questions, we need a diverse and large dataset of Aha-experiences. Thus, the present project aims to complement and enhance existing evidence found in experimental studies by gathering and synthesizing Aha-experiences as reported by the participants of the study.

The major strength, and weakness, of this project was the use of a single, large-scale survey. The survey targeted two different populations by applying two similar, yet distinctive questionnaires. The first questionnaire, aimed at a broad, general population, asked participants to report an Aha-experience without setting any limits on the topic. The second questionnaire, directed towards high-school students, asked for school-related Aha-experiences. Besides some minor differences, the two questionnaires were identical in their structure. Separated into five interconnected parts, the survey first asked the participants to write down a self-experienced Aha-moment. The second part contained multiple-response items asking for contextual information about the reported Aha-experience (e.g., where, when and with whom it occurred). The third part contained several items measuring seven dimensions of the phenomenology of the Aha-experience from before, during and after the Aha-experience. The fourth part encompassed items measuring the frequency of Aha-experiences (Aha-frequencies). The final part asked the participant to rate two inventories measuring Big Five personality traits and self-efficacy.

A defining aspect of the survey was included at the beginning of the questionnaire, where we asked participants whether they have had an Aha-experience and, subsequently, if they could describe a specific Aha-experience. The answers in this initial section defined the flow of the survey and separated the participants in three distinct groups. Foremost of interest, the first group encompassed participants that wrote down an Aha-experience. This group constituted more than half (51.3%) of the total sample and completed all parts of the questionnaire. The second group (16.2%) reported that they had once had an Aha-experience but could not remember a specific episode. This group completed the part containing Aha-frequencies and the final part containing personality traits and self-efficacy. The last group (32.4%) stated not to have had an Aha-experience and completed only this final part of the survey.

Limitations. There are some notable overall limitations with our retrospective approach. *First,* deploying a single survey on multiple populations within a short timeframe, compared to conducting sequential studies, prevents further development of the questionnaire during the project. Though we reviewed and replaced some phenomenology items after the initial study

with the University sample, the questionnaires used for the MTurk and School sample inherently have the same limitations. The Aha-experience is a metacognitive response to a cognitive event, dependent on both the individual and the specific situation (Liljedahl, 2004, p. 202). In hindsight, the questionnaire ought to have had items measuring the strength, or potency, of reported Aha-experiences (cf., Danek & Wiley, 2017; Loesche, Goslin, & Bugmann, 2018). Consequently, the study lacks the ability to differentiate between trivial, major, and life-changing insights. However, the nature of the project entails little control of the reported Aha-experiences, meaning that adding additional parameters would significantly increase the sample, time and resources needed to collect an adequate amount of data points. *Second*, emotions are a defining aspect of the project, and research has shown that reporting emotional episodes over short time frames is qualitatively different from long term retrieval (Mauss & Robinson, 2009; Robinson & Clore, 2002a, 2002b). Thus, the retrospective design, using post-hoc self-reports, may bias results due to lay-theories about the mind. Respondents may report their Aha-experiences based on semantic knowledge rather than episodic memories. *Third,* there are other response biases, including social desirability, that may exaggerate or obscure results (Brenner & DeLamater, 2016; Fan et al., 2006; Furnham & Henderson, 1982; Ludeke, 2014). Specific limitations associated with each individual study are addressed in the General Discussion section.

Strengths. The main benefit of the design is the ability amass large amounts of data in a short amount of time and, more importantly, easily and directly compare results in the three different papers. The structure of the questionnaire, divided in three succinct parts, facilitated three separate papers on the phenomenology of Aha-experiences (Paper I), social and educational psychology (Paper II) and individual differences concerning the frequency of Aha-experiences (Paper III). The process of developing a large, coherent questionnaire has allowed the synthesizing of adjoining facets from adjoining aspects of psychology, adding a deeper understanding of a diverse collection of Aha-experiences. Consequently, the survey approach complements experimental studies, that otherwise have limited scope and are more difficult or costly to implement.

Ethical considerations. The questionnaire encompassed both closed and open-ended questions, and a defining aspect of the project was the written descriptions of Aha-experiences. We considered the data as sensitive, since the combined information gathered from the written

description and demographical data could potentially identify the participants or others mentioned in the Aha-experience. Consequently, we separated the written descriptions from the remaining by data using two datasets with shared numerical identifiers. Moreover, we checked the written descriptions for any information that could identify the participant or others described as part of the Aha-experience.

We acquired informed consent at the beginning of the questionnaire by briefly explaining the background and purpose of the project. We informed participants that participation was voluntary and that we would anonymize the data. Furthermore, we informed participants that they had a right to access, edit and delete any provided data at any time. Finally, we provided a more detailed description of the project at the end of the questionnaire. The project obtained ethical approval from the Norwegian Social Science Data Services (#35006) and the Internal Research Ethics Committee at the Department of Psychology, University of Oslo (#914575).

Summary of Papers

Paper I: The Phenomenology of Aha-experiences

Background. Derived from an integrative fluency account, we aimed to assess the relationship of the fundamental components of the Aha-experience: sudden insight, fluency, positive affect and subjective certainty. Previous experimental studies have examined and shown connections between the individual variables of the Aha-experience, but the present study is the first to test a coherent theoretical explanation. In addition, sudden insight involves a representational change that may affect an individual's immediate sense of agency. Thus, by controlling for sense of agency as a potential confounding variable, we may further elucidate the relationship of sudden insight with fluency, certainty and affect. Lastly, though qualitative studies have reported that Aha-experiences may change a person's attitude toward the domain in which an insight occurred, there existed to date no quantitative study that assessed this potential relationship.

Methods. In two independent samples ($N = 636$): MTurk ($n = 341$) and School ($n = 295$), we applied structural equation models to test the integrative fluency account. Furthermore, we used the model to evaluate the potential relationship between the Aha-experience, sense of agency and change in motivation and coping from before to after the Aha-experience (datasets and R scripts to replicate the study are available at phd.skaar.no/aha1).

Methods. Results. Initial analyses indicated that fluency, positive affect and subjective certainty are underlying facets of a broader dimension, dubbed metacognitive feelings. Sequentially, SEM exhibited that metacognitive feelings together with sense of agency, elicited by sudden insight, mediate change in motivation and coping.

Conclusion. The study strengthens the hypothesis that fluency is marked hedonically and epistemically, and in general conforms to the fluency account. Importantly, the study supports prior qualitative studies, linking Aha-experiences to positive change in motivation and coping within a given domain.

Paper II: Unravelling the Aha-experience

Background. Despite considerable investments, the underrepresentation of women in STEM fields is still evident. Prior research indicates that women generally show less interest in STEM compared to boys, which, naturally, may help explain the observed disparity. Consequently, it is prudent to uncover reasons for the gender differences in interest. Grounded in social role theory, we hypothesized that men would be more often alone prior to an Aha-experience and women more often together with someone relevant for the experience. Thus, as traditional STEM-education is marked as highly competitive and individual-oriented, female students do not optimally benefit from STEM instruction in terms of affective consequences.

Methods. The study encompassed three independent samples (N = 899): *University* (n = 257), *MTurk* (n = 341) and *School* (n = 301). We were interested in the relationship between gender and social context, meaning, whether the participant was alone or together with someone contributing to the Aha-experience. To explore this potential relationship, we analyzed Aha-experiences from three separate domains (personal, STEM, and other topics) that either increased or did not increase interest within the respective domain. We applied a hierarchical model comparable to a four-way contingency table to compute the odds-ratio and effect-sizes of social context by gender (datasets and R scripts to replicate the study are available at phd.skaar.net/aha2).

Results. Overall, results indicated that men, compared with women, were more likely to be alone during the Aha-experience. The effect was most credible for participants who reported increased interest in personal and STEM domains, whereas there were no differences for other topics.

Conclusion. Consistent with previous findings, the study suggests that women find more interest from cooperation than men and therefore have more Aha-experiences together with others that contributed to the Aha-experiences. We argue that the reported gender differences in social context are in line with the distinction between agentic orientation in men and communal orientation in women as derived from social role theory. These observations may help explain why girls are less interested in STEM than boys are and may have implications for school instruction.

Paper III: Openness to Aha-experiences

Background. The Aha-experience is a phenomenon associated with creativity and by some considered a subfield of creativity itself. Among individual differences, Openness to Experience appears to be the strongest predictor of creativity and creative self-efficacy. Thus, one might assume that Openness to Experience also shares a relationship with Aha-experiences, and the frequency of Aha-experiences. To date there are no studies that examine whether the relationship between Openness to Experience and creativity depends on creative achievement—for example in form of Aha-experiences—or creative aptitude. From an achievement perspective, creativity is a situation-dependent state. Consequently, the strength of the relationship between creativity and Openness ought to depend on maintained creative activity. On the other hand, from an aptitude perspective, the strength of the relationship needs to be stable over time.

Methods. Based on two independent samples (N = 1,314): *MTurk* (n = 744) and *School* (n = 570) sample, we first applied Bayesian equivalents of ANOVA to examine the relationship between Openness to Experience and participants who (1) reported an Aha-experience, (2) could not remember a specific Aha-experience or (3) claimed that they never had one. Second, we applied correlation and hierarchical multiple regression models to examine the relationship between Openness to Experience and the frequency of Aha-experiences for newer and older Aha-experiences (datasets and R scripts to replicate the study are available at phd.skaar.net/aha3).

Results. Analyses linked Openness to Experience to recollecting autobiographical memories. In other words, participants scoring high on Openness to Experience were more likely to report an Aha-experience. Furthermore, the additional analyses indicated that Openness to Experience shared a positive relationship with frequency of Aha-experiences. However, the relationship depended on elapsed time since the Aha-experience, and the relationship was only credible for newer Aha-experiences.

Conclusion. The study indicates that Openness relates to increased sensitivity to metacognitive processing at the fringe of consciousness. Furthermore, the results support the creative achievement assumptions as the data excludes the possibility of a stable relationship between Openness and Aha-frequencies, which is necessary for the creative aptitude assumption to be true.

Extended Results

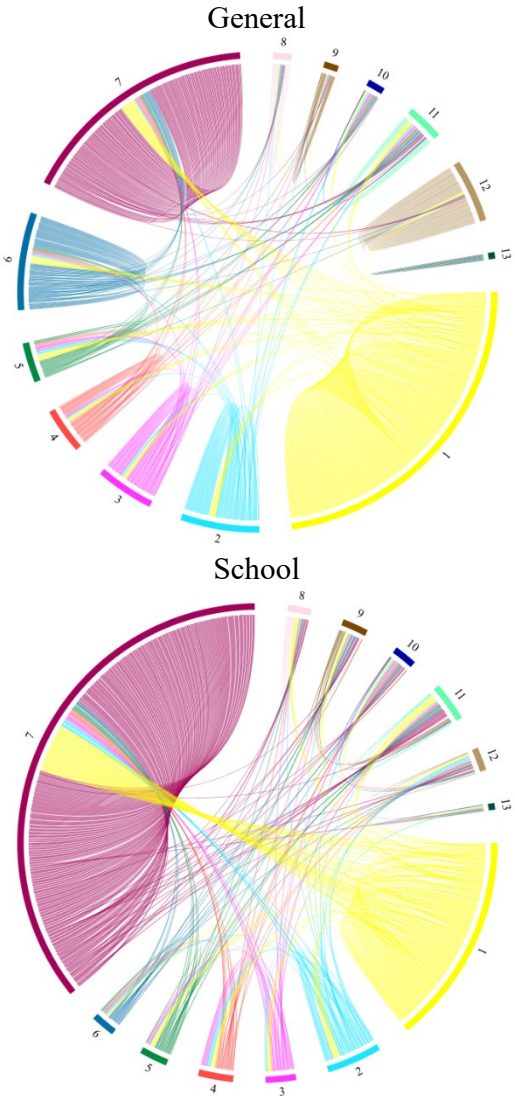
The main benefit of the current research design was the acquired collection of a rich and diverse tapestry of Aha-experiences. If anything, the present project has demonstrated that the Aha-experience occurs within many domains in numerous ways. Furthermore, drawn together, the three studies that constitute the current thesis allow both individual and combined inferences that provide a foundation for new hypotheses. The following section therefore delves into the existing results from the studies and aims to enrich these results through further examination of the existing data. In addition, Rozin (2006; 2007) argued that psychologists have little sense or respect for descriptive approaches to the domains of life. Thus, the section begins with a descriptive overview of the Aha-experiences, adding more context to the overall results. Datasets and R scripts to replicate results found in the thesis are available at phd.skaar.net/thesis.

Situational Settings

To better understand the Aha-experience as novel and personally meaningful experiences (Beghetto & Kaufman, 2007), the descriptive section makes a distinction between the General and the School questionnaire. The circular plots in this section represent the interrelated answers from multiple-response items. In order to better interpret the answers, we also recoded each category of multiple-responses into mutual exclusive groups based on the written feedback and a predetermined hierarchical structure. In other words, in cases with multiple options, group allocation was determined according to predetermined ranks outweighing each other. The figures are available in high resolution and as vector graphic at phd.skaar.net/thesis/settings/

Locations. The two main locations of Aha-experiences were at home or at school. Though the results were more pronounced for the School sample, the General samples also exhibited the same pattern. However, as seen from Figure 4, the School sample included more multiple responses. For instance, as participants from the School sample often reported doing homework, they frequently reported being both at home and at school. The recoding structure encompassed three distinct groups: (1) *work*, which included study or work, (2) *home*, one's own or that of another and (3) *somewhere else*, all other locations. Consequently, after recoding the answers, the differences between the two populations became more distinct. Whereas 78% from the Schools study reported being at work, 23% from the General samples reported the same.

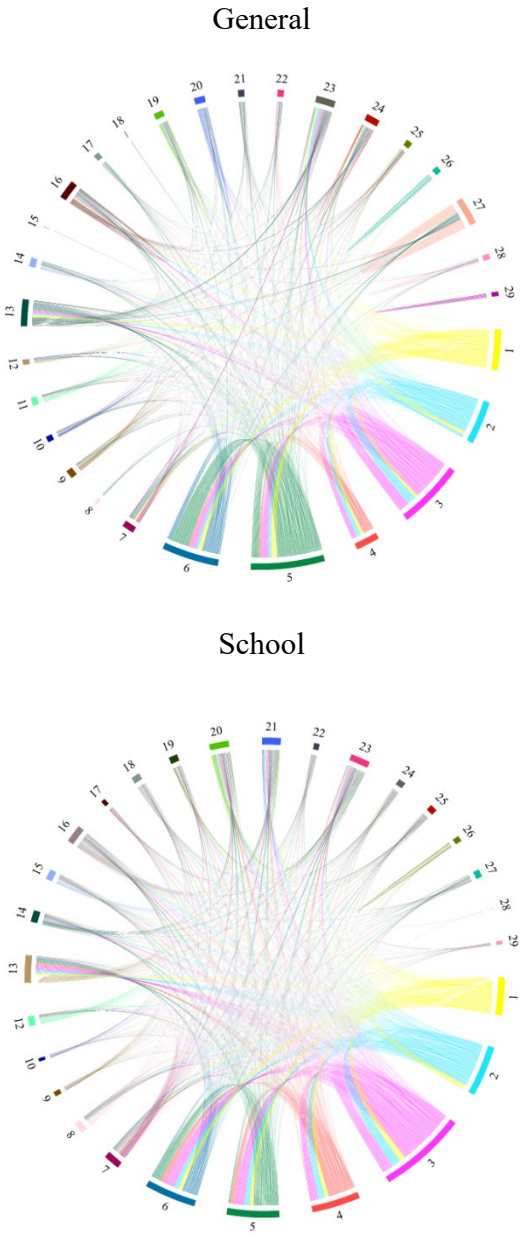
Conversely, 20% from the School sample reported being at home, in contrasts to 54% from the General study. Lastly, only 2% of the School sample reported being somewhere that was not a private residence or school, compared to 24% from the General samples.



#	Locations	General (1013)	School (758)
1	Own home	34.35	23.63
2	Home of another	6.97	4.48
3	Nature	4.59	1.74
4	Transportation	3.74	2.24
5	Abroad	3.06	1.49
6	Work	9.52	1.24
7	School	24.83	57.71
8	Religious assembly hall	1.36	1.00
9	Restaurant	1.19	1.24
10	Nightclub	0.51	1.00
11	Fitness center	2.21	2.49
12	Somewhere else	6.97	1.24
13	Dont know	0.68	0.50

Figure 4. Locations of Aha-experiences for general and school samples. Percent with *n* in parentheses, where *n* indicates the total number of entries.

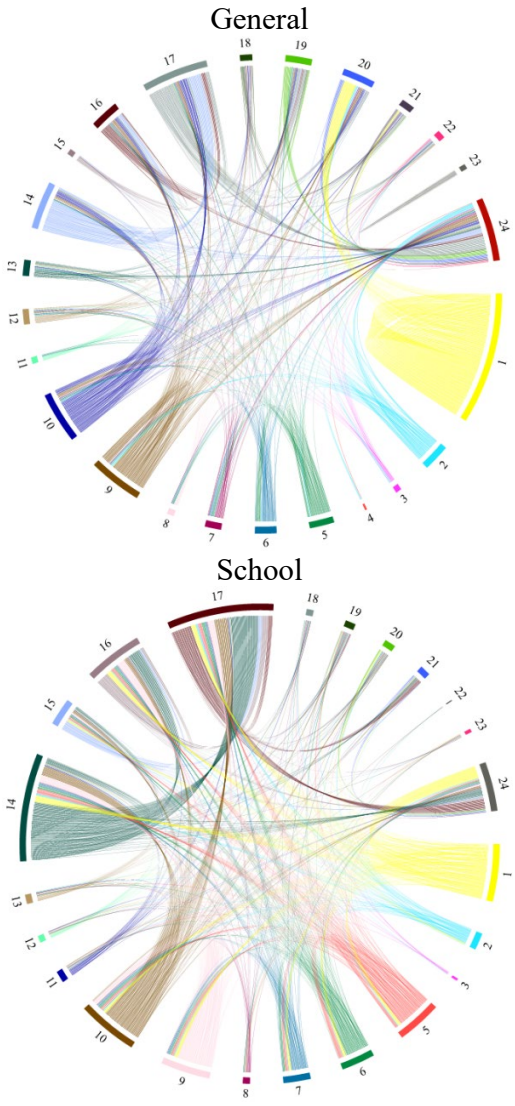
Activities. Figure 5 depicts a wide array of conducted activities prior to the Aha-experience. The category was recoded into three groups: (1) *Interaction,* either listening or talking to someone, (2) *work,* which entailed both work and studying and (3) *leisure* activities. The latter encompassed, especially, browsing the internet, listening to music and watching TV. The interaction groups were roughly the same size between the General (42%) and School (45%) studies, and the main difference was between work (General = 26%, School = 47%) and leisure (General = 32%, School = 8%). The results showed that while interaction may play an important role, it is not crucial for a majority of Aha-experiences.



#	Activities	General (1084)	School (797)
1	Worked	7.38	7.65
2	Read	7.66	9.03
3	Studied	13.75	25.72
4	Wrote	3.69	8.28
5	Discussed or talked	16.51	11.42
6	Listened to someone	12.73	11.67
7	Planned something	2.86	1.38
8	Gave a presentation	0.46	1.00
9	Did housework	1.38	0.25
10	Prayed	1.20	0.38
11	Meditated	1.38	0.00
12	Sang	0.92	0.75
13	Listened to music	4.52	4.64
14	Played an instrument	0.83	1.13
15	Watched sports	0.09	0.75
16	Worked out	2.49	1.88
17	Drank alcohol	0.65	0.88
18	Shopped	0.18	0.50
19	Slept	1.48	0.75
20	Watched TV	2.12	2.13
21	Watched a movie	0.74	1.88
22	Watched a show	0.65	0.25
23	Browsed the Internet	3.32	1.88
24	Traveled	1.57	0.63
25	Vacationed	0.83	0.75
26	Text: Work or study	1.57	2.13
27	Text: Leisure	6.83	1.38
28	Text: Interaction	1.20	0.25
29	Dont know	1.01	0.63

Figure 5. Activities of Aha-experiences for general and school samples. Percent with *n* in parentheses, where *n* indicates the total number of entries. Text indicates categories based on free text.

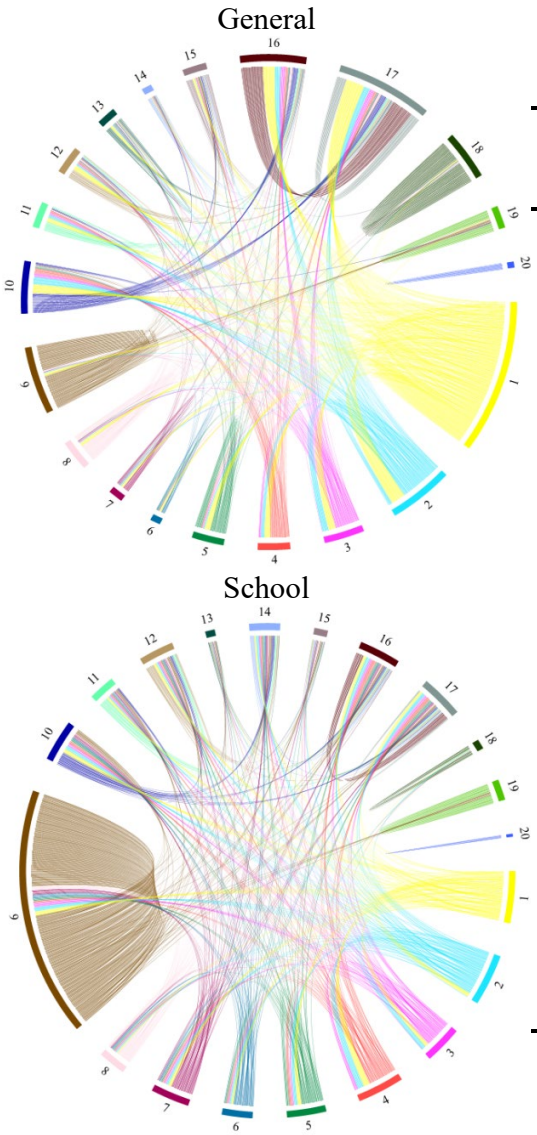
Social contexts. The differences between the two studies were apparent in Figure 6. The role of social context was more pronounced in the School sample, and the importance of teachers was highlighted in more than a quarter of the cases. Similarly, participants considered fellow students important for the Aha-experience. Though these characteristics were also present in the General samples, participants in these samples were more frequently alone. The social context category was first recoded into three groups: (1) Together with others that contributed to the Aha-experience (General = 44%, School = 70%), (2) Together with others that did not contribute to the Aha-experience (General = 19%, School = 29%) and (3) alone (General = 37%, School = 1%). The final group was dichotomized into alone (General = 56%, School = 30%) versus together (General = 44%, School = 70%).



#	Social Context	General (1013)	School (758)
1	Alone	22.51	9.63
2	Spouse/Partner	4.05	1.58
3	An offspring	0.99	0.26
4	Several offspring	0.39	0.00
5	Father	2.67	4.49
6	Mother	2.47	2.64
7	Brother or sister	1.97	2.51
8	Several siblings	0.59	0.40
9	A friend	6.91	5.54
10	Several friends	6.52	7.39
11	Boss	0.59	0.53
12	A coworker	2.07	0.26
13	Several coworkers	2.37	0.40
14	A teacher	6.12	18.87
15	Several teachers	0.69	2.24
16	A fellow student	2.86	8.05
17	Several fellow students	9.77	18.47
18	An unknown person	0.99	0.26
19	Several unknown persons	3.46	0.79
20	Text: Family and friends	7.31	1.45
21	Text: Professional capacity	1.68	2.24
22	Text: Other	1.28	0.26
23	Dont know	0.79	0.26
24	Others not important	10.96	11.48

Figure 6. Social contexts of Aha-experiences for general and school samples. Percent with *n* in parentheses, where *n* indicates the total number of entries. Text indicates categories based on free text.

Domains. Interestingly, the two main domains of Aha-experiences were introspection and mathematics. However, the ratio of the two domains was nearly reversed between the General and School samples (see Figure 6), with introspection as the largest domain for the General samples and, conversely, mathematics for the School sample. We recoded the category into three distinct groups: (1) STEM (General = 21%, School = 75%), (2) personal (General = 59%, School = 17%) and (3) other topics (General = 29%, School = 8%).



#	Domains	General (1004)	School (473)
1	Introspection	20.92	5.50
2	Love	6.77	4.23
3	Friendship	2.89	2.96
4	Morality	2.39	4.23
5	Health	3.98	4.65
6	Sports	1.29	2.54
7	Music	1.79	2.96
8	Language	3.69	2.96
9	Mathematics	10.56	44.82
10	Conflict	4.88	3.17
11	Religion	1.99	1.48
12	Philosophy	2.69	3.17
13	Art	2.19	0.63
14	Politics	1.10	1.69
15	Economy	2.99	0.85
16	Social relations	6.57	3.38
17	Text: Personal	11.45	3.59
18	Text: Other Topics	7.27	1.90
19	Text: STEM	3.69	4.65
20	Dont know	0.90	0.63

Figure 7. Domains of Aha-experiences for general and school samples. Percent with *n* in parentheses, where *n* indicates the total number of entries. Text indicates categories based on free text.

An example of a STEM-related Aha-experience was:

> When I was in one of my math classes we were trying to understand why calculus was useful. It never occurred to me why or how we got the formulas we used. The teacher drew a circle on the board and asked us how to find the area. Then she said okay what if I rotated the circle, how do you find the volume. We were already familiar with integration for area under the curve type of stuff, but never really thought about volume. She pretended like she was rotating the circle on the board, and it totally clicked for me. You can use those same formulas to find the volume of objects by find the correct parameters to integrate over. I was pretty excited to actually have that understanding, made me really love taking calculus. I finally understood why we needed all that background in math. To me it felt like everything Id learned for the past 10 years in math sort of culminated to that point.

The *personal* experience involves a change of perspective about oneself (e.g., purpose in life, personal health or growth, future goals or accepting past experiences), and may include *interpersonal* elements (e.g., relationships with family and friends, or romantic/sexual relationships in general). An example was:

> I had an Aha experience when I realized what I wanted to do for a career after school. It came all of a sudden, and I saw that I wanted to be a history professor in college. I will have to go for my doctorate to achieve this goal, but I am looking forward to it.

Finally, many Aha-experiences do not truly belong to any of the two categories. Consequently, we added a third category, *other subjects*, which are often like STEM, and generally include solutions of a problem (e.g., riddles, games) or acquiring a skill (e.g., languages, physical/sports techniques) that was not within the STEM fields. An example was:

> Something in a video game, I was playing a video game where there was a difficult puzzle to solve. After taking some time off, I realized what I had to do to get past the puzzle. It was enlightening, and I felt extremely happy.

Time of the year. We also asked the participants and what time of day and what time of year they had the reported Aha-experience. Results presented in Table 1 indicated a more evenly

distribution of Aha-experiences throughout the day in the General samples, whereas participants from the School sample predominantly had their Aha-experiences in the morning and decreasingly throughout the day. Attempts to interpret the results are speculative, however, the results may indicate that though Aha-experiences can occur at any point of the day, School-related Aha-experiences are more likely in the morning when students are attending school and are more focused on school subjects. Furthermore, as seen from Table 2, the reported Aha-experiences from the General samples were more evenly spread through the year. Interestingly, a majority of participants (63.78 %) from the School sample reported having their Aha-experiences in either autumn or winter. Though it is not surprising that students have less school-related Aha-experiences during summer, it is remarkable that only 11.3 percent of students reported Aha-experiences during spring. If it is not a statistical quirk, one possible explanation may be that students are more refreshed and focused after the summer holiday and, conversely, longing for the summer holiday during spring. Another possible explanation may be that students are more inclined to study during seasons with poor weather, whereas spring offer more opportunities outdoors. A third explanation may be that students more frequently encounter novel topics in the beginning of the academic year, while spring to greater extent encompasses repetition and final exams.

Table 1

Time of Day

	General		School	
Item	*n*	*%*	*Item*	*n*
Morning	159	26.81	186	61.79
Afternoon	196	33.05	51	16.94
Evening	122	20.57	39	12.96
Night	79	13.32	7	2.33
Don’t know	37	6.24	18	5.98

Table 2

Time of Year

	General		School	
Item	*n*	*%*	*n*	%
Winter	109	18.4	95	31.56
Spring	191	32.2	34	11.3
Summer	89	15	18	5.98
Autumn	126	21.2	97	32.23
Dont know	78	13.2	57	18.94

Drawn together, the situational settings of the Aha-experience demonstrate the multifarious nature of insight. Importantly, the results indicate that the Aha-experiences occur in many different domains, and that the given context of the questionnaire (i.e., broad/General or narrow/School) shapes the responses given. Derived from the three papers we can now look further and delve deeper into the existing data.

Negative Aha-experiences

Figure 8 depicts ratings of the four dimensions of all Aha-experiences that encompassed Paper I. Evidently, though the School sample consistently scored lower on all measures; the overall results provided equivalent results for both the General and School samples.

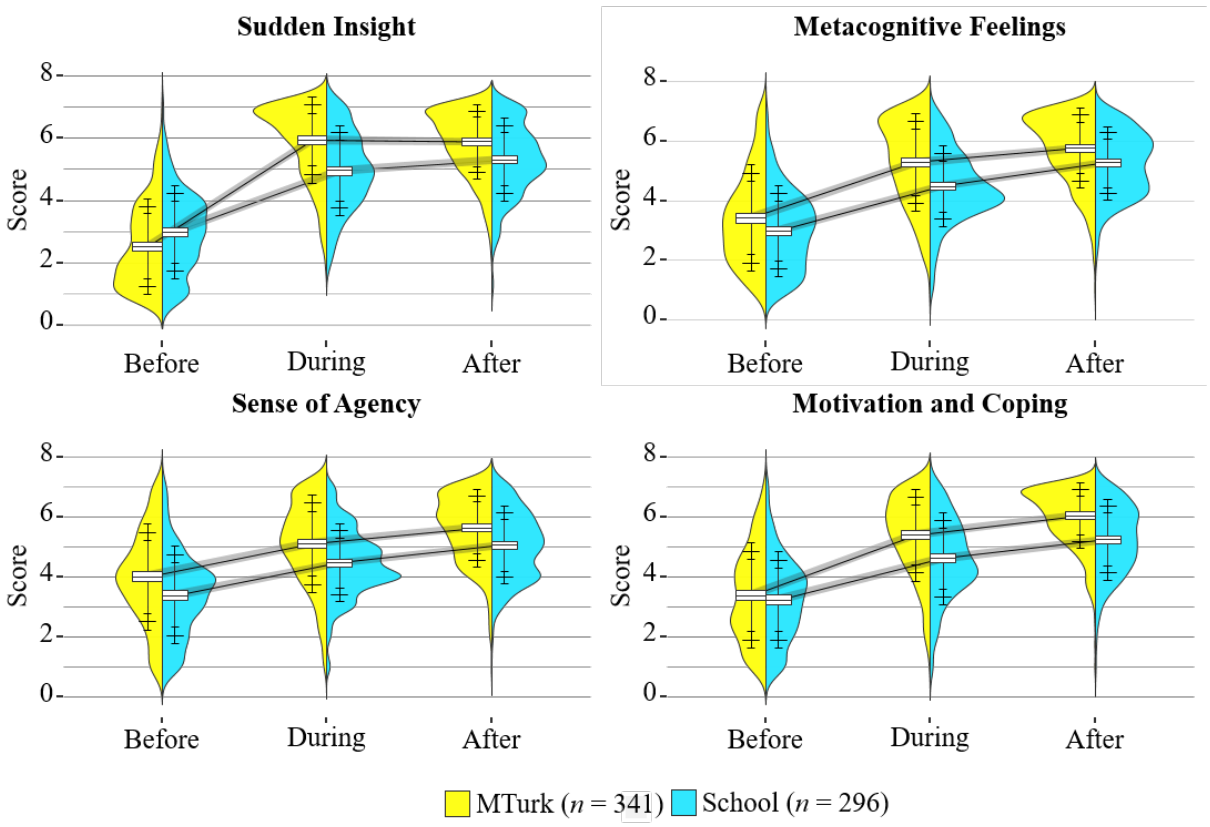


Figure 8. Ratings of phenomenology dimensions of Aha-experiences.

However, though participants generally reported positive changes, of the 636 participants, 55 reported a negative change in positive affect from before to during the Aha-experience. Consequently, some 9 % of participants reported a negative Aha-experience (see phd.skaar.net/thesis/results1/). An example of such experience is:

> My Aha-experience was the first moment in my adult life that I realized that my life will end one day. I just woke the day after I had hung out with my friend who is in remission from Stage 4 lymphoma and realized that my consciousness will end eventually.

For positive Aha-experiences, all four dimensions shared a credible and positive relationship. Conversely, for negative Aha-experiences, sudden insight shared a negative correlation with metacognitive feelings (r = -.51, 95% HDI [-.70, -.26]) and sense of agency (r = -.34, 95% HDI [-.59, -.06]). Though the relationship between metacognitive feelings and sense of agency remained positive (r = .41, 95% HDI [.10, .64]), motivation and coping shared no credible

relationship with the other three dimensions. Thus, the preliminary results indicate that the negative Aha-experience share a similar, yet contrasting phenomenology as positive Aha-experiences but does not relate to changes in motivation and coping.

Social Context and Aha-frequencies

Liljedahl's (2004) study suggests that Aha-experiences are often facilitated by ongoing and frequent peer interaction. Based on results in Paper II and Paper III, it is conceivable that social context predicts Aha-frequencies, and consequently that men, being more often alone prior to Aha-experiences, ought to have less Aha-experiences compared to women. To test this assumption, we can use first use a hierarchical model similar to the one used in Paper II and examine whether men are less likely to report a specific Aha-experience. In the model, group-level distribution of gender is informed by three Aha-Types, which in turn are informed by the three different samples. The three Aha-Types are (1) participants that reported a specific Aha-experience (Reported), (2) participants that did not remember a specific Aha-experience (Non-reported) and (3) participants that stated not to have had an Aha-experience (No-Aha). Results from this analysis show inconsequential differences between the three groups (see phd.skaar.net/thesis/results2/). Furthermore, we can directly analyse the relationship between Aha-frequencies and social context using a model similar to Kruschke (2013). Results from this analysis indicate neglible differences between participiants being alone or together (see phd.skaar.net/thesis/results3/).

Naturally, these results assume that participants reporting being alone or together generally have Aha-experiences in such a fashion and thus limiting the scopes of interpretation. However, on face, there are no indications that social context or gender predicts recollecting Aha-experiences or Aha-frequencies. Rather, the role of social context seems dependent on the overall context of the Aha-experience. Participants from the School sample were more likely in a situational setting involving teachers or other students that contributed to the Aha-experience, whereas participants from the University and MTurk sample were more often physically alone prior to the Aha-experience. These results conform with Tidikis and Ash (2013), where the authors found that groups, compared to individual approaches, did not lead to solving more problems or reduce solving time of insight tasks. However, by adapting the hierarchical model, replacing Aha-Types with activities, we found that women, in contrast to men, generally do

engage in interaction during work or leisure-type activities rather than performing these activities in isolation (see phd.skaar.net/thesis/results4/).

Openness and Sudden Insight

Paper III identified Openness as a predictor of Aha-experiences and Aha-frequencies. The results pose the question whether Openness relates to the phenomenology of Aha-experiences. Few studies have examined the relationship between personality traits and the Aha-experience. However, one study exhibited that Openness was the best predictor of sudden insight (Ovington, 2016). Similarly, descriptive analyses indicated that of the four phenomenology dimensions used in Paper I, only change in sudden insight from before to during the Aha-experience shared a credible relationship with any of the Big-Five personality traits. Furthermore, a multiple regression analysis showed that only Openness and Agreeableness were credible predictors of (positive) change in sudden insight (see phd.skaar.net/thesis/results5/). The positive relationship between Agreeableness and sudden insight is surprising given that creativity research suggest that creative individuals score low on Agreeableness (King, Walker, & Broyles, 1996), and that Agreeableness generally is a poor (i.e., non-significant) predictor of creativity (Bridges & Schendan, 2018; Silvia, Kaufman, Reiter-Palmon, & Wigert, 2011; Zare & Flinchbaugh, 2019). However, some studies have identified Agreeableness as a positive predictor of creative performance when individuals score high on intrinsic motivation and low on extrinsic motivation (Liang & Chang, 2014; Sung & Choi, 2009). Consequently, it is probable that the Aha-experience is associated with intrinsic motivation (cf., Amabile, 2013).

General Discussion

The present project aimed to investigate the phenomenology of Aha-experiences through self-reports from more than 1,800 participants. The following sections will discuss the main findings of the three papers by considering recent literature on insight and creativity. To achieve this, the section begins with a brief overview of insight research and, in so doing, outlining the contribution of the current project to the research field.

Research on Insight

Insight was first studied scientifically by gestalt psychologists (Gilhooly & Webb, 2018; Klein & Jarosz, 2011; Sternberg & Davidson, 1995). Initially, the purpose was to develop tasks intended to overcome *functional fixedness*, that is, situations where common notions of how to use a method or tool prevents novel and innovative ways needed to solve a problem (Duncker, 1945; Duncker & Krechevsky, 1939; Öllinger & Knoblich, 2009). Cognitive restructuring is a contended concept in research on insight, and implies a fundamental change in perception or understanding of a problem that may reveal the pathway to the solution of the problem (Pretz, Naples, & Sternberg, 2003). According to Gestalt theory, insights are the product of *special processes*, meaning nonmonotonic problem solving through representational change (Danek, 2018, p. 54). Later, in the early 1980s, critics of Gestalt theory argued that while insights may be subjectively different from analytical problem solving, the underlying cognitive processes do not depend on mental restructuring and that there is nothing special about sudden insights (Bowden & Grunewald, 2018). From the *business as usual* perspective, insights are the product of conscious and analytic processes similar to any problem solving (Chronicle, MacGregor, & Ormerod, 2004; Gilhooly & Webb, 2018). Based on the two understandings, insights are either regarded as a separate cognitive phenomenon or a subjectively different experience rooted in the same processes as analytical problem solving (Bowden & Grunewald, 2018). Consequently, to date there exists no single definition of insight but rather three different ways of approaching the topic: (1) processes (2) task and (3) and phenomenological perspectives of insight (Webb, Little, & Cropper, 2018). First, concerning the debate of representational change, process-based approaches to insight wish to study the processes underlying problem solving. Second, task-based approaches wish to develop or identify tasks indented to elicit insights, generally through assumed representational change. The two approaches were the predominant methods of

studying insight. However, as stated in the introduction, sudden insights may have different phenomenological consequences from analytical problem solving. The latter perspective, the focus of the present project, is a more recent contribution to psychology and many researchers advocate that the phenomenology dimension is crucial to further the research on insight (e.g., Bowden & Grunewald, 2018; Danek, 2018). Similarly, we argue that though self-reports and introspection have limited value in understanding the underlying cognitive processes of insight (Jäkel & Schreiber, 2013), such reports are essential in understanding the subjective Aha-experience.

Fluency Truth Beauty

The main merit of Paper I is the development of an integrative model encompassing the phenomenology of Aha-experiences. Increase of experienced ease of ongoing mental processes, positive affect and subjective certainty from before to during the Aha-experience were highly correlated, and the three facets are likely integrative parts of principal metacognitive feelings. Metacognitive feelings includes subjective experiences or feelings that arise when a mental operation is performed (Reber & Greifeneder, 2017). Indeed, Aha-experiences are associated with ease, beauty and truth because they have a common underlying mechanism (Reber, 2018). As seen from Figure 9, we describe the general Aha-experience as an increase in intrinsic motivation caused by a sudden insight mediated by metacognitive feelings and sense of agency. Congruent with recent research, sudden insights generally increase metacognitive feelings, including a subjective certainty that the insight is true (Hedne et al., 2016; Kizilirmak et al., 2019; Loesche et al., 2018; Steele, Johnson, & Medeiros, 2018). The study complements previous studies indicating that sudden insight (Danek, Fraps, von Müller, Grothe, & Öllinger, 2014a; Ohlsson, 1984) and positive affect (Isen & Reeve, 2005) generally foster intrinsic motivation. Furthermore, metacognitive feelings mediated the effect of sudden insight on sense of agency, indicating that an increase of metacognitive feelings is associated with an increase in subjective control of thought. Similar to studies linking fluency of action to judgments of control (Chambon et al., 2014; Haggard & Chambon, 2012), the results are in line with Olson et al. (2016), suggesting that metacognitive feelings related to fluency correlates with sense of agency for thought. In other words, individuals experience more control of their thoughts when their ideas and mental constructs are fluent.

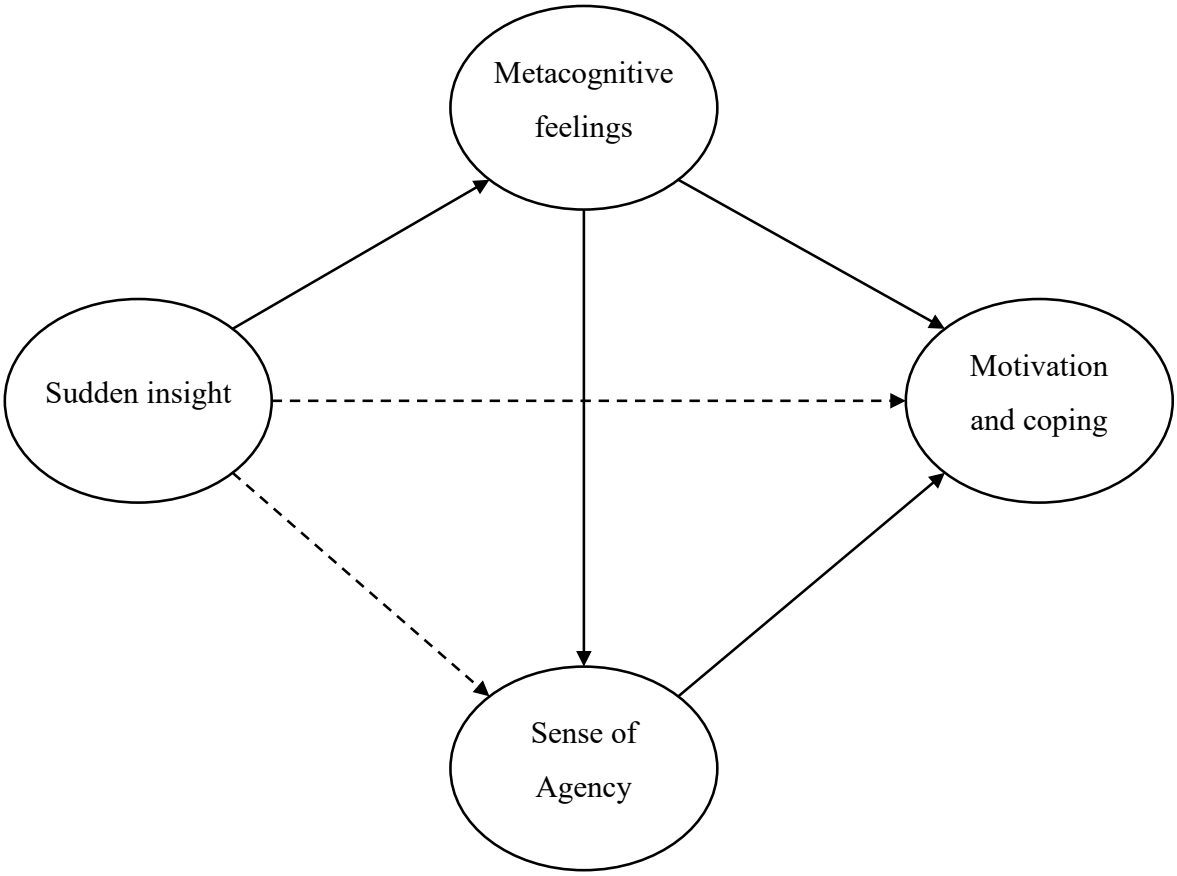


Figure 9. The phenomenology of Aha-experiences.

Thus, Paper I supports both the integrative fluency account by Topolinski and Reber (2010a) and Liljedahl's qualitative study (2004) that suggested that Aha-experiences may have transformative effect on an individual's beliefs and attitudes within the domain of the Aha-experience. Still, studies have shown that activating affective states (e.g., angry, fearful, happy, elated), compared to deactivating affective states (e.g., sad, depressed, relaxed, serene), lead to more creative fluency (De Dreu, Baas, & Nijstad, 2008; Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009; Yeh, Lai, Lin, Lin, & Sun, 2015; Zenasni & Lubart, 2008; see Baas, De Dreu, & Nijstad, 2008 for a meta-analysis). Consequently, it is plausible that a shift in positive affect rather than the sudden insight itself precedes the observed positive correlation between changes in metacognitive feelings and sudden insight from before to during the Aha-experience. In other words, positive changes in activating affective states may influence the way one approaches a problem, thereby finding novel solutions and thus increasing fluency and subjective certainty

that leads up to a sudden insight. However, as argued by Shen et al. (2015), the Aha-experience is likely a combination of cognitive suddenness and its affective component (e.g., happiness). Moreover, results from Paper I are consistent with prior evidence suggesting that fluency is marked hedonically (Duke, Fiacconi, & Köhler, 2014; Reber et al., 2004; Winkielman et al., 2003) and epistemically (Reber & Unkelbach, 2010). Recently, we conducted an experiment to test results found in Paper I. We asked participants to solve matchstick arithmetic tasks, an insight task, and Piagets water level tasks, a non -insight spatial ability task (Skaar & Reber, 2019). Results indicated that not only did participants use different strategies in solving the tasks; the two tasks also differed in the ability to evoke affective responses. Whereas insight tasks were solved using a combination of step-by-step strategies and sudden insight, trial-and-error and step-by-step strategies were used to solve non-insight spatial ability tasks. Furthermore, when comparing solving insight and non-insight tasks, the former to greater extent elicited motivation and coping. The results are in line with Weisberg's (2018) proposal that that insights are the product of gradual development and deliberate analysis of a problem that leads up to restructuring and sudden insight. Thus, the product of both special and business as usual processes.

The Role of Social Context

Derived from social role theory (Eagly, 1987), we theorized in Paper II that social context would play a different role for men and women. We observed that roughly half of participants in the study were alone or that others present were not relevant for the Aha-experience, whereas the remaining reported being together with someone who influenced the experience. However, the results were highly dependent on the questionnaire, and participants from the General sample were more frequently alone, while participants from the School sample were predominately interacting with someone prior to the Aha-experience. Furthermore, regardless of questionnaire and targeted population, the main results showed that men, compared with women, were more often alone prior to the Aha-experience. Conversely, women were more often together with someone who contributed to the Aha-experience. Importantly, the gender differences were only credible for Aha-experiences within STEM and personal domains that increased situational interest. The overall results of Paper II (see also Extended Results section) are largely consistent with previous findings that women find more interest from cooperation than men (Atkins &

Rohrbeck, 1993; Fennema & Peterson, 1986; Hänze & Berger, 2007; T. J. Smith, McKenna, & Hines, 2014).

However, a limitation of the study is that the social context and activity measures do not include information on gender composition or group-size of those reporting being together with someone that contributed to the Aha-experience, which may affect group performance (Adams & Ferreira, 2009; Williams & Polman, 2015). Kennedy (2003) found that women were more motivated by cooperation and aimed for universalistic solutions, whereas men were more motivated by self-interest and choose more competitive solutions. A recent study by Keck and Tang (2018) examined confidence judgments and found that members of all-male groups were least willing to cooperate and shared less information in group discussions. Overall, all-male groups differed little from individual male approaches. These studies are in line with social role theory (Eagly, 1987) described in the introduction, and it is plausible that gender compositions in the social context may affect the Aha-experience and Aha-frequencies. Nonetheless, it is crucial to keep in mind that the results found in Paper II may stem from participants' stereotypical view of social interaction rather than actual behavior (cf., Mills, 2003).

Openness to Aha-experiences

In Paper III, we examined the relationship between creativity and Aha-experiences, with Openness believed to interlink the two. We argued that non-sensory feelings at the fringe of consciousness, namely metacognitive feelings, mediate memory retrieval of the specific Aha-experience (Mangan, 2001; Norman, 2002). Thus, we hypothesized that since Openness relates to creativity (S. B. Kaufman & Gregoire, 2015), fringe feelings (R. A. Baer et al., 2006; Norman et al., 2006) and to Aha-experiences (Ovington, 2016), participants scoring higher on Openness would more frequently report and describe Aha-experiences. Similarly, we assumed that Openness would positively correlate with Aha-frequencies. Results from Paper III supported the two assumptions, and further strengthened the existing evidence linking Openness to creativity and Aha-experiences.

However, we were also interested in examining whether the relationship between Openness and Aha-frequencies were equivalent in newer and older Aha-experiences. Since Openness is linked with motivational processes associated with exploring novel and complex information (DeYoung, 2013; DeYoung et al., 2005), it is reasonable to assume that individuals

scoring high on Openness would have more frequent Aha-experiences due to the incentive reward from such experiences. Correspondingly, there is a question of whether the effect of incentive reward is reduced if not nourished, and this assumption invites the recurring debate over nature versus nurture. Thus, whether the relationship between Openness and Aha-experiences is considered fixed and connected with creative abilities or malleable and connected with creative achievements through Aha-experiences (O'Connor, Nemeth, & Akutsu, 2013; Zhang, 2015).

Creativity researchers generally use the term *fixed* and *growth* mindset when referring to (self-) beliefs concerning the malleable nature of creativity (Hass, Reiter-Palmon, & Katz-Buonincontro, 2017; Intasao & Hao, 2018). Individuals can endorse both mindsets, usually by attributing Big-C creativity to innate, fixed ability, whereas everyday creativity can be developed as any other type of skill (Karwowski, 2014). Paper III provides preliminary evidence for the latter. The results indicate that mini-c are shaped by creative achievements, and that individuals who score high on Openness have more frequent Aha-experiences if a growth mindset is sustained.

This study has several limitations (cf., Paper III). As both studies relied on retrospective self-reports, it is conceivable that the results reflect self-beliefs rather than actual behavior (cf., Beaulieu-Prévost & Zadra, 2007). Similarly, as the study does not encompass experimental or longitudinal data, it is not possible to ascertain at what point the relationship between Openness and Aha-frequencies decreases. There is likely a threshold when the effects of incentive reward no longer influences, that is, increases or decreases the strength of the relationship. However, despite the limitations, we can, based on inference by exclusion, conclude that results of Paper III support the creative achievement assumptions as the data excludes the possibility of a stable relationship between Openness and Aha-frequencies, which is necessary for the creative aptitude assumption to be true.

Concluding Remarks

The present project contributes to our understanding of the phenomenology of the Aha-experience and the three studies demonstrate that Aha-experiences occur in many different contexts and within multifaceted domains. Moreover, the thesis provides evidence strengthening the assumption that Aha-experiences are associated with creativity and that individual traits like

Openness may facilitate Aha-experiences. A common denominator of the Aha-experiences is a change in metacognitive feelings associated with fluency, positive affect and subjective certainty, where these metacognitive feelings are determinative for the motivational outcome of the Aha-experience. Participants generally report positive Aha-experiences that lead to positive changes in motivation and coping, regardless of the domain in which the Aha-experience occurred.

Future directions. A direct and continuous path for future investigations is to add items measuring the strength of Aha-experiences to the existing questionnaires, thereby enriching the diverse Aha-experiences gathered in this project. However, as we have examined three different, albeit intermingled facets of the Aha-experience: situational factors, phenomenology and the relationship between Aha-frequencies and personality, the studies provide several routes for further enquiry.

First, Paper I provides an initial model of the phenomenology of Aha-experiences, underlining the significance of metacognitive feelings. Yet, experiments may offer information in controlled settings that our surveys could not, as we have recently demonstrated (Skaar & Reber, 2019). For instance, though researchers have examined the relationship between sudden insight and mechanisms related to working memory capacity (e.g., Chuderski & Jastrzębski, 2018), the relationship between these mechanisms and phenomenology are unknown. Thus, from a cognitive psychology perspective it may be fruitful to establish experimental paradigms to examine the integrative fluency account.

Second, in Paper II we found that social context might play a different role for women than for men, as women were more often with someone that contributed to the Aha-experience. The educational implications of Paper II suggest that women benefit more from cooperative learning environments than men do. Consequently, given that much of STEM education consists of solitary activities, women do not optimally benefit from STEM instruction in terms of affective consequences. Social and educational psychologists may be interested to explore the relationship between gender and social context in light of group-sizes and gender compositions of groups. Furthermore, it may be fruitful to examine the relationship between sudden insight and intrinsic versus extrinsic motivation.

Third, Paper III found preliminary evidence linking Openness to Aha-frequencies, yet, the relationship seemed dependent on the elapsed time since the last memorable Aha-experience. From a cognitive neuroscience perspective, a possible direction for future studies is to examine

the function of the dopaminergic reward system in regard to Aha-frequencies, thus providing a better understanding of the creative achievement versus creative aptitude hypothesis.

Finally, there are topics not covered in the project. From a lifespan developmental perspective, it is interesting to examine at what age children might start to have Aha-experiences and whether Aha-frequency declines in old age. Furthermore, there are clinical conditions that may affect Aha-experiences, do depressive, autistic or Alzheimer patients have Aha-experiences? Arguably, the study of Aha-experiences is interesting from any psychological perspective.

Final thoughts. After more than four years studying the Aha-experience, my thoughts reflect Keats' poem the "Ode on a Grecian Urn" and Poincaré's description of the inventive and creative mathematician, and I believe the Aha-experience could simply be described as the abrupt beauty of truth. "Beauty is truth, truth beauty ,—that is all / Ye know on earth, and all ye need to know" (Keats, 1884, p. 236).

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