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Empirical Article

Alone or together: The role of gender and social context prior to Aha-experiences

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Prior research indicates that boys show more interest in science, technology, engineering, and mathematics (STEM) than girls do. Given that Aha-experiences yield positive affect and increase interest, the question arises whether there are gender differences in Aha-experiences that could help explain the gender differences in interest. Derived from social role theory, we hypothesized that men report having Aha-experiences alone, whereas women report having Aha-experiences together with others. In a retrospective survey study comprising three independent samples (N = 899), we conducted chi-square analyses to explore the relationship of gender, social context (alone; not alone), domain, and situational interest. Across all participants, we found that men were more probably alone and women more probably together with others when they had an Aha-experience. More fine-grained analyses revealed that the effect was especially pronounced when the Aha-experience increased situational interest within STEM or the personal domain. The study suggests that social context played a different role in the occurrence of Aha-experiences in men and women. We discuss the implications of our findings for STEM instruction at school.

Key words: Social role theory, gender, STEM, interest, social context, aha-experiences.

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INTRODUCTION

The digital revolution increased the demand for expertise in fields of science, technology, engineering, and mathematics (STEM). Despite significant investments, this demand is yet to be fulfilled (Wang & Degol, 2013). In part, the discrepancy is due to a well-known, well-studied, but unresolved gender gap in STEM fields, where women are underrepresented, especially in physics, engineering, and computer science (Cimpian, Kim & McDermott, 2020; Farrell & McHugh, 2017). One reason for the gender gap in career choices is the observation that girls, in general, show less broad interest in STEM-related subjects than boys do (Fredricks & Eccles, 2002; Høgheim & Reber, 2019; Stoet & Geary, 2018) and are more likely to believe that science is predominantly a male domain (Makarova, Aeschlimann & Herzog, 2019). As Aha-experiences yield positive affect and increase interest and motivation, especially in STEM domains (Skaar & Reber, 2020, 2021), it is important to explore the role of gender in Aha-experiences. In the current study, we explored gender differences in Aha-experiences as one potential alternative reason for the fact that women experience less individual interest and lower ability self-concept in STEM subjects.

Interest, ability and self-concept in mathematics

Mathematics is essential for learning within the STEM fields and has therefore been a recurrent object of educational research. Several studies have shown that girls, compared with boys, on average are less interested in, and have more negative attitudes toward, mathematics (Eccles, 1994; Høgheim & Reber, 2019; Jacobs, Lanza, Osgood, Eccles & Wigfield, 2002). Interest is defined as the disposition to voluntarily engage in an activity (Dewey, 1913) and can be divided into an affective component – an activity elicits positive affect – and a value component – an activity increases perceived value (Schiefele, 1991). Moreover, it is necessary to distinguish between short-term (situational) and long-term (individual) interest.

Situational interest is a context-specific, short-term change in affective and cognitive processing (Hidi & Baird, 1986). *Individual* interest, on the other hand, is the motivational predisposition to engage with specific activities, like mathematics (Ainley, Hidi & Berndorff, 2002; Harackiewicz, Smith & Priniski, 2016). Individual interest is considered a relatively stable psychological state, meaning that the motivation to reengage with the specific domain of interest is present over prolonged periods. In other words, situational interest is *being* interested now, whereas individual interest is *having* interest over time (Høgheim & Reber, 2019).

According to recent theorizing and empirical analysis, situational interest can be divided into *triggered* and *maintained* components (Hidi & Renninger, 2006). Whereas triggered interest is associated with temporary engagement due to novelty or surprise, maintained interest has greater longevity due to subjective meaningfulness or relevance (Linnenbrink-Garcia *et al.*, 2010; Mitchell, 1993). Given the right stimulation, the former may develop into the latter, and studies indicate that it is feasible to increase affective and cognitive involvement, for instance, through personalizing instructional materials in mathematics (e.g., Høgheim & Reber, 2015; Renninger, Ewen & Lasher, 2002). Furthermore, it has been shown that triggered and, to a larger degree, maintained situational interest contributes to the development of individual interest (Guthrie, Hoa, Wigfield, Tonks & Perencevich, 2005; Linnenbrink-Garcia, Patall & Messersmith, 2013).

International and longitudinal studies have shown that girls, relative to boys, are more likely to have lower self-concept in mathematics (Nagy *et al.*, 2010; Wilkins, 2004). Moreover, several studies have found a negative association between boredom and academic achievement (Daniels *et al.*, 2009; Goetz, Frenzel, Pekrun, Hall & Lüdtke, 2007; Pekrun, Elliot & Maier, 2009). However, there is little evidence that there are gender differences in situational interest when learning mathematics (Høgheim & Reber, 2019; Vainikainen, Salmi & Thuneberg, 2015). Research has documented small or even trivial gender differences in overall mathematics performance and test scores (Hyde, Lindberg, Linn, Ellis & Williams, 2008; Lindberg, Hyde, Petersen & Linn, 2010). However, gender differences may be related to sociocultural factors, such as gender-biased and unequal learning environments (Brotman & Moore, 2008; Hoffmann, 2002). Several studies have shown that what society expects of girls in mathematics is different from what is expected of boys, even when their performance levels are indistinguishable (Cimpian, Lubienski, Timmer, Makowski & Miller, 2016; Robinson-Cimpian, Lubienski, Ganley & Copur-Gencturk, 2014; Stoet, Bailey, Moore & Geary, 2016; Upadyaya & Eccles, 2014). Expectations may act as self-fulfilling prophecies (see Jussim & Harber, 2005), and the gendered stereotypes appear to have a more negative effect on girls' long-term interest and self-concepts of ability in STEM (Beilock, Gunderson, Ramirez & Levine, 2010; Frenzel, Pekrun & Goetz, 2007; Makarova, Aeschlimann & Herzog, 2019). Furthermore, research has shown that self-concept predicts future academic and work choices and may in part explain the gender gap (Eccles & Wang, 2016).

The findings are in line with the gender similarities hypothesis (Hyde, 2005). From this perspective, many, if not all gender differences may be attributed to social factors such as cultural stereotypes, sexism, and other gender biases. Indeed, Else-Quest, Hyde, and Linn (2010) found that nations with less gender inequality also had a smaller gender gap in mathematics performance, and in fairly gender equal societies (e.g., Nordic countries), girls tend to outperform boys (Guiso, Monte, Sapienza & Zingales, 2008). We argue that it is possible to both identify and understand gender stereotypes by utilizing a biosocial framework.

Social role theory

Eagly and Wood (1999, 2012, 2016) proposed *social role theory* and argued that sex-differentiated dispositions and behaviors are influenced by an interaction of both biological and social processes ("biosocial interactions"; Eagly & Wood, 2013). According to this account, 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). Division of labor stems from biological factors, predominantly men's physical strength and women's ability to bear children, in interaction with the requirements of the socioeconomic and ecological environment. Therefore, 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 cultivate distinct sex-differentiation in distribution of labor also promote distinct gender roles. Throughout childhood and adolescence, individuals tend to comply with their assigned gender roles, which in turn reinforces existing social roles (Eagly, Wood & Diekman, 2000; Wood & Eagly, 2010). Gender role beliefs form gender stereotypes that offer opportunities and restrictions, which further drive gender differences and similarities in career choices, partner preferences, domestic behaviors, and other domains (Koenig & Eagly, 2014; Wood & Eagly, 2010; Zentner & Eagly, 2015).

Eagly and colleagues (Eagly, 1987; Eagly & Steffen, 1984) concluded that biosocial influences have led women to adopt more communal roles and men more agentic roles, and that these gender stereotypes are similar in most human societies (Saewyc, 2017). The communal role emphasizes relational, cooperative, and nurturing behavior, and the agentic role accentuates assertive, competitive, and dominant behavior (Wood & Eagly, 2010). Derived from the gender role beliefs, behavior of the feminine stereotype is portrayed as personal and communal (e.g., affectionate, emotional) and the masculine as individual and agentic (e.g., ambitious, courageous), and consequently, the stereotypes promote female interest in persons and male interests in things (Su, Rounds & Armstrong, 2009). A recent meta-analysis (Eagly, Nater, Miller, Kaufmann & Sczesny, 2020) suggests that gender role beliefs concerning the feminine communal stereotype have increased in the period 1946–2018, whereas the agentic masculine stereotype has remained stable.

We argue that boys and girls enter formal education on uneven terms. 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; Stoet & Geary, 2018). Correspondingly, girls are raised with the expectation that they will have to work harder than boys to achieve the same results (Yee & Eccles, 1988). Not surprisingly, 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 a greater extent than other subjects, often is regarded as a fast-paced, individual, and competitive field of learning, the gender stereotypes leave particularly girls at a disadvantage (Boaler, 2002, 2008, 2016; Cotton, McIntyre & Price, 2013; Fischer, 2017). Also, many boys with perceived low abilities in mathematics may opt to forfeit the alleged competition rather than adopting girls' more studious methods of learning (Jones & Myhill, 2004; Martino, 1999). Arguably, the resulting behavior causes the bimodal distribution for boys as seen in PISA and SAT scores (see Cimpian, Lubienski, Timmer, Makowski & Miller, 2016). Given such gender stereotypes, 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 (e.g., nursing, preschool teaching). Importantly, meta-analyses have emphasized the importance of context for explaining gender differences and similarities (e.g., Hyde, 2014; Leaper & Robnett, 2011). To explore gender differences further, we were interested in assessing whether there are gender differences in reported Aha-experiences.

The Aha-experience

In the present study the Aha-experience is defined as the sudden reorganization of a mental representation leading up to a novel understanding that has previously been nonobvious or nondominant (Kounios & Beeman, 2014). Topolinski and Reber (2010) presented an account of Aha-experiences that assumes a vital role of processing fluency, which is the subjective ease with which a mental operation is performed and plays a significant role in cognitive processes related to education (see Reber & Greifeneder, 2017). According to this account, the Aha-experience is a sudden experience of fluent processing that prompts positive affect and increases subjective confidence in the truth of the solution (for empirical evidence, see Skaar & Reber, 2020, 2021). In addition, though Aha-experiences may follow false insights (see Danek & Wiley, 2017; Grimmer, Laukkonen, Tangen & von Hippel, 2022), solutions accompanied by Aha-experiences seem to be more probably correct than wrong (Salvi, Bricolo, Kounios, Bowden & Beeman, 2016). Moreover, Aha-experiences are usually stronger for correct solutions than for false solutions (Grimmer, Laukkonen, Tangen & von Hippel, 2022), yield a memory advantage for solutions (Danek, Fraps, von Müller, Grothe & Öllinger, 2013; Danek & Wiley, 2020; Ludmer, Dudai & Rubin, 2011), and increase interest (Liljedahl, 2005).

Regarding interest, Liljedahl (2005) observed in a qualitative study that interest increased when students reported at least one Aha-experience when solving mathematical problems. As interest has an affective and a value component (Schiefele, 1991), and Aha-experiences increase positive affect, it is plausible to assume that Aha-experiences boost the affective component of interest. Correspondingly, Russo *et al*. (2020, 2021) found that teachers frequently reported that observing students having an Aha-experience gave them joy while teaching mathematics. Furthermore, teacher enjoyment was positively correlated with the quality and quantity of mathematics instruction students received. In a survey study, respondents reported that their Aha-experience increased interest and motivation (Skaar & Reber, 2020). These findings demonstrate the importance of Aha-experiences for interest and thus the importance of examining gender differences in Aha-experiences.

Social context. The Aha-experience is often associated with Archimedes' solitary "Eureka!" moment as he stepped into the bath. Csikszentmihalyi's (1996) work on creativity has strengthened the stereotype of the *solitary genius* whose Aha-experiences occur primarily when alone (Csikszentmihalyi & Sawyer, 1995). Similarly, STEM subjects, especially mathematics, are often considered a solitary activity (Chronaki & Kollosche, 2019; Gilje, 2017; Gilje *et al.*, 2016; Schoenfeld, 2016). However, Liljedahl (2005), in the above-mentioned study, created learning situations with special emphasis on social interaction as part of acquiring mathematical understanding. Liljedahl found that group discussion and peer interaction facilitated Aha-experiences. Thus, the social component may contribute to changes of conceptual representation, changes that are necessary for insight and a subsequent Aha-experience.

Furthermore, it is plausible that gender role beliefs concerning the masculine, agentic role emphasize the solitary road to insights, whereas the feminine, communal role underlines social interaction. Studies have shown that boys tend to exhibit individualistic or dominating behavior whereas girls prefer egalitarian and prosocial behavior under both cooperative and competitive conditions (Frey, Nolen, Van Schoiack Edstrom & Hirschstein, 2005; Hong, Hwang & Peng, 2012). Correspondingly, studies have shown that girls benefit more from cooperative learning environments than boys do (Atkins & Rohrbeck, 1993; Fennema & Peterson, 1986; Hänze & Berger, 2007; Smith, McKenna & Hines, 2014). Such gender differences could explain the contradictory evidence so far, because the solitary Aha-experiences stemmed from anecdotes on insights overwhelmingly by men, but most students (more than 80%) in the elementary teacher preparation course examined in the above-mentioned study by Liljedahl (2005) were women (P. Liljedahl, personal communication, 2017, February 15).

We therefore predict that men, compared with women, are more likely to have Aha-experiences when alone, whereas women, compared with men, are more likely to have Aha-experiences when together with others who contributed to the Aha-experience. This is our main hypothesis. Thereafter, we examine whether the relationship between gender and social context depends on both situational interest and domain. This analysis is essential because the basic finding would be relevant for interest in STEM fields only if the result that men experience Aha-experiences alone and women together with others also can be found for situations relevant to interest in STEM fields (cf. Wysocki, Lawson & Rhemtulla, 2022).

To summarize, we contrast the hypothesis that Aha-experiences mostly occur in solitude with the hypothesis that they mostly occur together with others. As there is no systematic research on this topic, we do not make specific predictions. We then test the main hypothesis, derived from research on interest in STEM and social role theory, that men are more likely to have Aha-experiences alone and women are more likely have Aha-experiences together with others. If this effect should be relevant for interest in STEM education, we would have to show it also applies to situations in which Aha-experiences increase interest in STEM.

METHODS

Participants

Power analysis indicated that a sample size of 233 (min = 87, max = 784) would obtain statistical power of $\beta = 0.80$ to identify a small to medium effect size ($\omega = 0.20$, min = 0.1, max = 0.3) with $p \leq 0.05$. We sampled a total of N = 1,849 participants from three different populations. The first sample (N = 501, mean age = 28.55, SD = 11.09, 115 male) were recruited at two Norwegian universities. The second sample (N = 761, mean age = 25.78, SD = 4.72, 425 male) was acquired through Amazon Mechanical Turk (MTurk). The final sample (N = 587, mean age = 17.95, SD = 1.21, 190 male) was recruited from two public Norwegian high schools. The MTurk workers were paid \$9 an hour whereas the Norwegian students were paid 100 NOK (approximately \$12) an hour. We compensated participation of the school sample at class level to fund field trips. The study obtained ethical approval from the Norwegian Social Science Data Services and the Internal Research Ethics Committee at the Department of Psychology, University of Oslo.

Only those participants who remembered and reported an Aha-experience (N = 949) were included in the final analyses. Initial data screening led to the removal of 50 cases from the total sample because they were not considered Aha-experiences. Thus, the final sample in this study consisted of 899 participants with an age range of 16–71 (mean age = 23.73, *SD* = 7.73, 365 male).

Materials and procedure

This study presents the findings of the first part of a larger survey (see Online Resource 1 for complete surveys, available [provisional link for editor and reviewers] at https://tinyurl.com/y85wlx5k). Participants were asked to describe a particular, self-experienced Aha-moment utilizing an online questionnaire (Qualtrics, 2021). There were two versions of the questionnaire. The general survey given to the university and MTurk populations did not restrict the topic of the Aha-experience. The school-oriented survey given to the school population asked participants to describe a school-related experience. Except for some adaptations of the interest items (see below) and items not included in the present study, the questionnaires in the three studies were identical. The purpose of the three distinct samples, and the rationale for administrating a general and a school-related survey, was to examine whether the restriction in the latter would affect the gender distribution concerning social context and, moreover, to examine differences in reported domains of Aha-experiences given different contexts and populations.

Measures

The initial data screening of the Aha-experiences was based on two main criteria: (1) the suddenness or abruptness of the experience and, more importantly, (2) a change of perception in a distinct (e.g., STEM or personal) domain. The data screening was conducted by two judges, the first author and a research assistant, with an acceptable inter-rater agreement of the Aha-experiences (κ_{949} = 0.76, 95% CI [0.68, 0.84]). We further categorized the Aha-experience based on their written account and from multiple-response items.

Social context. To assess the social component of Aha-experiences, we asked participants to provide an overview of anyone present prior to the Aha-experience by selecting relevant options from a multiple-response list containing 20-plus items. Participants could select being alone, or choose one or more options, including an "Other" option with a field to enter free text. The general study (21 items), administered to the university and MTurk samples, contained two items concerning offspring ("with one of my children" and "with several of my children"), whereas the school-related study (20 items) used only one item ("with one or more of my children"). Otherwise, the questionnaires contained the same items. Furthermore, we asked participants whether they believed others present contributed to the Aha-experience. Thus, if *no* was selected, the participants would belong to the *others irrelevant* group. Correspondingly, if *yes* was selected, they belonged to the *others relevant* category. The final category was collapsed into a dichotomy between *alone*, which included alone or with someone irrelevant to the Aha-experience, and *together* when the respondent was together with someone relevant to the Aha-experience.

Domain. Based on a written description of the Aha-experience, we grouped the reported Aha-experiences into three specific domains: (1) *STEM* experiences, (2) *personal* experiences, and (3) *other topics*. The two domains of interest for our study were STEM-related and personal (e.g., intrapersonal and interpersonal) Aha-experiences. The *STEM* experience is generally associated with the solution or understanding of a task, or field, within science, technology, engineering, and, in most cases, mathematics. 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 addition, many Aha-experiences do not belong to either of these two categories. Consequently, we added a third category, *other subjects*, which are often like STEM and usually include solutions to a problem (e.g., riddles, games) or acquiring a skill (e.g., languages, physical/sports techniques) that were not within the STEM fields. Thus, the domain of the latter category was less homogeneous than the STEM and personal domains. Inter-rater agreement indicated satisfactory agreement between the two independent judges, the main author, and a research assistant (κ_{327} = 0.90, 95% CI [0.88, 0.92]).

Interest. The two items measuring *triggered* interest (i.e., "the experience sparked an interest in something new") and *maintained* interest (i.e., "the experience helped me maintain a previous interest") was initially a binary yes/no-question in the original data collection. However, in the two latter samples the items were measured on a 7-point Likert-type scale that ranged over 1 = *completely disagree*, 2 = *strongly disagree*, 3 = *slightly disagree*, 4 = *neither agree nor disagree*, 5 = *slightly agree*, 6 = *strongly agree*, and 7 = *completely agree*. Thus, to utilize all data, and to answer the question of whether an Aha-experience stimulated, that is, triggered or maintained an interest, we dichotomized the items, where 1–4 equaled *no* and 5–7 – those who reported a new or maintained interest – equaled *yes*.

Data-analytic strategy

Analyses were conducted in *R* (R Core Team, 2022), where the main inferential analysis was a chi-square test of independence. The analysis was used to test the hypothesis that the relative odds of social context (i.e., alone or together) depended on gender. We further conducted exploratory contingency analyses, where the final model assumed that the three different samples constituted the highest level in the hierarchy, where the relative odds of social context were informed by gender, which in turn were informed by interest, and domain. Descriptive and inferential analyses (i.e., chi-square tests) were conducted using the built-in *stats* package in *R*, in addition to *psych* (Revelle, 2021). Graphics were created using ggplot2 (Wickham, 2009), and data and graphics were handled using *bfw* (Skaar, 2022).

We present the results as odds ratios (OR) and Cohen's *d*. The estimate of Cohen's *d* is computed according to Chinn (2000). Uncertainty associated with each measure was identified by a 95% confidence interval (see Online Resource 2 for complete data, Online Resource 3 for results, and Online Resource 4 for *R* files including a robust Bayesian multi-level hierarchical model replicating presented results).

RESULTS

We start by reporting the results for social context, testing the contradictory predictions from reports that usually report solitary Aha-experiences versus the findings by Liljedahl (2005) that most Aha-experiences occurred during group discussions. We predicted from social role theory that men differ from women in social context – whether they were alone or together with others – when they had an Aha-experience. We first present the results for this main hypothesis. We then present exploratory analyses for Aha-experiences that increased interest versus Aha-experiences that did not increase interest, and Aha-experiences for separate domains: STEM, personal, and other topics. Finally, we present an analysis including STEM and personal Aha-experiences that increase interest.

Social context

Table 1 depicts the frequencies of the Aha-experiences for all three social context categories and for the collapsed category alone that included irrelevant others (third column). When using the dichotomous scale, shown in the third and fourth columns in Table 1, 459 (51.75%) respondents reported being with someone relevant for the Aha-experience, whereas 428 (48.25%) reported being physically alone, or that others present were irrelevant for the Aha-experience. This finding favored neither the notion that Aha-experiences require solitude nor the hypothesis that collaboration facilitates Aha-experiences, though overall participants reported more often that they were with others compared with alone. Participants from the university sample exhibited the least bias toward social context. Participants from the MTurk sample were more likely to be alone during the Aha-experience. Notably, only 1.33% of the school sample reported being physically alone, but for another 28.90%, the others were not relevant for the Aha-experience, which is understandable as 77.66% of the participants had their Aha-experience at school. Thus, results could be a consequence of the underlying school-related context of the questionnaire. Accordingly, participants from the school sample exhibited a clear bias toward being with someone relevant for the Aha-experience.

Interest

The analyses indicated that Aha-experiences often involved a combination of triggering and maintaining an interest within a domain (see Table 2, fourth column). The data also indicated that an Aha-experience was more likely to trigger a new interest rather than maintaining a previous interest. However, a fair share of reports indicated that not all Aha-experiences stimulate interest (see Table 2, fifth column). Consequently, the final dichotomized variable contained 591 (67.7%) cases in which the Aha-experience had stimulated situational interest, either triggered, maintained, or a combination of the two, whereas in the remaining 282 (32.3%) cases, the Aha-experience did not stimulate interest.

Domain

Overall, there was a clear difference between the general survey of the University and MTurk samples and the school-related survey (see Table 3). In the general survey, less than 30% reported a STEM Aha-experience, whereas more than 75% in the school sample reported such experiences. The differences might indicate that recalled Aha-experiences are dependent on context and that STEM experiences, unlike personal and other topics, are more likely to be associated with school.

Table 1. *Social context by sample (percentage)*

Sample	Alone	Others irrelevant	Alone incl. others irrelevant	Others relevant
University (250)	29.20	16.00	45.20	54.80
MTurk (336)	45.54	21.13	66.67	33.33
School (301)	1.33	28.90	30.23	69.77
Combined (887)	25.93	22.32	48.25	51.75

Note: Sample size in parentheses.

Table 2. *Triggered and maintained interest by sample (percentage)*

Sample	Triggered	Maintained	Both triggered and maintained	None
University (231)	22.94	14.72	18.18	44.16
MTurk (341)	19.35	13.49	47.51	19.65
School (301)	23.59	9.97	28.90	37.54
Combined (873)	21.76	12.60	33.33	32.30

Note: Sample size in parentheses.

Gender and social context

Initial results provided evidence to support the main hypothesis, demonstrated by a significant relationship between social context and gender ($\chi^2[1,\ N = 862] = 17.20,\ p \leq 0.001$). Presented in Table 4, we can examine the differences between observed and expected (parentheses) frequencies given that social context and gender are independent.

The results indicated that men, compared with women, were more likely to be alone prior to the Aha-experience, where the overall odds ratio showed that men were 1.80 times more likely to be alone prior to the Aha-experience. Though all three independent samples provided comparable results, differences in the university sample were negligible (see Fig. 1). However, when we considered situational interest and domain-specific Aha-experiences, the following exploratory analyses provided more consistent results in all samples.

Interest. First, we examined whether situational interest could better explain gender differences in social context. As depicted in Table 5, the differences where more pronounced in Aha-experiences that increased interest ($\chi^2[1,\ N = 575] = 21.15,\ p \leq 0.001$). Though differences in the university sample were not significant, the odds ratios were comparable in all three samples, indicating a small but stable effect.

Conversely, as seen from Table 6, there were no significant gender differences in social context for Aha-experiences that did not increase situational interest ($\chi^2[1,\ N = 264] = 0.33,\ p = 0.564$). The MTurk sample exhibited small, insignificant differences, the school sample provided negligible differences, and the university sample, though also negligible, provided an opposing effect. Consequently, when we further examined the domain-specific Aha-experiences, we excluded the experiences that did not increase situational interest.

Interest and domain. Naturally, by further subsetting the data, results are more uncertain. Therefore, strengths, though inflated by the small sample sizes, and direction of effects are more meaningful than significance in the independent samples. First, by examining Aha-experiences that increase interest within STEM ($\chi^2[1,\ N = 232] = .54,\ p \leq 0.001$), we observed that the direction of effects is the same in all three samples. Though the strength of the effect varied from small (school) to medium (MTurk) and

Table 3. *Domain of Aha-experiences by sample (percentage)*

Sample	STEM	Personal	Other topics
University (257)	21.01	33.46	45.53
MTurk (341)	25.22	48.09	26.69
School (301)	76.74	10.96	12.29
Combined (899)	41.27	31.48	27.25

Note: Sample size in parentheses.

Table 4. *Social context by gender*

	Alone		Together						
Data set (*n*)	Men	Women	Men	Women	Odds ratio		*d*		*p*
University (239)	38 (35)	72 (75)	39 (42)	90 (87)	1.22	0.68, 2.17	0.11	−0.21, 0.43	0.567
MTurk (335)	127 (116)	96 (107)	47 (58)	65 (54)	1.83	1.13, 2.98	0.33	0.07, 0.60	0.013
School (288)	41 (33)	45 (53)	69 (77)	133 (125)	1.75	1.02, 3.03	0.31	0.01, 0.61	0.043
Combined (862)	206 (175)	213 (244)	155 (186)	288 (257)	1.80	1.35, 2.38	0.32	0.17, 0.48	≤0.001

Notes: *d* = Cohen's *d*; *p* = *p*-value.
Subscripts for odds ratio and Cohen's *d* indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

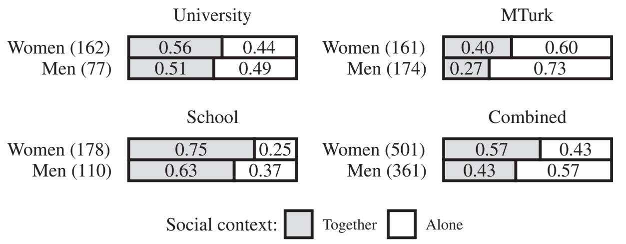

Fig. 1. Gender differences in social context for Aha-experiences. Proportions (n in parentheses).

large (university), the overall results indicated a medium effect, in which men were 3.46 times more likely to be alone when compared with women (see Table 7).

Though the overall effect was weaker, results (χ^2[1, N = 199] = 5.51, p = 0.019) for Aha-experiences increasing interest within personal domains were comparable to STEM (see Table 8). The combined sample indicated a medium effect size, where men were 2.12 times more likely to be alone prior to the Aha-experience.

Results from the multifarious other topics domain indicated no clear gender differences in the social context of Aha-experiences

Table 5. *Social context by gender and Aha-experiences increasing interest*

	Alone		Together						
Data set (*n*)	Men	Women	Men	Women	Odds ratio		*d*		*p*
University (122)	23 (19)	35 (39)	16 (20)	48 (44)	1.96	0.85, 4.61	0.37	−0.09, 0.84	0.124
MTurk (272)	100 (91)	76 (85)	40 (49)	56 (47)	1.84	1.08, 3.15	0.34	0.04, 0.63	0.024
School (181)	25 (18)	28 (35)	37 (44)	91 (84)	2.19	1.07, 4.47	0.43	0.04, 0.83	0.029
Combined (575)	148 (120)	139 (167)	93 (121)	195 (167)	2.23	1.57, 3.18	0.44	0.25, 0.64	≤0.001

Notes: *d* = Cohen's *d*; *p* = *p*-value.
Subscripts for odds ratio and Cohen's *d* indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

Table 6. *Social context by gender and Aha-experiences not increasing interest*

	Alone		Together						
Data set (*n*)	Men	Women	Men	Women	Odds ratio		*d*		*p*
University (94)	13 (15)	27 (25)	22 (20)	32 (34)	0.70	0.27, 1.78	−0.19	−0.72, 0.32	0.548
MTurk (63)	27 (25)	20 (22)	7 (9)	9 (7)	1.72	0.48, 6.47	0.30	−0.41, 1.03	0.510
School (107)	16 (15)	17 (18)	32 (33)	42 (41)	1.23	0.50, 3.05	0.12	−0.38, 0.61	0.769
Combined (264)	56 (53)	64 (67)	61 (64)	83 (80)	1.19	0.71, 2.00	0.10	−0.19, 0.38	0.564

Notes: *d* = Cohen's *d*; *p* = *p*-value.
Subscripts for odds ratio and Cohen's *d* indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

(χ^2[1, N = 144] = 1.36, p = 0.244). Though the effect was in the same direction for all samples, the effect was small in the inadequately small school sample and negligible to nonexistent in both the university and MTurk samples (see Table 9).

Thus, the final exploratory analysis (χ^2[1, N = 431] = 21.22, $p \leq 0.001$) indicated that gender differences concerning social context were only credible for Aha-experiences that increased situational interest within the STEM and personal domains (see Table 10 and Fig. 2). The results were significant in all three samples, indicating an overall medium effect, in which men were 2.53 times more likely to be alone when compared with women.

DISCUSSION

The results allow two main conclusions. First, across all studies, there were about as many solitary Aha-moments (n = 428) as Aha-experiences together with others (459). However, the individual samples yielded more diverse results (see Table 1). The university sample was most like the overall data. The MTurk sample, on the other hand, showed that two-thirds of the participants were alone and one-third together with relevant others. The opposite was evident for the school sample, with roughly 30% alone and 70% together with relevant others. The discrepancy in results underlines the importance of context to disentangle and interpret results.

One plausible explanation for the differences is the age of participants and particularly the setting of the survey. The school and university participants were younger than the MTurk participants, and most of their Aha-experiences were related to an educational setting. As becomes obvious from the results of the current study, solitude seems unnecessary as a condition for having such moments, despite the claim to that effect made by Csikszentmihalyi and Sawyer (1995), but neither is being together with others a decisive advantage, as Liljedahl's (2005) study might have suggested. The two sets of questionnaires, the general survey administered to the university and MTurk samples and the school-related survey for the school sample, were slightly different. However, it is unlikely that these small variations in the two questionnaires can explain the observed differences between settings and the following gender differences.

Second, confirming our main hypothesis, men were in general more likely than women to report being alone when having an Aha-experience, and women were more likely to report being with someone who contributed to the Aha-experience. Note that despite the disparity of social context across the three samples, the odds of being alone or together for men and women remained similar. Thus, the data suggest that men, in part, are more likely to conform to agentic stereotypes and women to communal stereotypes, as proposed in the goal congruity model (Diekman & Eagly, 2008; Diekman, Steinberg, Brown, Belanger & Clark, 2017). Moreover, we found that gender differences between social contexts were contingent on domain and interest. The differences were most credible for participants who reported increased interest in the STEM and personal domains but not for the more heterogeneous

Table 7. *Social context by gender and STEM Aha-experiences increasing interest*

	Alone		Together						
Data set (n)	Men	Women	Men	Women	Odds ratio		d		p
University (30)	9 (6)	4 (7)	4 (7)	13 (10)	6.76	1.14, 50.78	1.05	0.07, 2.17	0.033
MTurk (70)	38 (36)	10 (12)	14 (16)	8 (6)	2.15	0.60, 7.54	0.42	−0.28, 1.11	0.278
School (132)	17 (13)	20 (24)	29 (33)	66 (62)	1.92	0.82, 4.52	0.36	−0.11, 0.83	0.142
Combined (232)	64 (47)	34 (51)	47 (64)	87 (70)	3.46	1.95, 6.25	0.69	0.37, 1.01	≤0.001

Notes: d = Cohen's d; p = p-value.
Subscripts for odds ratio and Cohen's d indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

Table 8. *Social context by gender and personal Aha-experiences increasing interest*

	Alone		Together						
Data set (n)	Men	Women	Men	Women	Odds ratio		d		p
University (40)	9 (8)	10 (11)	7 (8)	14 (13)	1.77	0.42, 7.83	0.32	−0.48, 1.13	0.561
MTurk (133)	35 (30)	45 (50)	15 (20)	38 (33)	1.96	0.89, 4.48	0.37	−0.07, 0.83	0.106
School (26)	5 (3)	5 (7)	3 (5)	13 (11)	4.07	0.55, 37.21	0.77	−0.33, 1.99	0.214
Combined (199)	49 (41)	60 (68)	25 (33)	65 (57)	2.12	1.12, 4.04	0.41	0.06, 0.77	0.019

Notes: d = Cohen's d; p = p-value.
Subscripts for odds ratio and Cohen's d indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

Table 9. *Social context by gender and other topics Aha-experiences increasing interest*

	Alone		Together						
Data set (*n*)	Men	Women	Men	Women	Odds ratio		*d*		*p*
University (52)	5 (5)	21 (21)	5 (5)	21 (21)	1.00	0.20, 5.06	0.00	−0.89, 0.89	1.000
MTurk (69)	27 (26)	21 (22)	11 (12)	10 (9)	1.17	0.37, 3.69	0.08	−0.55, 0.72	0.973
School (23)	3 (2)	3 (4)	5 (6)	12 (11)	2.30	0.23, 24.09	0.46	−0.82, 1.75	0.680
Combined (144)	35 (31)	45 (49)	21 (25)	43 (39)	1.59	0.76, 3.35	0.25	−0.15, 0.67	0.244

Notes: d = Cohen's d; p = p-value.
Subscripts for odds ratio and Cohen's d indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

Table 10. *Social context by gender and Aha-experiences increasing interest (excluding other topics)*

	Alone		Together						
Data set (*n*)	Men	Women	Men	Women	Odds ratio		*d*		*p*
University (70)	18 (13)	14 (19)	11 (16)	27 (22)	3.10	1.06, 9.57	0.62	0.03, 1.25	0.039
MTurk (203)	73 (64)	55 (64)	29 (38)	46 (37)	2.10	1.13, 3.94	0.41	0.07, 0.76	0.017
School (158)	22 (16)	25 (31)	32 (38)	79 (73)	2.16	1.01, 4.65	0.42	0.00, 0.85	0.046
Combined (431)	113 (89)	94 (118)	72 (96)	152 (128)	2.53	1.68, 3.83	0.51	0.29, 0.74	≤0.001

Notes: d = Cohen's d; p = p-value.
Subscripts for odds ratio and Cohen's d indicate lower and upper bounds for the 95% confidence interval.
Probabilities computed on differences between observed and expected (parentheses) frequencies are based on standardized residuals, given that social context and gender are independent.

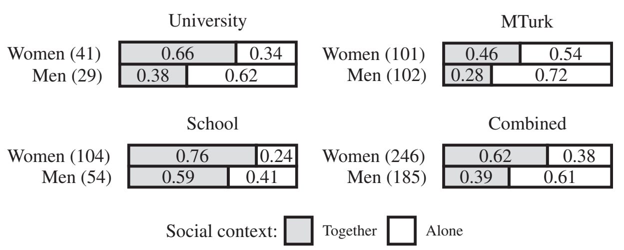

Fig. 2. Gender differences in social context for Aha-experiences increasing situational interest within the STEM and personal domains. Proportions (n in parentheses).

other topics domain. Arguably, Aha-experiences that increase interest are more relevant, or important, to the person than Aha-experiences that do not, which might explain the observation that the gender differences in being alone versus together were most prominent for participants who reported increased interest. Thus, we can conclude that the study provides empirical evidence for credible gender differences in social context for Aha-experiences that increase situational interest within specific domains, including the STEM domain. This effect is important in view of educational implications discussed at the end of this article.

Limitations

A major limitation of the study is the small sample size when analyzing four-way contingency interactions. Thus, the power is not adequate to give a precise estimation of the effect sizes. However, we can be reasonably certain that the gender differences are not trivial or spurious and detectable in both the general and school-related populations. Given that natural Aha-experiences are difficult to observe or elicit through experimental manipulations, self-reports are the most feasible method for assessing Aha-experiences within broad domains. A weakness of the survey is that the question remains why men, to a greater extent than women, report that they had the Aha-experience alone. It is possible, for example, that men remember and report the situation differently (e.g., to a lesser extent acknowledge the contribution of others). Studies have shown that individuals use gender roles as a framework to explain their own behavior, even when there are few gender differences in actual behavior (Herrick, 1999; Ng, 1998; Ng & Byra, 2006; Walker, 1994). Jaffe, Lee, Huang, and Oshagan (1999) concluded that though men experience a social expectation of male independence, they exhibit an equal need for social interdependence when compared with women (Eagly, Wood & Johannesen-Schmidt, 2004; Gardner & Gabriel, 2004). However, gender differences in mathematics interest career choice are not just effects of differential self-reports but behavioral facts. More closely relevant for our study, Liljedahl (2005) provided preliminary evidence that our findings go beyond gender differences in memory and interpersonal goals. His research emphasized the role of collaboration for Aha-experiences in mathematical inquiry. As most students in the elementary teacher preparation course were women, it seems that women favor collaboration that may facilitate Aha-moments. Future research may try to connect survey results on Aha-experiences with behavioral measures of interest and career choice.

Implications

The reported gender differences in social context are in line with gender role beliefs concerning the distinction between agentic orientation in men and communal orientation in women as derived from social role theory. This point of view corresponds with Boaler's (2016, p. 162) claim that women, relative to men, are more likely to find collaborative, inquiry-based work to be an important aspect of STEM education (cf. Chronaki & Kollosche, 2019). Such cooperation would be in line with the communal goal congruity model (see Diekman, Steinberg, Brown, Belanger & Clark, 2017), here applied to mathematics teaching in the classroom. Moreover, though girls are more likely to benefit from cooperative learning environments compared with individual environments, cooperative environments do not impede boys' development in mathematics (Atkins & Rohrbeck, 1993; Hänze & Berger, 2007; Smith, McKenna & Hines, 2014). Contrary to girls' favored strategies, STEM classrooms are seen as a place where students solve their tasks in solitude, and often in a competitive setting (Boaler, 2002; Fischer, 2017; Gilje, 2017; Gilje *et al*., 2016; Hänze & Berger, 2007), which may reinforce the belief, especially among girls, that STEM subjects are perceived as male domains (Makarova, Aeschlimann & Herzog, 2019). Moreover, given Russo *et al*.'s (2020, 2021) notion that student Aha-experiences are important for teachers' enjoyment of mathematical instruction, which in turn is important for the quality and quantity of instruction, it is imperative that girls and boys have an environment that provides equal opportunities for such Aha-experiences. Importantly, Hyde (2014) argued that an overemphasis on gender differences may have serious costs, and studies have shown that gender-segregated education may strengthen gender stereotypes (Fabes, Pahlke, Martin & Hanish, 2013; Halpern *et al*., 2011). It is therefore crucial to understand biosocial factors that form gender roles to inform educational practice in a way that prevents further consolidation of these roles.

The study sheds some light on gender differences that might help explain why women are less likely to be interested in mathematics and other STEM subjects (Høgheim & Reber, 2019). As outlined in the introduction, interest can be divided into an affective and a value component (Schiefele, 1991). Previous research has shown that women do not ascribe less value to mathematics than men do but nevertheless show lower interest (Jacobs, Lanza, Osgood, Eccles & Wigfield, 2002). If our assumption is correct that Aha-experiences are likely to influence interest via their affective component (for preliminary evidence, see Skaar & Reber, 2020), gender differences in Aha-experiences might help explain gender differences in the affective component of interest. Liljedahl (2005) has shown that Aha-experiences increased interest in a mathematics course that satisfied a prerequisite to enter a study program for prospective elementary school teachers; most of the participants were women. Our study clearly revealed that there are gender differences in Aha-experiences that may adversely affect girls. Girls have more Aha-experiences together with others than boys do. Importantly, this not only is a general effect but also applies to Aha-experiences that increased interest in STEM fields. As much of STEM education consists of solitary activities, girls do not optimally benefit from STEM instruction in terms of affective consequences.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest with respect to the authorship or the publication of this article.

INFORMED CONSENT

All participants received a written description of the study, explaining the nature of the study and that participation was both anonymous and voluntary. See supplemental data.

DATA AVAILABILITY STATEMENT

The code (written in the R statistical language) used to analyze the relevant data is provided on the Open Science Framework website. 10.17605/OSF.IO/7HZ4P. All materials needed to reproduce the analyses are available at this link: https://doi.org/10.17605/OSF.IO/7HZ4P.

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