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Beyond numbers: the role of mathematics self-concept and spatial anxiety in shaping mental rotation performance and STEM preferences in primary education

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Introduction: Factors such as low self-concept and anxiety have been shown to negatively impact mathematical achievement and spatial skills, as well as enjoyment of math-related subjects. Understanding these factors is crucial for promoting STEM interest and performance, particularly among primary school students.

Methods: This cross-sectional study examines the influence of gender, childhood development stage, maths self-concept, spatial anxiety, perceived difficulty, mental rotation performance, and STEM preferences in a sample of 144 primary school students (mean age $M = 8.47$), comprising 70 girls and 74 boys. Data were collected through four questionnaires and a computerized Mental Rotation Task (MRT).

Results: Girls and tweens (9-to-11-year-olds) exhibit lower maths self-concept, impacting their preference for maths as a STEM subject. Girls also demonstrate higher spatial anxiety and perceived difficulty of the MRT compared to boys. Maths self-concept is significantly associated with spatial anxiety and perceived difficulty, while gender is not. Maths self-concept shows marginal effects on students' accuracy on the MRT, with evidence of a mediating effect of spatial anxiety.

Discussion: These findings underscore the importance of maths self-concept in shaping STEM preferences, particularly among girls and tweens. Additionally, maths self-concept serves as a mitigating factor for spatial anxiety and perceived difficulty in spatial tasks among primary school children. The study also suggests that spatial anxiety may contribute to gender disparities in mathematics and STEM-related domains. Further research is needed to explore interventions targeting maths self-concept and spatial anxiety to promote equitable STEM engagement amongst primary school students.

KEYWORDS

mathematics self-concept, spatial anxiety, STEM subject preferences, stage of childhood development, mental rotation performance, primary education

1 Introduction

> "I must tell you what my opinion of my own mind and powers is exactly … I believe myself to possess a most singular combination of qualities exactly fitted to make me pre-eminently a discoverer of the hidden realities of nature."
>
> Ada Noel King, *The Bride of Science* (Woolley, 2000).

Augusta Ada King Noel, Countess of Lovelace, was a British pioneer in the fields of mathematics and science. She was born in London in 1815, into an era in which fundamental rights for women had not yet been established. Ada, who was also the daughter of the renowned poet Lord Byron, often found herself overshadowed by her father's reputation for literary greatness and notoriety (Chiaverini, 2017). However, with her mother's encouragement, Ada pursued a keen interest in mathematics and computation carving her niche in the field and achieving greatness in her own right. Throughout her short life, Ada, who referred to herself as the "Enchantress of Numbers," demonstrated a strong and undeterred self-belief in her intellectual ability as the opening quote illustrates.

The focus of this cross-sectional study is therefore to examine the role of self-concept, specifically maths self-concept, and its association with preference for STEM (Science, Technology, Engineering and Mathematics) subjects and spatial ability in a sample of primary school children at two stages of childhood development. Furthermore, the association between maths self-concept, spatial anxiety, the perceived difficulty of the spatial task and their role in spatial ability are investigated.

1.1 Mathematical skills: nature or nurture?

While it might come last in the acronym "STEM," maths is the foundation of science, technology, and engineering. Educational research has frequently focused on STEM in the context of science with less focus on maths in classroom activities (Maass et al., 2019; Larsen et al., 2022). However, maths alongside its models serves as the language of science and the means through which scientific concepts are interpreted and communicated (Just and Siller, 2022). Traditionally, maths skills were thought to be fixed and innate: Recent evidence reveals distinct individual differences in the brains and genes of individuals with a propensity towards maths (Chen et al., 2017; Skeide et al., 2020). From a biopsychosocial perspective, however, the role of the environment, attitudes and even emotions experienced around engagement with the subject also play an important role in the development of mathematical ability (Petrill et al., 2009). Contrary to the notion of fixed abilities, research supports the idea that maths skills, even in low-performing school children, are malleable (Lopez-Pedersen et al., 2023). Moreover, findings demonstrate that experts in the field are characterized not by giftedness alone, but by extended and intense training which leads to enhancement of numerical cognition (Sella and Cohen Kadosh, 2018). That said, it is also essential to understand and appreciate how attitudes and emotions impact maths learning and achievement. They must also be taken into account in order improve outcomes in this field for all children (Dowker et al., 2016).

1.2 Maths self-concept and its impact on maths achievement

There is evidence that humans are born sensitive to numeracy (Berger et al., 2006) and that in fact, attitudes and perceptions as well as classroom experience shape children's beliefs about their mathematical ability (Attard, 2013). For many, an aversion towards maths is attributed to negative experiences during their school years leading to decreased engagement with the subject (Boaler, 2015; Hawes et al., 2022). Maths frequently serves as that academic domain in which children encounter significant challenges, characterized by profound setbacks, a circumstance further compounded by the responses of educators and attitudes adopted by parents (Rossnan, 2006; Boaler, 2015; Davadas and Lay, 2017). These experiences shape what is referred to as maths self-concept, or how children think about themselves in relation to maths, which in turn impacts their engagement with and achievement in the subject (Cvencek et al., 2020). Maths self-concept is an important factor accounting for differences in school children's mathematical achievement with the socialization process having a significant effect on this (Manger and Eikeland, 1998; Eccles, 2009; Else-Quest et al., 2010).

In a longitudinal study conducted over 6 years in Germany, Marsh et al. (2018) found that maths self-concept was predictive of secondary school students' maths scores and grades (Marsh et al., 2018). A study conducted over 9 years in Australia found maths self-concept to be a significant predictor of post-school preference for STEM studies (Parker et al., 2014). The Programme for International Student Assessment (PISA) conducted a large-scale, longitudinal study across 35 member countries of the Organisation for Economic Co-operation and Development (OECD) and 31 partner countries and economies whose finding show that students who have low maths self-concept perform worse than students who are more confident in their maths ability (OECD, 2013).

The Reciprocal Effects Model (REM) posits a mutually reinforcing relationship between self-concept and academic achievement over time (Marsh, 1990; Marsh and Craven, 2006). According to this theoretical framework, proficiency in mathematics fosters a positive self-concept in students, which, in turn, contributes to enhanced academic performance (Sewasew et al., 2018). Encouraging active involvement and participation in mathematics is therefore anticipated to yield positive effects on students' self-concept. For example, studies conducted in the United States and China with pre- and primary school children found a reciprocal relationship between maths self-concept, interest, and achievement (Fisher et al., 2012; Cai et al., 2018).

All of these findings emphasize the critical role of maths self-concept in shaping educational trajectories.

1.3 Gender differences in maths self-concept and the impact on STEM as a career choice

Unlike the abundance of confidence demonstrated by Countess Lovelace with regards to her intellectual and scientific prowess, many of todays' girls and women do not appear so self-assured when it comes to their mathematical ability. Although women now excel in the STEM field, poor maths self-concept may explain why they continue to be under-represented in university programs which are the most mathematically intensive, such as engineering, computer science and the physical sciences (Ceci et al., 2014). Frequently, students with low maths self-concept lack faith in their maths ability which in turn can have a major impact on their preference for STEM careers (Goldman and Penner, 2016).

There is evidence from research conducted with adults that despite similar levels of maths achievement, women demonstrate lower maths self-concept than men (Sax et al., 2015). Initially, girls display similar or even superior maths achievement compared to boys, but a shift occurs as they advance through the school system, especially in the upper levels of the skills distribution (Fryer and Levitt, 2010; Cimpian et al., 2016). In a longitudinal study conducted in the USA, spanning children from kindergarten through primary school, initially both girls and boys demonstrated comparable proficiency in mathematics. However, by third grade, significant gender differences were found in both maths confidence and achievement particularly at the top of the attainment distribution (Fryer and Levitt, 2010). The gender gap observed at the upper tiers of maths achievement is especially disconcerting, given that this subgroup often generates future STEM professionals (Cimpian et al., 2016).

Moreover, international assessments reveal persistent gender gaps in maths self-concept, with girls expressing less confidence in mastering challenging mathematical concepts compared to boys (OECD, 2013). Notably, countries such as Switzerland, Denmark, and Germany revealed particularly pronounced gender disparities in maths self-concept (OECD, 2013).

1.4 STEM stereotypes influence tweens' and girls' preference for maths and related careers

Stereotype threat (ST) describes situations in which individuals perceive themselves to be at risk of conforming to negative stereotypes about their ingroup (Aronson et al., 2014). ST is a factor which has been found to negatively influence attractivity of STEM subjects such as maths, physics, computer science and associated professions for young people (Garriott et al., 2017). A stereotype frequently associated with individuals who excel in such fields is that of the "nerd" or "geek," the characteristics of whom include disproportionate intelligence, awkwardness in social circumstances, unattractive appearance and romantically unsuccessful (Starr and Leaper, 2019). Findings confirm that the "STEM-nerd" or enthusiast stereotype was endorsed among secondary school students in the USA (Garriott et al., 2017), as well as middle-school students in Germany (Kessels, 2005). This attitude is problematic because it may undermine some young people's interest in the field due to the threat of confirming a negative stereotype (Starr, 2018).

A period in which young people begin to explore their identities and in which self-concept and stereotypes become more salient is the pre-adolescent or tween stage of childhood development (Starr, 2018). Tweens are young people around the age of 9 to 12 years, a period directly preceding adolescence and following middle childhood (McArthur et al., 2021). Tweens are on the cusp of a significant educational transition between primary and secondary school. In many countries, they are required to make important choices regarding subjects they will focus on in secondary education. Moreover, tweens are beginning to develop an awareness of gender identity as well as societal norms, roles, and hierarchies (McArthur et al., 2021). They are more cognizant of negative cultural stereotypes such as those surrounding STEM professions and this can affect their preference for and engagement with associated subjects such as maths (McGuire et al., 2022). At this stage, however, awareness of stereotypes is new and not yet established making it ideal for introducing interventions such as peer engagement programs to foster positive socialization towards STEM (Space Science Institute, 2023).

The STEM-enthusiast stereotype has also been found to negatively influence girl's identification with related career fields and associated professions (Starr, 2018). Although male STEM professionals such as computer scientists, are often unfairly stereotyped as socially awkward outsiders who neglect their appearance, there remains a societal expectation for women to be attractive, sociable, and skilled in romantic pursuits (Cheryan et al., 2013). Mentoring programs for young women in the tween and adolescent stage, such as the Ada Lovelace Project based in Germany (Ada Lovelace-Projekt, 2023), employ female role models to exercise a positive influence on STEM's appeal for these groups (Quaiser-Pohl, 2012; Quaiser-Pohl and Endepohls-Ulpe, 2012; Quaiser-Pohl et al., 2012, 2014a).

1.5 Mental rotation and its relationship with mathematics skills

Mental Rotation (MR), the ability to rotate mental representations of two- and three-dimensional objects, is a spatial skill extensively studied in psychology and education (Quaiser-Pohl et al., 2014b; Neuburger et al., 2015; Buckley et al., 2018). Studies have shown that boys perform significantly better on mental rotation tasks than girls, making it an important topic to research (Linn and Petersen, 1985; Voyer et al., 1995).

The relationship between spatial and mathematical ability has been widely investigated and is well-established (Hawes et al., 2015; Mix, 2019; Lowrie et al., 2020). The findings from a recent meta-analysis conducted by Hawes et al. (2022) align with previous research and theoretical assertions, indicating that engaging in spatial training serves as an effective method for improving both comprehension and performance in mathematics (Hawes et al., 2022).

As with mathematical and other spatial skills, mental rotation (MR) ability can be improved through practice and training (Uttal et al., 2013). This training can have a spillover effect on maths performance, also enhancing these skills. Furthermore, mental rotation has been linked to higher-level mathematical skills and is a significant predictor of mathematical ability in pre-and primary school children (Moe, 2018; Rahe and Quaiser-Pohl, 2019).

Mental rotation performance has also been identified as a significant predictor of academic success and career choice in STEM fields (Moe, 2018; Moe et al., 2018). However, gender disparities in mental rotation performance can be exacerbated by factors such as stereotype threat and spatial anxiety, particularly among girls. Addressing these barriers is crucial for promoting equitable participation in STEM fields and fostering a diverse talent pool.

1.6 Stereotype threat, child spatial anxiety, and mental-rotation performance

Gender-stereotyped beliefs influence boys' and girls' preferences and behaviors early in life, including their play and choice of toys (Ruthsatz et al., 2019). Boys' preference for construction toys and other games that are related to object manipulation in space may lead to gender differences as a result of more practice and confidence acquired during play (Moe et al., 2018). An increased familiarity with spatially related objects and activities appears to be advantageous to male participants on a mental rotation task consisting of items with frequently used cubical figures (Ruthsatz et al., 2014). Female performance on spatial tasks may also be compromised by the fear of confirming existing gender negative stereotypes about spatial abilities (McGlone and Aronson, 2006; Campbell and Collaer, 2009). Research on spatial ability consistently finds the most significant and dependable cognitive gender gaps on mental rotation tests, where men typically outperform women by around one standard deviation (Wraga et al., 2006). Noteworthy, however, is the effect of emotions such as anxiety on mental rotation performance and cognitive processes in general. For instance, pronounced gender differences in spatial anxiety and spatial self-efficacy have been found to mediate gender differences in mental rotation performance, particularly on more demanding tasks (Arrighi and Hausmann, 2022).

Child Spatial Anxiety (CSA) or feelings of nervousness at the prospect of engaging in spatial tasks, is known to affect mental rotation performance in young children (Ramirez et al., 2012). Worry associated with maths and complex cognitive tasks such as mental manipulation can limit executive resources such as working memory (WM) and can lead to performance deficits in these domains (Engle, 2002). WM is a short-term memory store which actively holds information in the mind needed to complete complex tasks such as mental rotation or numerical operations (Alloway and Passolunghi, 2011). An interaction between working memory and spatial anxiety appears to contribute to gender differences in mental rotation performance. Girls are further disadvantaged by the added effects of stereotype threat which usurps working memory capacity needed to perform well on spatial tasks (Schmader et al., 2008; Schmader, 2010; Ramirez et al., 2012). Consequently, girls' performance may be impacted by the fluctuating spatial anxiety during related tasks.

In the tween stage of development, spatial ability undergoes significant growth and development, surpassing the levels observed in middle childhood (Hodgkiss et al., 2021). The development of mental rotation in pre-adolescence is associated with changes in the brain, particularly in regions related to spatial processing and cognitive control. The parietal cortex, which plays a crucial role in spatial cognition, undergoes maturation during this period. Structural changes, such as increased grey matter density and synaptic pruning, contribute to improved spatial abilities (Modroño et al., 2018). This developmental period therefore presents a prime opportunity for the expansion and enhancement of cognitive abilities, which are essential for excelling in STEM subjects during secondary education. Subjects such as advanced mathematics, computer science, physics, and chemistry benefit greatly from development in spatial cognition. This developmental juncture sets the stage for not only cognitive enhancement but also potential challenges such as the emergence of negative attitudes and emotions related to spatial tasks. Hence, it is important that in girls and pre-adolescents, spatial skills are actively nurtured and interest in mathematics sustained.

1.7 Perceived difficulty of a mental-rotation task and its relationship to affect, self-concept and performance

Transitioning from the intricate dynamics of spatial anxiety, stereotype and gender influences on mental rotation performance, the focus shifts to the perceived difficulty of a mental rotation task. This can also have consequences for students' affect, self-concept, and cognitive performance (Nuutila et al., 2021). High perceived difficulty of a task can lead to increased frustration and negative emotional reaction which in turn impairs performance (Brunstein and Schmitt, 2010). However, self-efficacy and interest in the subject matter can buffer these effects leading to increased time and effort spent attempting to solve associated tasks (van Steensel et al., 2019).

The difficulty of a mental rotation task depends on its characteristics, for example, on the rotational axis, stimulus complexity, dimensionality and familiarity of stimuli (Nolte et al., 2022). These factors can influence both the number of items answered correctly but also the time spent attempting to solve them. Response time as well as accuracy is often measured in studies of mental rotation as longer processing time can lead to increased accuracy on the task (Liesefeld et al., 2014). Indeed, the removal of time limitations imposed on mental rotation tasks has been found to influence gender differences in performance due to diversity in processing strategies (Voyer, 2011).

Women are known to approach mental rotation tasks more cautiously and analytically, a processing style known to be more time-consuming (Peters, 2005). A study of the eye-movement patterns of primary school students found that girls tend to analyse parts of the stimulus whereas boys approach these more holistically (Taragin et al., 2019). A holistic strategy involves a comprehensive approach, where all parts of a test stimulus are viewed as a whole. An analytic strategy involves breaking down the problem into individual components and finding solutions for each component separately (Li and O'Boyle, 2013). Therefore, if children perceive a mental rotation task as more difficult, this may impair their performance. Raised negative affect such as anxiety and higher frustration levels interfere with response time. Test takers may take too long to solve items, which can compromise their performance on time-limited tests. Alternatively, they might not spend enough time on and put sufficient effort into solving items which may lead to guessing the solutions (Liesefeld et al., 2014; Neuburger et al., 2015).

1.8 Rationale and aim of the current study

In summary, this study investigates the effect of children's maths self-concept, their spatial task-related anxiety, and their perception of task difficulty on mental rotation performance across two age groups. Moreover, the role of gender, childhood developmental stage, maths self-concept, spatial anxiety, and perceived difficulty in shaping children's preferences for STEM or maths and their performance on spatial tasks is examined. Our study aims to provide insights for improving STEM engagement and reducing gender gaps in STEM fields.

1.8.1 Research questions and hypotheses

Based on our review of the literature, in this study we will examine the following research questions:

Q.1. Are there gender and age differences in children's maths self-concept, spatial anxiety, perceived difficulty of spatial tasks, mental rotation performance and preference for STEM subjects?

Hypothesis 1. *We expect there will be significant gender differences in maths self-concept, spatial anxiety, perceived difficulty, accuracy and response times on the mental rotation task and preference for the STEM subject maths in primary school students. Specifically, girls will have significantly lower maths self-concept, higher spatial anxiety, and higher perceived difficulty than boys. Girls will have lower scores and longer response times on the mental rotation task than boys. Girls are less likely to choose the STEM subject maths than boys.*

Hypothesis 2. *We expect there will be significant age differences in maths self-concept, spatial anxiety, perceived difficulty, accuracy and response times on the mental rotation task and preference for the STEM subject maths in primary school students. Specifically, tweens (9-to-11-year-olds) will have significantly lower maths self-concept, lower spatial anxiety and lower perceived difficulty than students in middle childhood (6-to-8-year-olds). Tweens will have significantly higher scores and shorter response times on the mental rotation task than students in middle childhood. Tweens are less likely to choose the STEM subject maths than students in middle childhood.*

Q.2. Does students' preference for STEM or non-STEM subjects predict maths self-concept?

Hypothesis 3. *We expect students who prefer the STEM subject maths at school will have higher maths self-concept than students who prefer non-STEM subjects.*

Q.3. How does maths self-concept relate to spatial anxiety and perceived difficulty?

Hypothesis 4. *We expect maths self-concept is significantly associated with spatial anxiety and perceived difficulty of the mental rotation task in primary school students. Specifically, as maths self-concept increases. Spatial anxiety decreases. Additionally, as maths self-concept increases, perceived difficulty decreases.*

Q.4. Does maths self-concept predict mental rotation performance? Is this association mediated by spatial anxiety and perceived task difficulty?

Hypothesis 5. *We expect maths self-concept is a significant predictor of accuracy and response time on the mental rotation task and that this association is mediated by spatial anxiety and perceived difficulty.*

2 Materials and methods

2.1 Participants

A total of one-hundred-and-forty-eight students were recruited from primary schools in the state of Rhineland Palatinate in Germany ($N = 148$). All of the students belonged to first, second, third, and fourth-grade classes, respectively, and were enrolled in five primary schools in Rhineland Palatinate, Germany. One-hundred-and-forty-seven students ($N = 147$) took the mental rotation task and completed the questionnaires. Due to a technical error however, one student could not complete the questionnaires during the data collection. As three children were no longer enrolled in primary education, their data were removed from the sample leaving a total of one-hundred-and-forty-four ($N = 144$) whose data were analysed for this study. Seven children included in the sample were tested in the home environment as opposed to the school setting. Upon analysis, however, their responses and performance on the various measures did not significantly differ from that of the rest of the participants.

Included in the sample were 74 students who identified as boys and 70 as girls. The average age of the students was $M = 8.47$ ($SD = 1.12$) years old. The gender variable was dichotomous and contained boys (M) coded 0 and girls (F) coded 1. A variable for the stage of childhood development students was also dichotomous and contained two groups: Group 1 consisting of 72 children aged 6 to 8 years old ($N = 72$) in Middle Childhood, coded 0; Group 2 consisting of 72 children aged 9 to 11 years old ($N = 72$) in the Tween or pre-adolescent stage, coded 1. The age distribution by gender is shown in Table 1 and across two stages of childhood development in the bar chart in Figure 1.

Every student entered their preferred subject at school into the online questionnaire. Preferred subjects were then divided into three categories: A STEM group was created based on preference for Maths as preferred subject and coded 0; A Non-STEM group was based on preference for Art, Music, and languages as preferred subjects, coded 8; An 'Other' group represented students' preference for Physical Education (P.E.) and was coded 9.

Schools from which the data were collected, were situated in areas with diverse socio-economic and cultural populations, in both urban and rural areas.

An *a-priori* G*Power analysis was used to calculate the minimum number of participants needed for the planned statistical analyses with a medium effect size and power of 0.8. The sample size was found to be adequate and the number of participants in each of the groups was balanced, with the exception of the one-way analysis of variance (ANOVA) (Faul et al., 2007). The G*Power protocol is appended to this report (Appendix 1).

2.2 Material and instrumentation

2.2.1 Demographic data

An online questionnaire, created in PsychoPy®, was presented to each participant at the beginning of the experiment before

TABLE 1 Gender (sex) * stage of childhood development crosstabulation count.

		Stage of childhood development		
		Middle childhood	Tweens	Total
Sex	Boys	35	39	74
	Girls	37	33	70
Total		72	72	144

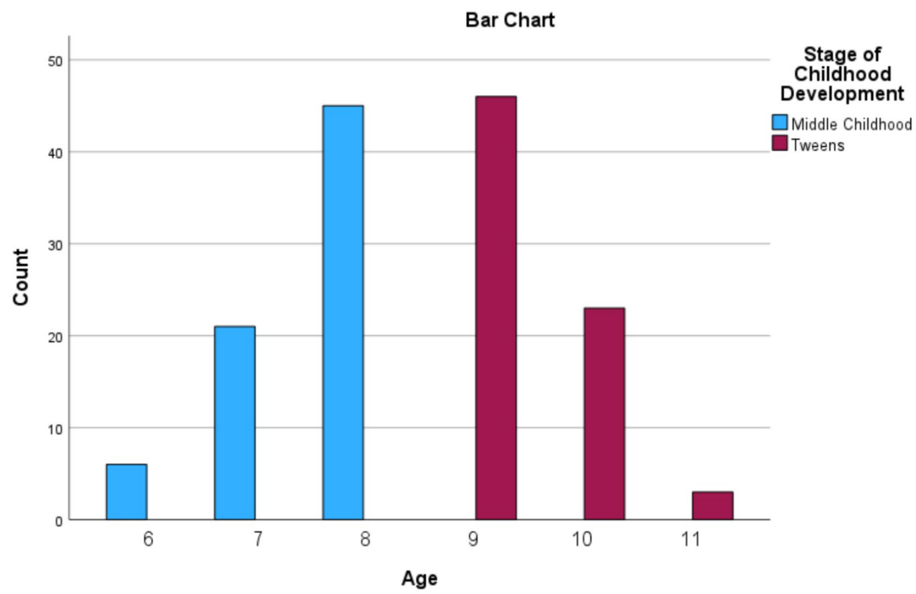

FIGURE 1
Age distribution of students across two stages of childhood development.

undertaking the mental rotation task (MRT) in order to collect data relating to participants' age and gender.

2.2.2 Self-report questionnaires

In order to avoid priming or activation of stereotypes, four self-report questionnaires were presented following the MRT. The purpose of these questionnaires was to assess the students' levels of maths self-concept, spatial anxiety and perceived difficulty of stimuli, all of which were presented to the students in the German language.

2.2.2.1 Preferred subject at school

Students were asked to name their favourite subject and a blank space was provided for them to type this. It was explained that students could pick a preferred subject from all of the subjects at school.

2.2.2.2 Academic self-concept questionnaire in primary school children

Students were asked to complete the Academic Self-Concept in Primary School Children (ASKG) questionnaire (Ehm, 2014). This is a German language self-report measure based on the revised hierarchical self-concept model from Marsh et al. (1988). It allows primary school students to self-assess their mathematical, reading and writing skills on three subscales on a 7-point sliding scale. Each subscale consists of 6 items. The mathematics self-concept subscale was analysed for this study. An example of an item from this subscale is as follows: "I like Maths…" Participants are then asked to choose from a scale of 1 labelled "not at all" to 7 labelled "very much," how much they like or dislike mathematics at school. Researchers explained to students that the higher up the sliding scale they choose, the more they demonstrate enjoyment of mathematics for example. A reliability analysis of the full ASKG conducted on the data from our sample yielded a Cronbach's Alpha of $\alpha = 0.90$. Cronbach's Alpha for the mathematics self-concept subscale was also $\alpha = 0.90$.

2.2.2.3 Child spatial anxiety

The Child Spatial Anxiety Questionnaire (CSAQ) (Ramirez et al., 2012) consists of 8 items in which students are asked to rate how anxiety-provoking they find various spatial tasks. All tasks described in the questionnaire require spatial ability and skills. Researchers explained to students in advance that this questionnaire was about feelings and gave an example of how children might experience nervousness and anxiety, i.e., heart racing, rapid breathing, hands trembling. An example of one item from the CSAQ is as follows: "How would you feel if your teacher asked you to measure something with a ruler?" Participants are then asked to rate on a scale of 1 to 5, 1 being "not nervous at all, calm," 3 being "neither calm nor nervous" and 5 being "very, very nervous," how anxious they would feel about completing this task. A reliability analysis of the CSAQ conducted on the data from our sample yielded a Cronbach's Alpha of $\alpha = 0.65$. Despite reliability of the CSAQ being marginally below the acceptable range of $\alpha = 0.70$, it was nevertheless chosen for its practicality and suitability in the school setting.

2.2.2.4 Perceived difficulty of stimuli

The Perceived Difficulty of Stimuli (PDQ) scale, adapted from the Stereotyped Nature of Stimuli questionnaire (Neuburger et al., 2015), uses emojis on a sliding 5-point scale to assess perceived difficulty of items in the MRT. Participants are presented with 6 stimuli included in items from the MRT and are asked to rate the difficulty of these items on the emoji scale. The first point on the scale (1) represents easy or happy face emoji, and the fifth (5) difficult or sad face emoji. The third point (3) represents neither easy nor difficult or neutral face emoji. A reliability analysis of the PDQ conducted on the data from our sample yielded a Cronbach's Alpha of $\alpha = 0.72$.

2.2.3 Mental rotation task

A computerized mental rotation task (MRT; Vandenberg and Kuse 1978) was programmed in PsychoPy® software and installed on

Microsoft Pro 8 Surface tablets, each with a keyboard and a mouse. The task was programmed to record both accuracy and response time in seconds. Items included stimuli for younger children, i.e., animals, letters and cubes rotated in picture-plane (Quaiser-Pohl, 2003) as well as abstract and concrete stimuli rotated in picture-plane and in-depth. Abstract items consisted of stimuli such as cubes, pellets (Ruthsatz et al., 2014) and polyhedral figures (Ruthsatz et al., forthcoming). Concrete items consisted of male and female-stereotyped stimuli (Ruthsatz et al., 2015) and gender-neutral stimuli (Ruthsatz et al., forthcoming). Examples of some of the items used in the task are shown in Figure 2.

The task was divided into two parts, each with a time limit: Part one (MRT 1) consisted of 6 abstract and 10 concrete items which were rotated in picture-plane only. It was limited to 5 min. Part two (MRT 2) contained 6 abstract and 6 concrete items rotated in-depth and was limited to 8 min (see sample items in Appendix 5). MRT 2 was considered more difficult due to the rotational axes of the stimuli (Neuburger Ruthsatz et al., 2012). Items were presented randomly in each part of the task with one target stimulus on the left and four comparison stimuli on the right. Participants were instructed to identify two out of four stimuli on the right which, although rotated, were identical to that on the left. A reliability analysis of the full MRT conducted on the data from our sample yielded a Cronbach's Alpha of $\alpha = 0.86$. A Cronbach's Alpha analysis on MRT 1 yielded $\alpha = 0.71$ and on MRT 2 $\alpha = 0.86$.

2.3 Procedure

Approval for the pilot study was provided by the Ethics Committee of the University of Koblenz and the state authorities in Rhineland Palatine overseeing schools. Informed consent was sought and provided by parents and guardians of all students involved in the study. The class teacher and the principal also gave permission for the study to be conducted in the school. Students provided verbal assent prior to commencing the experiment and were informed that they could withdraw their participation at any stage of the experiment with no consequences. The students were tested by two female researchers in a separate classroom with access to their teacher, if required. The room had adequate lighting and individual seating arrangements. The researchers explained the MRT to the students by rotating objects such as a pair of scissors, a toy and a wooden object. They demonstrated that rotating the object does not change its features. Students were then asked to imagine the object in their mind, then try to rotate it mentally. The purpose of the study and the significance of mental rotation in everyday life and for school work was also explained. The researchers also checked in advance that students were familiar and comfortable with the use of a keyboard and a mouse. Furthermore, any student who required eye glasses was reminded to wear these while viewing the tablet screen (Jansen et al., 2013).

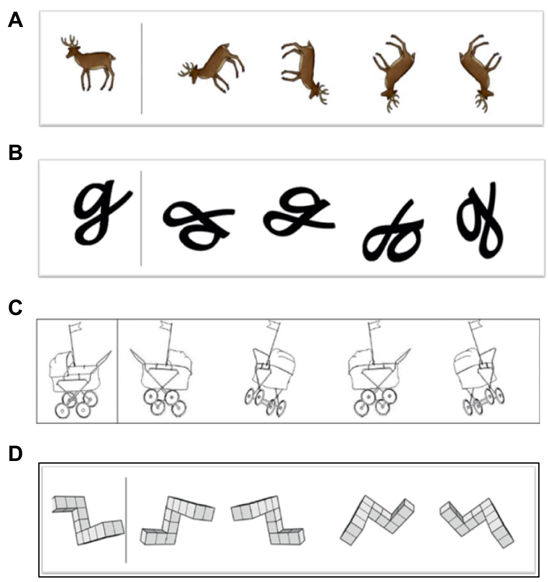

FIGURE 2
Examples of MRT items used with concrete objects: **(A)** animal stimulus and **(B)** letter stimulus (Quaiser-Pohl, 2003); **(C)** female-stereotyped stimulus "Pram" (Ruthsatz et al., 2015; Rahe and Quaiser-Pohl, 2019) and with an abstract object **(D)** "Cube" figure (Ruthsatz et al., 2014).

2.4 Data analysis

Quantitative data analyses were conducted using SPSS® 29 software. We employed a range of statistical tests to explore various aspects of our research questions.

Independent samples *t*-tests were conducted to investigate potential age and gender differences in the following variables: Maths self-concept (MSC); Child spatial anxiety (CSA); Perceived difficulty of stimuli (PD) and Accuracy and Response Times on the mental rotation task (MRT). Data for all dependent variables were examined for normality, outliers were identified and removed, and missing data were imputed with the median for each variable. The independent variables were found to be normally distributed.

A Chi-Squared test of association was used to check which groups were less likely to choose the preferred STEM subject, girls or boys and tweens or children in middle childhood. The assumptions for application of this test were met, that is, the sample size was large enough, the nominal variables were categorical, participants were randomly and independently sampled, the data consisted of raw frequencies and the expected frequency (Fe) within each cell was greater than 1 and no more than 20% of the cells had less than 5.

One-way ANOVA was used to assess differences in maths self-concept based on preferred school subjects was conducted. Assumptions of normal distribution of data were met but homogeneity of variance was not due to unequal sizes of STEM, Non-STEM, and Other (physical education) subject groups. Therefore, the ANOVA was run on a subsample of $N = 97$ with equal numbers of participants in each group.

A two-way multivariate analysis of variance (MANOVA) was used to assess the interaction effects of gender and stage of childhood development on child spatial anxiety, perceived difficulty, and mental rotation performance (accuracy and response time in the MRT). Assumptions for the MANOVA, such as homogeneity of variances (verified with Levene's test) and the absence of multivariate outliers (confirmed with Box's test), were satisfied (Tabachnick and Fidell, 2013).

Multiple Regression was performed to test the relationship between gender, age, maths self-concept, spatial anxiety, and perceived difficulty of the MRT and the relationship of maths-self-concept to accuracy and response time on the task. A mediation analysis was performed utilizing the PROCESS procedure in SPSS Version 4.2 (Hayes, 2022) to test whether the effects of maths self-concept on accuracy and response time were mediated by spatial anxiety and perceived difficulty of the task. Assumptions for regression and mediation analyses were validated, including the continuous nature of the criterion variable, absence of substantial outliers, normal distribution of residual scores, and the absence of multicollinearity (tolerance values below 0.2). Furthermore, for mediation analysis, independence of observations and absence of measurement error were insured. For moderator analyses, homoscedasticity was checked in PROCESS and was found not to be violated (MacKinnon, 2008).

3 Results

3.1 Gender differences in maths self-concept, spatial anxiety, perceived difficulty, mental rotation performance and preference for the STEM subject maths in primary school children

> *H.1. Girls will have significantly lower maths self-concept, higher spatial anxiety, and higher perceived difficulty than boys. Girls will have lower scores and longer response times on the mental rotation task than boys. Girls are less likely to choose the STEM subject maths than boys.*

An independent samples *t*-test with the dependent variables 'Maths Self-Concept, Child Spatial Anxiety and Perceived Difficulty' and independent variable 'Sex' found that there was a statistically significant difference in maths self-concept of boys ($M = 28.85$, $SD = 7.06$) and girls ($M = 25.57$, $SD = 7.67$) ($t(141) = 2.67$, $p = 0.009$, *CI* (95%) 0.850 → 5.72) with a small to medium effect size ($d = 0.45$). Therefore, girls showed significantly lower maths self-concept than boys. There was a statistically significant difference in spatial anxiety of boys ($M = 16.07$, $SD = 4.94$) and girls ($M = 18.20$, $SD = 5.05$) ($t(141) = -2.52$, $p = 0.013$, *CI* (95%) −3.80 → −0.46) with a small to medium effect size ($d = -0.42$). There was a statistically significant difference in perceived difficulty of boys ($M = 11.71$, $SD = 3.41$) and girls ($M = 13.10$, $SD = 3.10$) ($t(141) = -2.35$, $p = 0.014$, *CI* (95%) −2.44 → −0.28) with a small to medium effect size ($d = -0.42$). Therefore, girls showed significantly higher spatial anxiety and perceived difficulty than boys. There was no statistically significant difference between girls and boys in accuracy and response times on the mental rotation task (Table 2).

A Chi-Square test for association with the criterion variable 'Subject_Preference' and predictor variable 'Sex' revealed a statistically significant relationship between students' preference for the STEM subject and gender ($X2$ (1, $N = 141$) = 7.58, $p = 0.023$). The association between preference for the STEM subject and gender was moderately positive. Specifically, girls were less likely than boys to choose STEM subject maths (Figure 3).

3.2 Age differences in maths self-concept, spatial anxiety, perceived difficulty, mental rotation performance and preference for the STEM subject maths in primary school children

> *H.2. Tweens (9-to-11-year-olds) will have significantly lower maths self-concept, lower spatial anxiety and lower perceived difficulty than students in middle childhood (6-to-8-year-olds). Tweens will have significantly higher scores and shorter response times on the mental rotation task than students in middle childhood. Tweens are less likely to choose the STEM subject maths than students in middle childhood.*

An independent samples *t*-test with the dependent variable 'Maths Self-Concept, Child Spatial Anxiety and Perceived Difficulty' and independent variable 'Stage of Childhood Development' found that there was a statistically significant difference in maths self-concept of the tween group ($M = 25.79$, $SD = 7.57$) and the middle childhood group ($M = 28.67$, $SD = 7.24$) ($t(141) = 2.32$, $p = 0.022$, *CI* (95%) 0.43 → 5.33) with a small to medium effect size ($d = 0.39$). Therefore, students in the tween group demonstrated significantly lower maths self-concept than students in the middle childhood group. There was no difference in spatial anxiety and perceived difficulty between the tween group and the middle childhood group. The was a statistically significant difference between the tween group ($M = 0.35$, $SD = 0.20$) and the middle childhood group ($M = 0.27$, $SD = 1.67$) ($t(141) = -2.66$, $p = 0.009$, *CI* (95%) −0.141 → −0.021) with a small to medium effect size ($d = -0.45$) in accuracy on the mental

TABLE 2 Independent samples test: gender differences in maths self-concept (MSC), spatial anxiety (CSA) and perceived difficulty of the mental rotation task (PD).

	Levene's test for equality of variances		*t*-test for equality of means				
	F	Sig.	*t*	df	Significance	95% Confidence interval of the difference	
					Two-sided *p*	Lower	Upper
MSC	1.997	0.162	2.667	141	0.009	0.85045	5.72108
CSA	0.002	0.969	−2.522	141	0.013	−3.78837	−0.45922
PD	0.223	0.638	−2.504	141	0.014	−2.43947	−0.28575

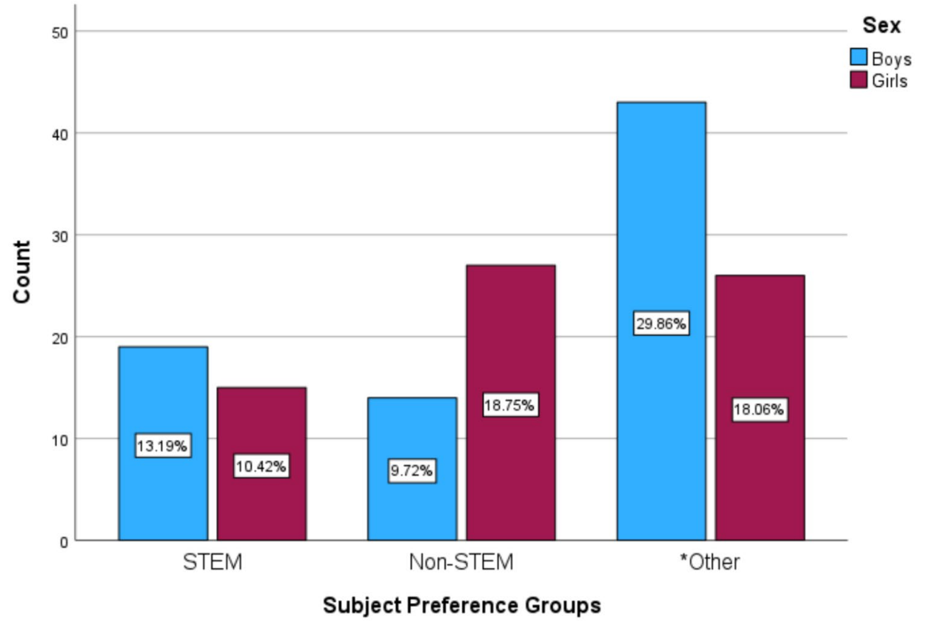

FIGURE 3
Percentage of STEM or non-STEM as the preferred subject at school by gender (sex). *'Other' represents physical education (P.E.) as the preferred subject.

TABLE 3 Independent samples test: age differences in maths self-concept (MSC), and accuracy on the mental rotation task.

	Levene's test for equality of variances		*t*-test for equality of means				
	F	Sig.	*t*	df	Significance	95% confidence interval of the difference	
					Two-sided *p*	Lower	Upper
MSC	0.862	0.355	2.234	141	0.022	0.42953	5.32764
Accuracy	5.115	0.025	−2.657	136.725	0.009	−0.14144	−0.02073

rotation test but there was no difference in response times. Therefore, tweens scored higher than students in middle childhood on the mental rotation task (Table 3).

A Chi-Square test for association with the criterion variable 'Subject_Preference' and predictor variable 'Stage of Childhood Development' revealed a statistically significant relationship between students' preference for the STEM subject and developmental stage ($X2$ (1, $N = 142) = 15.66$, $p < 0.001$). The association between preference for the STEM subject and developmental stage was moderately positive. Specifically, tweens were less likely than students in middle childhood to choose the STEM subject maths (Figure 4).

A two-way MANOVA was used to test the interaction effects of Gender and Stage of Childhood Development on Spatial Anxiety, Perceived Difficulty, Accuracy and Response Time on the Mental Rotation Task (MRT). Following a Bonferroni adjustment at 0.025, there were no significant interaction effects of gender and age on perceived difficulty or on accuracy and response time in the MRT. There were, however, significant interaction effects of gender and age on spatial anxiety (F (1, 143) = 5.81, $p = 0.017$) with a small to medium effect size ($\eta p^2 = 0.04$). Pairwise comparisons highlight there were no differences in spatial anxiety between girls and boys in the tween group but spatial anxiety in girls in the middle childhood group was significantly higher than in boys in the same group (*Mean Difference* = 3.33) (Figure 5).

3.3 Students' preference for STEM or non-STEM subjects predicts maths self-concept

> *H.3. Students who prefer the STEM subject maths at school will have higher maths self-concept than students who prefer non-STEM subjects.*

A one-way analysis of variance with dependent variable 'Maths Self-Concept' and Between Subjects Factor 'STEM_Subject' was conducted on a subsample of the data ($N = 97$) in order to ensure group homogeneity in the STEM, Non-STEM (Art, Music, Languages) and Other (Physical Education or P.E.) groups. All groups had thirty-two participants ($N = 32$) with forty-nine boys

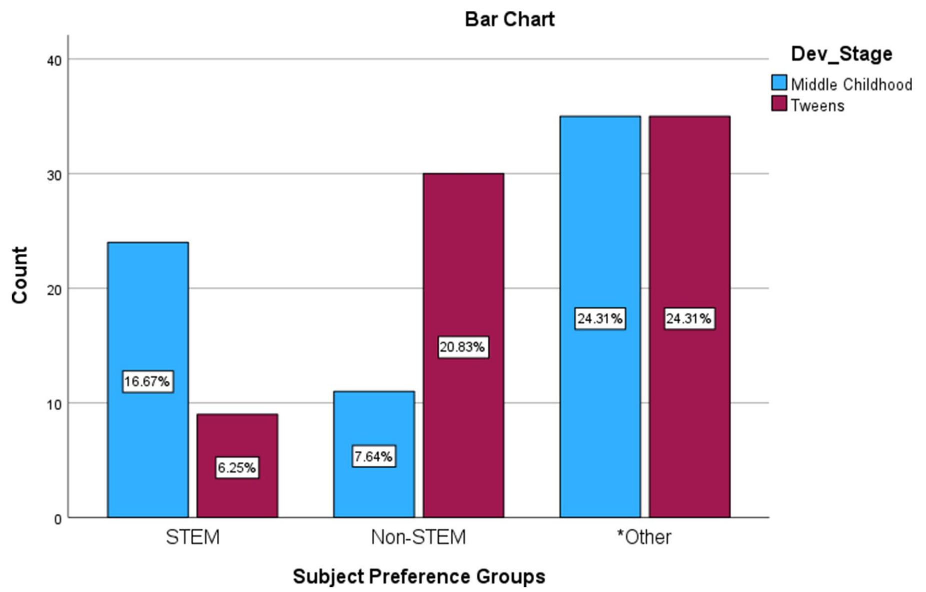

FIGURE 4
Percentage of STEM or non-STEM as the preferred subject at school by stage of childhood development (Dev_Stage). *'Other' represents physical education (P.E.) as the preferred subject.

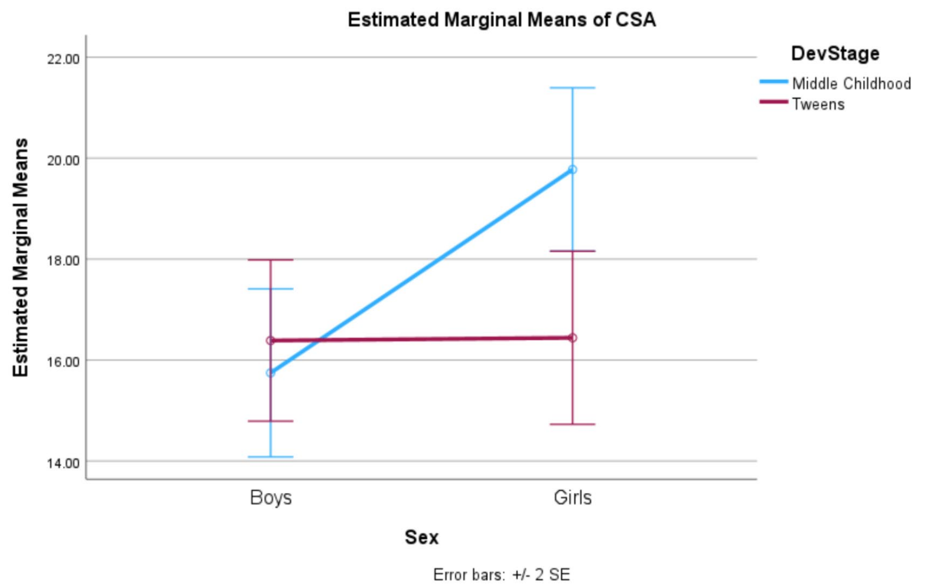

FIGURE 5
Interaction effects of gender and developmental stage on spatial anxiety in primary school students.

($N = 49$) and fifty-one girls ($N = 51$). Fifty-two students were in the Middle Childhood stage of development ($N = 52$) and there were forty-eight tweens ($N = 48$). The ANOVA was run to examine the relationship between students' preferred subject at school and their levels of maths self-concept. The results indicated a statistically significant difference in maths self-concept on this subsample among the three preferred subject groups (F (2, 95) = 10.70, $p < 0.001$) with a large effect size ($\eta^2 = 0.19$). This large effect size indicates that 19%, so a substantial amount of the variance, in maths self-concept can be explained by students' subject preferences. Subsequent Tukey HSD *post hoc* analyses were conducted to further explore these differences and this revealed the following significant differences in maths self-concept:

In the STEM subject preference group, maths self-concept was significantly higher than in the non-STEM group (*Mean difference* = 8.22, $p < 0.001$, 95% *CI* [3.92, 12.53]).

In the STEM subject preference group, maths self-concept was not significantly higher than in the Other (P.E.) group (*Mean difference* = 2.78, $p = 0.277$, 95% *CI* [−1.52, 7.10]).

In the Other (P.E.) preference group, maths self-concept was significantly higher than in the non-STEM group (*Mean difference* = 5.44, $p = 0.009$, 95% *CI* [1.13, 9.75]).

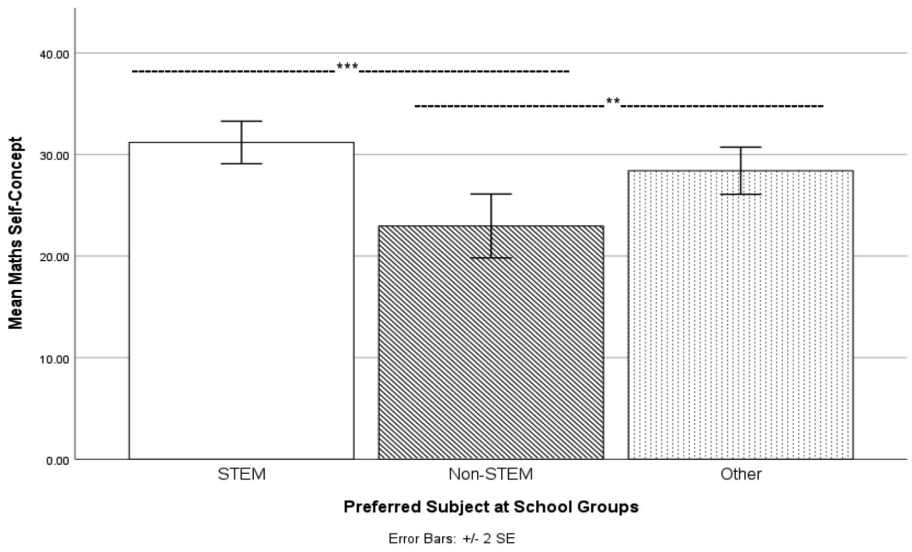

FIGURE 6
Differences in maths self-concept by preference for STEM, non-STEM and other subjects at school. STEM represents maths, non-STEM represents art, music & languages and other represents physical education (P.E.). (*** demonstrates statistical significance at $p < 0.001$; ** demonstrates statistical significance at $p < 0.05$).

In summary, students who indicated a preference for the STEM subject Maths or for P.E. demonstrated significantly higher levels of maths self-concept compared to those who preferred a non-STEM subject (Figure 6).

3.4 Maths self-concept is significantly associated with spatial anxiety and perceived difficulty of the mental rotation task

> *H.4. Maths self-concept is significantly associated with spatial anxiety and perceived difficulty of the mental rotation task in primary school students. Specifically, as maths self-concept increases, spatial anxiety decreases. Additionally, as maths self-concept increases, perceived difficulty decreases.*

Multiple regression with criterion variable 'Child Spatial Anxiety' and predictor variables 'Sex', 'Age' and 'Maths Self-Concept' was used to analyse the association of maths self-concept with spatial anxiety in primary school children. The results of the regression indicated that three predictors explained 18% of the variance in Child Spatial Anxiety ($R^2adj = 0.183$, F (3, 142) = 11.60, $p < 0.001$). Age ($\beta = -0.25$, $p = 0.003$, 95% $CI = -1.83 \rightarrow -0.45$) and Maths Self-Concept ($\beta = -0.38$, $p = <$ 0.001, 95% $CI = -0.36 \rightarrow -0.15$) are significantly associated with spatial anxiety in primary school children but gender is not ($\beta = 0.11$, $p = 0.174$, 95% $CI = -0.49 \rightarrow 2.68$) The negative beta coefficient for age and maths self-concept suggests that, as students' age and maths self-concept increase, spatial anxiety tends to decrease (Table 4).

Multiple regression with criterion variable 'Perceived Difficulty' and predictor variables 'Sex', 'Age' and 'Maths Self-Concept' was used to analyse the association of maths self-concept with perceived difficulty of the mental rotation task in primary school children. The results of the regression indicated that three predictors explained 7% of the variance in Perceived Difficulty ($R^2adj = 0.073$, F (3, 142) = 4.72, $p = 0.004$). Maths Self-Concept ($\beta = -0.23$, $p = 0.007$, 95% $CI = -0.18 \rightarrow -0.03$) is significantly associated with Perceived Difficulty but Gender ($\beta = 0.15$, $p = 0.076$, 95% $CI = -0.10 \rightarrow 2.10$) and Age ($\beta = -0.08$, $p = 0.341$, 95% $CI = -0.72 \rightarrow -0.25$) and are not. The negative beta coefficient for maths self-concept suggests that, as students' maths self-concept increases, their perceived difficulty of the task tends to decrease (Table 5).

3.5 Maths self-concept predicts accuracy and response time on the mental rotation task and is mediated by spatial anxiety and perceived difficulty

> *H.4. Maths self-concept is a significant predictor of accuracy and response time on the mental rotation task and this association is mediated by spatial anxiety and perceived difficulty.*

3.5.1 Accuracy

A simple mediation was performed utilizing the PROCESS procedure in SPSS Version 4.2 (Hayes, 2022) was conducted to examine the indirect effect of Maths Self-Concept (MSC) on Accuracy on the MRT (Acc_MRT) through two proposed mediators: Spatial Anxiety (CSA) and Perceived Difficulty of the MRT (PD).

The total effect of MSC on Acc_MRT was found to be marginally significant, $\beta = 0.0038$, $SE = 0.0019$, $t(141) = 1.96$, $p = 0.052$, 95% CI [0.0000, 0.0077], completely standardized indirect effect (CSI) = 0.1542. The direct effect of MSC on Acc_MRT was not significant, $\beta = 0.0029$, SE = 0.0020, $t(141) = 1.42$, $p = 0.159$, 95% CI [−0.0011, 0.0068], completely standardized direct effect (CSD) = 0.1153.

TABLE 4 Coefficients: age and maths self-concept (MSC) predict spatial anxiety (CSA) in primary school children.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	33.358	3.769		8.851	<0.001	25.906	40.810
	Sex	1.094	0.801	0.107	1.366	0.174	−0.489	2.677
	Age	−1.156	0.357	−0.252	−3.234	0.002	−1.863	−0.449
	MSC	−0.256	0.054	−0.376	−4.717	<0.001	−0.364	−0.149

a. Dependent Variable: CSA.

TABLE 5 Coefficients: maths self-concept (MSC) predicts perceived difficulty (PD) of the MRT in primary school children.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	16.683	2.597		6.425	<0.001	11.549	21.817
	Sex	0.987	0.552	0.149	1.790	0.076	−0.103	2.077
	Age	−0.235	0.246	−0.079	−0.956	0.341	−0.722	0.252
	MSC	−0.103	0.037	−0.233	−2.743	0.007	−0.177	−0.029

a. Dependent variable: PD.

Indirect effects analysis revealed that the total indirect effect of MSC on Acc_MRT through all mediators combined was significant, $\beta = 0.0010$, *BootSE* = 0.0009, 95% *CI* [−0.0006, 0.0031], *CSI* = 0.0389. Specifically, CSA mediated this relationship with a significant path a of the indirect effect, $\beta = 0.0003$, *BootSE* = 0.0009, 95% *CI* [−0.0014, 0.0022], *CSI* = 0.0133. However, path a of the indirect effect through PD was not significant, $\beta = 0.0006$, *BootSE* = 0.0006, 95% *CI* [−0.0003, 0.0021], *CSI* = 0.0256. Moreover, the specific indirect effect contrast (*C1*) comparing the mediation effects of CSA and PD showed a non-significant indirect effect, $\beta = -0.0003$, *BootSE* = 0.0012, 95% *CI* [−0.0029, 0.0020], *CSI* = −0.0123.

These findings suggest that the relationship between Maths Self-Concept and Accuracy on the MRT is partially mediated by Spatial Anxiety, but not by Perceived Difficulty (Figure 7).

3.5.2 Response time

A mediation analysis was conducted to explore the indirect effect of Maths Self-Concept (MSC) on Response Times on the Mental Rotation Task (RT_MRT) through Spatial Anxiety (CSA) and Perceived Difficulty of the MRT (PD).

The total effect of MSC on RT_MRT was not statistically significant, $\beta = 0.1016$, $SE = 0.0768$, $t(141) = 1.32$, $p = 0.188$, 95% *CI* [−0.0504, 0.2535], completely standardized indirect effect (*CSI)* = 0.1086. The direct effect of MSC on RT_MRT was also not significant, $\beta = 0.0811$, $SE = 0.0824$, $t(141) = 0.98$, $p = 0.327$, 95% *CI* [−0.0818, 0.2441], *CSI* = 0.0867.

Further examination of the indirect effects revealed that the total indirect effect of MSC on RT_MRT through all mediators combined was not significant, $\beta = 0.0204$, *BootSE* = 0.0337, 95% *CI* [−0.0428, 0.0924], *CSI* = 0.0218. Specifically, while path a of the indirect effect through CSA was significant, $\beta = 0.0441$, *BootSE* = 0.0344, 95% *CI* [−0.0189, 0.1158], CSI = 0.0471, path a of the indirect effect through PD was not significant, $\beta = -0.0236$, *BootSE* = 0.0236, 95% *CI* [−0.0759, 0.0158], *CSI* = −0.0253. Moreover, the specific indirect effect contrast (*C1)* comparing the mediation effects of CSA and PD showed a non-significant indirect effect, $\beta = 0.0677$, *BootSE* = 0.0484, 95% *CI* [−0.0213, 0.1700], *CSI* = 0.0724.

These results suggest that neither Spatial Anxiety nor Perceived Difficulty significantly mediate the relationship between Maths Self-Concept and Response Time on the MRT.

4 Discussion

4.1 Gender and age differences in children's maths self-concept, spatial anxiety, and perceived difficulty

In this study, notable gender disparities emerged in maths self-concept, spatial anxiety, and perceived difficulty of mental rotation tasks. Specifically, primary school girls exhibited markedly lower maths self-concept compared to boys, alongside reporting higher levels of spatial anxiety and perceived difficulty in spatial tasks. These findings underscore potential discrepancies in confidence and comfort levels among male and female students when navigating mathematical and spatial concepts during primary education.

Variances in emotional expression between genders are believed to stem from a combination of biologically influenced temperamental predispositions and socialization processes (Sanchis-Sanchis et al., 2020). Boys and girls tend to adhere to gender-specific norms regarding the expression of emotions; for instance, girls often exhibit more positive emotions but also display higher rates of negative internalizing emotions such as sadness and anxiety (Brody and Hall, 2008). Moreover, gender disparities in emotional expression can be influenced by the nature of the task children are engaged in (Chaplin and Aldao, 2013). Boys' increased exposure to

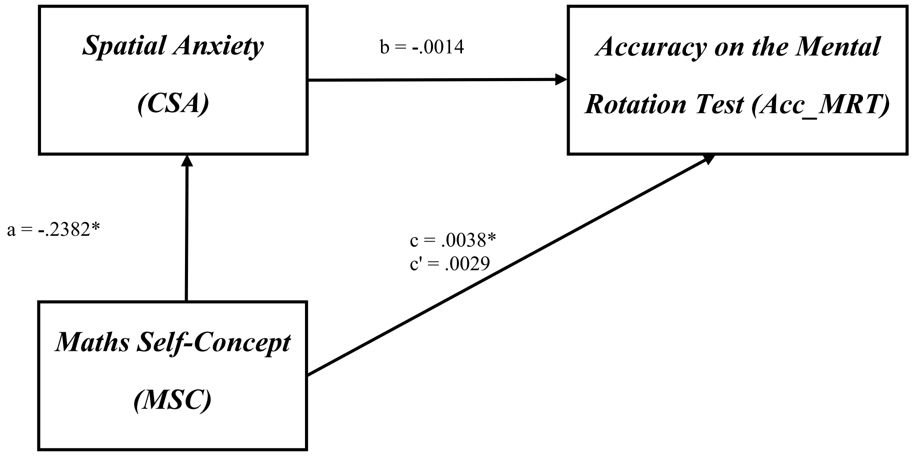

FIGURE 7
Simple mediation diagram: association between maths self-concept (MSC) and accuracy on the mental rotation task (Acc_MRT) as mediated by spatial anxiety (CSA). Paths a and b represent the indirect (mediated) effects of MSC on Acc_MRT through CSA. Path c represents the total (mediated and direct) effect of maths self-concept on accuracy in the MRT. Path c′ represents the direct effect of MSC on Acc_MRT and is calculated controlling for the indirect, mediated effect. Paths a and c are significant (*) indicating the association between MSC and Acc_MRT is partially mediated by CSA.

spatially-related objects and activities may contribute to their reduced spatial anxiety and perceived difficulty on mental rotation tasks (Ruthsatz et al., 2014). Furthermore, parental and teacher stereotypes, as well as their own anxieties regarding spatial tasks and related subjects, can potentially impede the development of girls' spatial skills and their inclination towards STEM disciplines (Gunderson et al., 2012; Garcia et al., 2021; Rocha et al., 2022). Hence, it is imperative to address these issues through targeted teacher training initiatives and support programs for parents of primary school children.

In the tween group, noticeably lower maths self-concept was observed compared to the middle childhood group, although no significant disparities emerged in spatial anxiety and perceived difficulty between these developmental phases. A decline in maths self-concept in the tween group may be a result of an emerging awareness of negative stereotypes associated with individuals who excel in maths and STEM (Starr, 2018). Fear of confirming negative stereotypes about maths and STEM can demotivate young people from engaging in these subjects preceding adolescence when social norms, hierarchies and a desire to fit in among peers is important (Cheryan et al., 2013).

Several factors, including developmental growth, exposure, and experience, may elucidate outcomes for spatial anxiety and perceived task difficulty. The tween stage signifies a period marked by substantial cognitive and socio-emotional development. Notably, neurobiological maturation during this stage enhances emotion regulatory processes, enabling older children to better manage task-related anxiety (Sanchis-Sanchis et al., 2020). As children progress through this stage, they typically experience improvements in cognitive abilities, including spatial reasoning skills, potentially contributing to a diminished perceived difficulty in spatial tasks (McGlone and Aronson, 2006; McArthur et al., 2021; McGuire et al., 2022). Furthermore, tweens are likely to have greater exposure to spatial tasks and activities, both within and outside of educational settings, compared to younger children. This increased exposure fosters familiarity with spatial tasks, thereby potentially reducing levels of spatial anxiety and perceived difficulty (Neuburger et al., 2011; Peterson et al., 2020).

These insights underscore the dynamic interplay between cognitive development, emotional regulation, and experiential learning for girls and during the tween stage, shaping perceptions and abilities related to mathematical and spatial domains.

4.2 Gender and age differences in children's' preference for STEM subjects, and mental rotation performance

Our analysis also yielded significant results with regards to students' preference for maths as a subject in primary school. Our findings show girls were less likely to choose maths as were children in the tween group. We observed that girls in primary education demonstrate a persistent belief that maths is not a subject with which they identify. Socialization and environmental factors may contribute significantly to children's relationship with maths and this may account for differences in interest and achievement in the STEM field beyond the school years. Moreover, low maths self-concept in the tween group suggests that as children progress through development, their preferences for STEM subjects change, warranting further investigation into the underlying factors. These shifts may be evidence that pre-adolescents as well as girls stereotypically believe maths and other STEM subjects to be male-dominated domains which are only for the most mathematically-gifted. The large effect size yielded by the ANOVA indicates that students' preferences for school subjects had a substantial impact on their maths self-concept. Specifically, students who expressed a preference for maths demonstrated higher levels of maths self-concept compared to those who preferred non-STEM subjects such as art, music, or languages.

Contrary to the bulk of research and despite girls' lower maths self-concept, higher spatial anxiety and perceived difficulty, we found no significant gender differences in mental rotation performance, neither accuracy nor response time, among students. Gender-specific differences in spatial experiences, role models, ability-related self-concept, and socio-economic status are well-established factors that exert a significant influence on mental rotation performance (Ruthsatz and Quaiser-Pohl, 2013). This study was conducted in Germany, known for its strong emphasis on education and social welfare. In this country, significant investments are made to provide equal access to resources and opportunities for all students, regardless of gender or socio-economic background (OECD, 2020).

Other factors may also be influential, such as the nature of mental rotation task used in the study: This included stimuli that appeal to both males and females (Ruthsatz et al., 2015) and stimuli such as polyhedral figures and other objects known to be gender-neutral (Ruthsatz et al., 2014, forthcoming). Additionally, time limits on the task, particularly on the second subscale consisting of stimuli rotated in-depth were longer than on a standard MRT to allow for gender-diverse processing strategies (Taragin et al., 2019; Saunders and Quaiser-Pohl, 2020). These factors may have diminished the power of negative emotions such as anxiety as well as stereotype threat, resulting in more equity across the task.

Despite dwindling interest in maths, tweens demonstrated higher accuracy in the mental rotation task compared to students in middle childhood, indicating potential advancements in spatial cognition and emotion suppression strategies as children progress through development and education (Neuburger et al., 2011; Sanchis-Sanchis et al., 2020).

Regarding girls' and tweens' lower maths self-concept, our findings suggest these groups may be at risk of a decline in interest and hence in achievement in STEM subjects. A trend towards disengagement from maths and related subjects at primary level has implications for childrens' academic and professional options for the future. If students' subject preferences are based on poor self-concept rather than actual ability, the STEM field will lose many potential candidates before they enter secondary school. Interventions such as peer mentoring to counteract negative attitudes and stereotypes for girls and tweens are helpful in maintaining their engagement with maths and STEM going forward (Quaiser-Pohl et al., 2014a; Ada Lovelace-Projekt, 2023; Space Science Institute, 2023). Moreover, as reciprocal relations between active participation in mathematics practice and maths self-concept have been observed, it is important to sustain and encourage students' engagement at primary level and beyond (Sewasew et al., 2018).

An unexpected outcome of this study was children's preference for sport and physical education (P.E. or "Sport" in German). Indeed, it was the most popular choice in our sample overall with more boys choosing P.E. as their preferred subject than girls. Moreover, maths self-concept in students who indicated a preference for physical education (P.E.) was significantly higher than those who preferred the non-STEM subjects but not substantially higher than in those who preferred maths. A close link between physical activity, mathematical skills and the development of spatial ability has already been identified in research (Jansen and Pietsch, 2022). Findings demonstrate that sport and regular exercise lead to enhancement of children's visuo-spatial skills (Morawietz and Muehlbauer, 2021). Moreover, specific physical activities such as kinetics and creative dance can improve mental rotation in primary school children (Jansen et al., 2013; Pietsch et al., 2017). Therefore, promoting sports and offering attractive physical education options for girls may be beneficial in improving mental rotation during the primary school years.

The findings of the two-way MANOVA examining the interplay between gender and age on aspects of the mental rotation task, spatial anxiety and the perceived difficulty of the task revealed interesting insights. Despite employing a stringent Bonferroni adjustment, no significant interaction effects emerged for perceived difficulty, accuracy, or response time in the MRT. However, a notable interaction effect was observed for spatial anxiety, underscoring the nuanced influence of gender and age on this domain. Specifically, girls in the middle childhood stage exhibited significantly higher levels of spatial anxiety compared to boys in the same developmental phase, contrasting with the absence of such disparity in the tween group. This outcome suggests that gender differences in spatial anxiety may manifest more prominently during certain developmental stages, possibly reflecting social or cognitive factors that vary across age groups. The effect size, although modest, implies a meaningful contribution of this interaction to understanding individual differences in spatial cognition during childhood. These findings underscore the importance of considering developmental nuances when exploring gender-related disparities in cognitive and emotional processes, highlighting avenues for future research to delve deeper into the underlying mechanisms driving such variations.

We conclude that while gender and age play a role in maths self-concept and spatial anxiety, other factors such as prior experience in tasks or activities involving mental rotation, such as playing certain video games or engaging in activities such as puzzles or construction play may be influencing performance on the spatial task and further research is needed to explore these (Quaiser-Pohl et al., 2006; Milani et al., 2019; Ruthsatz et al., 2019; Liu et al., 2020). Factors such as stress or fatigue, during test administration can also affect cognitive performance and might be explored using physiological measures such as skin conductance measurement (Memar and Mokaribolhassan, 2021). Higher motivation and interest in completing the task may also lead to improved performance (Moè, 2016). Variations in learning styles, cognitive strategies, and problem-solving approaches may also affect how individuals approach and perform on mental rotation tasks (Janssen and Geiser, 2010; Khooshabeh et al., 2013; Moè, 2013). Moreover, sample characteristics or methodological constraints may have affected the results warranting further exploration of individual differences or cognitive factors that might influence childrens' performance on spatial tasks.

4.3 Predictive effects of gender, age, maths self-concept on spatial anxiety and perceived difficulty of the spatial task

Due to its long-established and robust link to mathematics, the focus of this study was ultimately the impact of motivational factors such as maths self-concept on spatial ability. By considering gender, age, maths self-concept, we aimed to explore potentially predictive influences on spatial anxiety and perceived difficulty of the task in primary school children. Our findings reveal that the three predictors collectively account for a significant proportion of the variance in spatial anxiety and perceived difficulty. While age, maths self-concept emerged as significant for spatial anxiety in the regression model, gender was not. Specifically, older children and those with higher levels of maths self-concept tended to exhibit lower levels of spatial anxiety. Furthermore, maths self-concept accounted for a noteworthy proportion of the variance in students' perceived difficulty of the mental rotation task but gender and age did not.

Contrary to expectations, gender was not found to be a significantly predictor of spatial anxiety nor perceived difficulty in our sample. While gender differences in spatial abilities and anxiety have been documented in previous research (Ramirez et al., 2012; Arrighi and Hausmann, 2022), our findings suggest that other factors, such as age, maths self-concept may play a more prominent role in influencing spatial anxiety among this particular sample. The effect of gender on spatial anxiety and indeed perceived difficulty of the task may be moderated by, for example, environmental circumstances, individual learning experiences, or socio-cultural influences, factors not included in our analysis. Greater access to educational materials, extracurricular activities, and supportive family environments that foster the development of spatial skills can mitigate gender disparities and stereotype threat by providing girls with opportunities to develop and practice spatial reasoning abilities (Quaiser-Pohl and Endepohls-Ulpe, 2012; Ruthsatz and Quaiser-Pohl, 2013). Additionally, as outlined in the previous section, the nature of the mental rotation task itself may have reduced the risk of provoking stereotype threat. A pilot study in which primary school children were asked to rate the stereotyped nature of stimuli and the perceived difficulty of the same task found students identified objects as gendered, neutral, or difficult and this in turn impacted accuracy and response time on these items during the task (Lennon-Maslin et al., 2023).

Additionally, both researchers collecting the data were female, a feature of the study which may have contributed to the non-significant gender effects. The researchers may potentially have been perceived as positive science role models mitigating stereotype threat in girls. Additionally, the testing took place in small mixed gender groups of students from the same class, who were therefore familiar with one another. Moreover, securing participation from schools for this large research project posed a significant challenge. However, those schools who agreed to participate typically employed principals and teaching staff who were dedicated to fostering students' interest in STEM subjects. Moreover, parents, by the very nature of providing consent for their children to participate in the study, are actively nurturing and supporting their interest in science and research.

To conclude, interventions aimed at addressing socio-economic disparities, such as providing equal access to resources and support, can help level the playing field and improve girls' performance on mental rotation tasks. However, interventions to overcome anxiety and improve spatial skills should focus on all children regardless of gender whose maths self-concept has been identified as low. This may in turn reduce their perceived difficulty of spatial tasks and increase the likelihood of engagement with related activities and STEM subjects.

4.4 Mediating effects of spatial anxiety and perceived difficulty on the relationship between maths self-concept and accuracy on the mental rotation task

Concerning on the mental rotation task, the total effect of maths self-concept approached statistical significance. Moreover, path a of the indirect effect through spatial anxiety was significant, indicating that higher levels of maths self-concept are associated with higher scores on the mental rotation task via reduced spatial anxiety. This finding highlights the importance of fostering positive self-concept in maths from an early age. Children who feel confident in their mathematical abilities may experience less spatial anxiety, which can positively impact their performance on spatial tasks such as a mental rotation test. Therefore, interventions aimed at reducing spatial anxiety could potentially improve children's performance in both spatial and mathematical domains (Lauer et al., 2018; Garcia et al., 2021).

4.5 Mediating effects of spatial anxiety and perceived difficulty on the relationship between maths self-concept and response times on the mental rotation task

The results of the mediation analysis regarding the relationship between maths self-concept and response time on the mental rotation task revealed that neither the direct nor the total effect of maths self-concept on accuracy was statistically significant. Additionally, the indirect effects through spatial anxiety and perceived difficulty were not significant, suggesting that these variables do not mediate the relationship between maths self-concept and response time on the mental rotation task. Other psychological constructs or variables not included in the analysis might be more relevant in mediating this relationship. For example, motivation or task-specific strategies can influence both maths self-concept and performance on spatial tasks in primary school children (Moè, 2016). Furthermore, the relationship between maths self-concept, anxiety, and response time on the mental rotation task may be bidirectional or reciprocal: A recent study found that performance on mental rotation tasks mediates gender differences in maths anxiety (Rahe and Quaiser-Pohl, 2019), creating complex feedback loops that are not adequately captured in a simple mediation model. Therefore, further research investigating the interplay of other influential factors alongside maths self-concept and demographic variables such as gender and age could provide a more comprehensive understanding of response times on mental rotation tasks.

4.6 Implications of mediation findings for spatial ability development

The results of the mediation analyses underscore the interconnectedness of various cognitive skills. Positive self-concept in mathematics is known to influence mathematical performance but also indirectly affects spatial performance through reduced spatial anxiety. This suggests that interventions targeting one skill area may have spillover effects on other related skills. Specifically, exposure to mathematical and spatial activities in a supportive environment may raise comfort levels in children who might otherwise avoid these pursuits. Therefore, addressing spatial anxiety may have implications for improving performance on spatial tasks among primary school children, emphasizing the importance of considering affective factors in educational interventions aimed at enhancing mathematical abilities. However, this warrants further investigation in future research. These results highlight the need for a nuanced understanding of the factors influencing performance on cognitive tasks such as mental rotation and suggests avenues for future research and intervention development.

4.7 Limitations and future research

One limitation of this study is that maths performance was not measured. This will be collected in a future study. Moreover, the measurement of other emotional mediators such as maths anxiety may also contribute significantly and provide additional evidence to compliment maths self-concept. Future research may also benefit from the exploration of physiological measures of emotional arousal during a mental rotation task to counteract reliance on self-report.

Upon analysis of the data from our sample, the Child Spatial Anxiety Questionnaire, yielded internal reliability in the lower range. Removal of items with a reliability rating below the acceptable threshold of $\alpha = 0.70$ did not lead to an increased Cronbach's Alpha indicating that 8 items were not sufficient to assess the construct reliably. Ramirez et al. (2012) also refer to a low reliability rating for the CSAQ based on the number of items. These were purposely kept small in order to reduce fatigue in child participants (Ramirez et al., 2012). We also felt it was important to minimize participant fatigue, especially considering the age group and the number of other measures involved. Furthermore, we are not aware of any other measure of child spatial anxiety suitable for use in the busy school setting.

Although reliability of the Perceived Difficulty of items on the MRT questionnaire was within the acceptable range, there were more male-stereotyped objects (the hammer and the cubical figure) than female and neutral objects (the pellet and the polyhedral figure) included in this instrument. Upon analysis, gender differences in response times in favour of boys were found on the male-stereotyped "hammer" in the MRT. It may be, that this item triggered stereotype threat in girls and stereotype lift in boys. The questionnaire will be amended to include another female-stereotyped object to avoid the risk of triggering stereotype threat or lift in future studies.

The results of the regression analysis should be interpreted with caution as the study was cross-sectional. A future research project might adopt a longitudinal approach which follows a cohort of students across their primary school years, in order to study the effects of the predictor variables over time.

With regards to the ANOVA results, the sample size fell short of the G*Power *A priori* calculation of optimal sample size. Therefore, the ANOVA was run on a subsample in order to avoid violating assumptions of equal variances in groups. The effect size was however noteworthy with a large proportion of the variance in students' maths self-concept being explained by their preference for subjects at school. Important to note however, that students did not choose any other preferred STEM subject, so that the results can effectively only be applied to maths with potential implications for STEM.

To minimize the risk of introducing bias or stereotype threat and improve the validity of the study, collecting demographic data such as gender and age might best be done in conclusion rather than preceding testing.

5 Conclusion

This study provides insights into critical factors influencing children's attitudes and performance in mathematics, spatial tasks, and STEM subjects. One key finding is the persistent gender disparity in maths self-concept, spatial anxiety, perceived difficulty of spatial tasks, and preference for maths as a STEM subject, highlighting enduring negative stereotypes in these fields. Similarly, low maths self-concept and loss of interest and enthusiasm for maths in late primary school children warrants attention in order to prevent disengagement from STEM-related subjects in further education. Counteracting stereotypes early is essential to ensure childrens' academic choices are based on ability rather than attitude. The findings emphasize the importance of addressing spatial anxiety and promoting positive maths self-concept to enhance performance on spatial tasks among primary school children. Interventions aimed at improving maths self-concept may indirectly benefit spatial task performance by alleviating spatial anxiety. Further investigation is warranted to explore the complex interplay between cognitive, affective, and demographic factors influencing performance on spatial tasks in primary school children. Additionally, longitudinal studies could provide insights into the developmental trajectories of maths self-concept and spatial skills. In conclusion, while maths self-concept plays a role in performance on spatial tasks, its influence is mediated by factors such as spatial anxiety, with gender showing limited moderating effects. Understanding these dynamics is crucial for developing targeted interventions to effectively support children's mathematical self-concept and spatial skills development in educational settings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethikkommission, Universität Koblenz. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

ML-M: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. CQ-P: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. L-CW: Formal analysis, Supervision, Writing - review & editing.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1300598/full#supplementary-material

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