

## RESEARCH ARTICLE

# The role of cognitive and non-cognitive factors in mathematics achievement: The importance of the quality of the student-teacher relationship in middle school

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## Abstract

There is increasing evidence that several factors, including both cognitive and non-cognitive ones, play an important role in mathematics achievement. Relatively little is known about how socio-emotional features and the quality of the student-teacher relationship correlate with mathematics achievement among adolescents in transition to middle school. The aim of the present study is to examine the role of cognitive factors (general cognitive abilities), non-cognitive factors (math anxiety and self-esteem), and the quality of the student-teacher relationship on mathematics achievement. A large sample of Italian sixth graders was evaluated upon entering middle school. The results showed that general cognitive ability was the best predictor of mathematics achievement. As regards non-cognitive factors, the level of math anxiety was effective in predicting mathematics achievement, after controlling for other measures including self-esteem and the quality of the student-teacher relationship. In particular, we found that the quality of the student-teacher relationship had an indirect influence on mathematics achievement through the mediation of math anxiety. Our findings seem to indicate that the quality of the student-teacher relationship may be related to mathematics achievement, through its effects on math anxiety. This may have important implications for practitioners and educators, as we can suggest that interventions devoted to improving the quality of the student-teacher relationship may play a positive role in both preventing math anxiety and promoting mathematics learning.

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Solving mathematical tasks is a complex task that involves several distinct abilities that are essential in everyday life situations. Therefore, understanding the factors related to strong mathematical abilities is extremely important. Research has primarily focused on the influences of many individual factors, both cognitive and non-cognitive ones [1–3], and recent studies highlight the complexity of the interaction between them [4–6]. More recent

contributions have expanded the focus beyond the individual level, and have targeted factors allocated on the broader environmental level, such as the classroom, the relationship with the teachers and the family context [7–11]. There is now a general consensus that a deep understanding of mathematics achievement requires research attention of both individual and environmental factors and how these factors might interact [7–9]. With this respect, Chang and Beilock (2016) propose a conceptual framework which attempts to integrate these influences in order to explain the mathematics achievement gap existing among student. Although this theoretical model is extremely interesting, as it provides a framework from which to consider the multiple factors implicated in math performance, empirical evidence supporting the model is still scant.

As to the individual level, among the cognitive factors, general cognitive ability involves the ability to reason, plan, solve abstract problems, think abstractly, comprehend complex ideas, and maintain and manipulate complex materials [12]. The construct of general intelligence or general cognitive abilities (usually denoted as *g*) is a quantitative trait, and various theories of intelligence have attempted to measure and quantify human intellectual abilities [13]. Among the many contemporary intelligence theories, the Cattell–Horn–Carroll (CHC) theory is a most influential one that offers an interpretation of the relationship between intelligence and academic achievement [14, 15]. Specifically, the CHC theory of intelligence is a synthesis of Cattell and Horn’s theory of fluid and crystallized intelligence [16–18] and Carroll’s Three-Stratum model [15, 19]. There is extensive literature demonstrating that general cognitive abilities and mathematics achievement are strongly associated [20, 21]. The fact that general cognitive abilities are strongly related to mathematical outcomes is not surprising. The understanding of mathematical task esteems requires the formation of abstract representations of quantitative and qualitative relationships between variables [22]. Further, solving mathematical tasks requires the ability to link second-order relationships in a logical and ordered manner and the ability to manipulate visual representations [23]. In particular, general cognitive abilities seem to be involved in complex mathematical skills required in middle school age. For example, solving mathematics problems involves reasoning skills, as they are needed to: (a) construct a structure coherent with the salient information of the text of the problem; (b) integrate information from the text with inferences based on the child’s knowledge (fluid and crystallized intelligence); and, (c) create schema to formalize the relationships among quantities and guide the application of solution strategies [24]. Moreover, other complex mathematics tasks in middle school mathematics curricula, such as fractions and algebra, are built on foundational numerical and calculation skills, which are thought to require general cognitive abilities to a large degree [25–28].

Besides general cognitive ability, which has been consistently related to mathematics achievement [20], also non-cognitive factors seem to play an additional role and, among these, math anxiety [29–31]: this construct can be broadly defined as a state of discomfort caused by performing mathematical tasks and expresses itself as a feeling of fear that many people experience when engaging in mathematical tasks [32–34]. In fact, math anxiety is a multivariate construct that includes: math learning anxiety, which refers to feelings of tension when content has to be learned; math evaluation anxiety, which refers to situations in which performance in mathematics is being evaluated; and, finally, generalized school anxiety, as to an extension of anxiety to other school subject [35]. The relationship between math anxiety and mathematics could be interpreted within the theoretical framework of reduced competency account, which argues that math anxiety is actually the result of poor math ability [35]. In this theory, a student’s poor skill leads to low competence in mathematics achievement, which then contribute to raise levels math anxiety. This theoretical approach is supported by the studies of Maloney and colleagues [35]. These Authors showed that individuals starting with lower numerical

skills tend to underperform in math. As an effect of this underperformance, they become anxious. The consequence of this state of anxiety towards mathematics tasks is that students already with lower math skills, also tend to avoid studying this discipline. In fact, the typical behaviors of these students are avoidance of math homework or low participation in classroom activities [36]. These avoidant behaviours lead to further delays in learning and consequently higher levels of anxiety. Other studies have in fact showed that math anxiety, in particular among adolescent students, was connected to a scarce attendance of mathematics courses [35–36]. Math anxiety might be particularly interesting to investigate in middle school age, as the evidence shows that it might increase as student move to middle school [37].

Besides math anxiety, another non-cognitive factor, self-esteem, appears to be related to mathematics achievement [38–42]). Self-esteem is definable as “an individual’s subjective evaluation of his or her worth as a person” (Orth & Robins, 2014, p. 381), and includes evaluations of the self along a “good–bad” dimension [43, 44]. Self-esteem requires a higher-order integration of domain-specific attributes which occurs only in early adolescence; young children do not begin to describe themselves in terms of concrete cognitive abilities, physical abilities, how they behave, how they look, and friendships they have formed. Indeed, in young children these domains are not clearly differentiated from one another, as revealed through factor-analytic procedures, nor are they integrated into a higher-order concept of self-esteem [45]. For these reasons, adolescence seems to be the appropriate age to explore this construct and its impact on academic achievement. The concept of self-esteem and its relation to academic achievement is controversial in the literature, especially with respect to the age group we are interested in [43–46]. In their review, Baumeister et al. (2003, pp. 13–14) concluded that, “*the few studies suggesting any positive causal impact of self-esteem [on academic achievement] generally found only tiny effects. Some findings even point (again weakly) in the opposite direction, suggesting that high self-esteem may detract from subsequent performance*”. Conversely, other studies suggest that high self-esteem is an important factor to consider in the prediction of academic achievement in students [46–51]. In their work, Alves-Martins and colleagues (2010) showed that students with lower levels of school success attach less importance to school subjects and show poorly favorable attitudes towards school [52]. More clarifications come from a longitudinal study conducted by Trautwein et al. (2006), who examined the dynamics between mathematics achievement, self-concept, and self-esteem [53]. These scholars showed that high self-esteem is not a strong predictor of later achievement but, when they restricted their analyses to the reciprocal relationship between self-esteem and mathematics achievement, they found some small but significant predictive effect on mathematics achievement. In particular, the effects of self-esteem on mathematics achievement seem to be mediated by self-concepts. In sum, it is difficult to draw firm causal conclusions about the effects of self-esteem on mathematics achievement. There is no strong evidence specifically indicating that high self-esteem leads to improved mathematics achievement, or that better mathematics achievement leads to better self-esteem. It is precisely this controversial nature of the relationship between self-esteem and mathematics that led us to investigate the effects of this construct on mathematics achievement.

Other studies additionally explored the relation between self-esteem and math anxiety [54–57]. Existing findings support reciprocal influences between the two domains in middle school age. In particular, the study by Akin and Kurbanoglu (2011) showed that self-esteem predicted math anxiety directly as well as through a pathway mediated by the positive or negative attitudes to mathematics. Conversely, through a longitudinal design, Ahmed and colleagues (2012) showed that lower self-esteem levels predicted higher levels of math anxiety. At the same time, higher levels of math anxiety predicted lower levels of self-esteem, by controlling for previous levels of self-concept, supporting reciprocal influences between the two domains

over time [58]. Finally, a recent study by Xie and colleagues (2019) explored the relationship between self-esteem, math anxiety and mathematics achievement in a sample of students between 12 and 18 years old. The researchers showed, through structural equation models, how self-esteem was able to directly predict math anxiety but not mathematics achievement in male students, while in female students, self-esteem predicted neither math anxiety nor much less mathematics achievement [59]. In concise, given the complex nature of the construct and the controversial relation between self-esteem, math anxiety and mathematics achievement, we found it useful to bring new knowledge to literature.

Whether some consensus exists on the impact of general cognitive abilities, math anxiety, and self-esteem on mathematics achievement, the relations between these different constructs has not been addressed so far. To the best of our knowledge, only one study on sixth graders has explored jointly two of the three suggested predictors (intelligence and self-esteem) and their impact on mathematics performance [20]. Giofrè, Borella, and Mammarella (2017) showed that intelligence was the best predictor of mathematics achievement, but also self-esteem was able to predict mathematics achievement. The Authors showed that their data fitted best a model including a direct link from intelligence to the mathematics achievement and direct and indirect effects of self-esteem on mathematics achievement through intelligence. The researchers speculated that students with higher cognitive abilities also tended to have higher levels of self-esteem, which in turn led to higher mathematics performance.

As to the contextual factors which might impact mathematics achievement, recent research has stressed the importance of the quality of the student-teacher relationship (e.g., [60, 61]). For the last two decades, the quality of the student-teacher relationship has been a focus of educational research [62]. This line of study is rooted in attachment theory [63], which provides a theoretical framework for understanding the relevance of a caregiver's sensitivity to children's cues as a prerequisite for secure relationships. In applying this concept to relationships in the classroom, thanks to Robert Pianta's work [64], empirical attention to the relationships with teachers has been shifted from the educational dimension to the affective one. Specifically, Pianta (1999) proposed the conceptualization of the relationship between teachers and students as an attachment relationship: as such, it will function as a secure base for the student to explore new learning opportunities, as well as a safe haven in which to regulate negative emotions within the school context. Since this conceptualization was shared in the academic community, a great amount of research has been conducted in order to provide empirical support to the theoretical idea according to which a positive affective relationship with a teacher might promote learning and positive adaptation within the school context [62] and the affective quality of the student-teacher relationship has been shown to be an important predictor of children's development and wellbeing [65]. Many studies have found that students with close relationships with their teachers are more likely to experience at school academic interest, engagement, achievement, self-efficacy, and motivation as compared to students with more distant relationships [66–78]. Particularly for children who are at risk of failure in school, an emotionally supportive relationship with a teacher can act as a protective factor and have positive effects on developmental outcomes [66]. Furthermore, a positive teacher-student relationship would allow students with difficulties in learning new or complex content to approach the teacher easily, which increases the possibility of the teacher adapting instruction to favour the consolidation of academic performances [79]. One gap exists in this research area, as most studies have focused on the pre-school age group [80–83] and on the primary school age group [84–86], while early adolescence and the transition to middle school still seems scarcely explored. Considering this state of the art, we suggest that this age deserves more research attention.

Notwithstanding the relevance of cognitive (i.e. general cognitive abilities) and non-cognitive factors (i.e. math anxiety and self-esteem), at the individual level, as well as of the quality of student-teacher relationship, at the contextual one, on mathematics achievement, this far there is no empirical test of their joint influence in the transition to middle school. We selected this age group because general cognitive ability seems to be relatively stable from this age on [20, 87]. In addition, at these ages the complex interactions between cognitive and non-cognitive factors is influenced by the complexity of the mathematical task and by the increase in the required cognitive abilities [87]. In fact, middle school seems to be a critical moment in which to evaluate this interaction [87–90]. We decided to use a latent modelling approach because it presents several advantages (e.g., being more precise and reliable) as compared to traditional analyses, and it has been successfully used by researchers in this area (e.g. [20, 91, 92]).

## Method

### Participants

The initial sample consisted of 219 children attending the sixth grade. Children with clinical diagnoses and those belonging to disadvantaged socio-cultural groups were not included in the study (4 children). Children who were absent for at least one session were excluded from the analysis (30 children). Using casewise deletion with Mahalanobis distance, some participants ( $n = 4$ ) were found to be multivariate outliers ( $D > 40$ ) and were excluded from the analyses. Therefore, the final sample included 181 children (females = 49%, average age = 10.65,  $SD = 0.49$ ). The children were attending school in an urban area of Puglia, in Southern Italy. All information at the item level was available for these children.

### Ethics statement

The study had the prior approval of the Local Ethics Committee of the Department of Education, Psychology, Communication at the University of Bari. All the parents provided written informed consent on behalf of their children prior to their participation in the study.

### Instruments

**General cognitive abilities (g).** *Cattell culture fair intelligence test* [93]. The task consisted of four timed subtests (series completion, odd-one-out, matrices, and topology) with items of increasing difficulty within each subtest. The test contained 46 multiple choice items ( $KR-20 = .66$ ). The score was the sum of the correct answers. The CFIT is a well-known matrix reasoning instrument assumed to be independent from cultural experiences. It includes two equivalent forms (A and B) and four subtests involving multiple-choice problems progressing in difficulty: series (8 items), classification (14 items), matrices (12 items), and conditions (8 items). The combined form A + B is mainly used in a clinical setting, while in the school setting, form A is preferred. Thus, for our purposes, we considered form A. The scores ranged from 0 to 46. The validity of the CFIT has long been established [94] and the subtest scores are usually taken to be strong indicators of one comprehensive latent construct of fluid intelligence.

**Primary Mental Abilities–Spatial (PMA-S; [95]).** In this task, the subject was required to identify, among six different rotated figures, the figures that were exactly alike: i.e. figures that were rotated but mirrored. The test consisted of 20 trials with two or more correct alternatives for each ( $KR-20 = .89$ ). The score was the sum of the correct answers.

**Primary Mental Abilities–Reasoning (PMA-R; [95]).** In this paper-pencil test, the child had to complete a sequence of letters, choosing which letter from various alternatives logically completed the series (for example: in the series *abm, cdm, efm* and *ghm*, the answer is *i*). The

test included 30 items and had to be completed within 5 minutes (KR-20 = .85). The score was the sum of the correct answers.

**Primary Mental Abilities–Verbal (PMA-V; [95]).** In this paper-pencil test, the children had to choose a synonym for a given word from among four options; for example, for the item, *small*: (a) *slow*, (b) *cold*, (c) *simple*, and (d) *tiny*, the answer is (d) *tiny*. There was only one correct answer for each question. The test included 50 items and had to be completed within 4 minutes. The score was the sum of the correct answers (KR-20 = .85).

The *visual pattern test–active task (VPTA; [96–97])* tests the ability to maintain and process spatial information simultaneously presented on a digital blackboard in the classroom. A total of 18 matrices (adapted from the visual pattern test [98]) of increasing size (the smallest with 4 squares and 2 cells filled and the largest with 14 squares and 7 cells filled) contained a variable number of cells to remember (from 2 to 7). After each matrix had been shown for 3 seconds, the children were presented with a blank test matrix on which they were asked to reproduce the pattern of the previously seen cells by clicking in the cells corresponding to the same positions but one row lower (the bottom row in the presentation matrix was always empty). The score was the number of accurately placed cells.

**Math anxiety.** *Metacognition in Mathematics (MeMa) [99]* is composed of three different questionnaires that evaluate attitudes toward math. The first questionnaire is addressed to the children (from 8 to 14 years old), the second one is addressed to the primary and secondary school teachers, and the third one is for the parents. The questionnaire measures the level of math anxiety in students aged 8 to 14. For the purpose of this study, we only used the last questionnaire. It is composed of Likert Scale items and analyzes three different factors: *Mathematical Learning Anxiety* (16 items), *Mathematical Evaluation Anxiety* (8 items), and *School Generalized Anxiety* (6 items). Responses to these items are given on a 4-point scale (1 –low anxiety, to 4 –high anxiety; Cronbach's  $\alpha = .91$ ).

**Self-esteem.** *Multidimensional Self-Concept scale (MSC; [100])*. This self-reported scale aimed to evaluate children's feelings about themselves in six different domains of life, each assessed by a specific subscale which can be used separately. For the purposes of the study, three subscales were selected to assess the children's feelings about themselves in terms of their interpersonal relationships, emotional competencies, and general life situations. Each subscale consisted of 25 positive and negative sentences for which respondents were asked to rate their agreement on a 4-point Likert Scale, from "absolutely true" to "absolutely false". The test confirmed its good psychometric properties (quality of interpersonal relationships, Cronbach's  $\alpha = .87$ ; emotional competencies, Cronbach's  $\alpha = .87$ ; environment capability, Cronbach's  $\alpha = .79$ ). The selection of the scales for assessing self-esteem was led by identifying the relevant measures by emotional and relational dimensions, which immediately guided our study. In this perspective, only three scales of the MSC Test tool were in line with our objectives: (a) the scale of interpersonal relationships (examples of items: "people like to be with me"; "others avoid me"; "I often feel left out") allowed us to explore the dimension of relationships, a crucial aspect in our work; (b) the scale of control over the environment (examples of items: "I have confidence in myself", "I am not very intelligent", etc.) allowed us to measure the student's belief systems. In this perspective, some studies have highlighted the relevance of these aspects on the student's self-esteem [101, 102]; finally, (c) the emotional scale represents a measure of the student's emotional life. This measure seemed extremely useful in terms of the ability to recognize and manage emotions and to control negative emotions. The other scales of the instrument allowed us to detect measurements such as: (d) family life and relationships in the family and the degree to which the student feels loved and valued; (e) body intended as a physical aspect, physical and sporting abilities. Finally, we consciously decided not to focus our attention on the dimension of (f) academic self-concept, since the effects of this construct on

academic learning have been widely covered by the literature [103–110]. What instead seems to still be debated and is, consequently, more interesting is the effect of more general constructs such as self-esteem on academic learning [44, 45].

**Student-teacher relationship quality.** *Student-Teacher Relationship Questionnaire* (STRQ). An Italian adaptation [111] of the Student-Teacher Relationship Questionnaire [112] was used. The instrument examines children's perceived relationships with teachers, as well as their generalized perceptions of the overall school environment. Based on attachment theory [63, 113], all the questions are designed to assess the positive and negative affective and cognitive experiences of warmth, trust, accessibility, and responsiveness within these relationships [114]. School bonding questions were developed based on prior theory and research in the area of social bonding [115] and were designed to measure positive bonding experiences. The final questionnaire was composed of 19 items: *Affiliation with Teacher* (Cronbach's  $\alpha = .88$ )– 8 items, *Dissatisfaction with Teacher* (Cronbach's  $\alpha = .66$ )– 3 items, and *Bonds with School* (Cronbach's  $\alpha = .80$ )– 8 items. Responses to this instrument were given on a 4-point scale (1—almost never or never true to 4—almost always or always true).

**Mathematics achievement.** *Achievement in Mathematics* (AC-MT 11–14) [116]. All students were administered the Italian AC-MT 11–14 Test by means of a set of paper-and-pencil tasks that can be grouped into three areas: written calculation, mathematical reasoning, and number knowledge. As described in the AC-MT Test manual, all subtests had standardized measures, showing a high level of reliability (Cronbach's  $\alpha = .80$ ). *Written calculation* tasks assessed the use of arithmetic procedures, arising from knowledge of a body of rules (i.e., correct manipulation of numbers and operations, and rapid retrieval of results). *Mathematical reasoning* evaluates calculation speed and the student's ability to manipulate large numbers (approximate calculation) and reasoning ability based on flexible use of basic calculation procedures and strategies (facts retrieval). *Number knowledge* tasks assess the components of calculation. Written calculation tasks assess the use of arithmetic procedures, arising from the knowledge of a body of rules (i.e., correct manipulation of numbers and operations, as well as rapid retrieval of results). Number knowledge tasks assess the components of calculation (e.g., number magnitude judgments). Mathematical reasoning tasks assess calculation speed, the student's ability to manipulate large numbers (e.g., approximate calculation), and reasoning ability based on flexible use of basic calculation procedures and strategies (e.g., facts retrieval). The scores for the entire test ranged from 0 to 60. The Spearman-Brown split-half reliability coefficient in this study was .76 for the entirety of measurement.

## Procedure

Selection of the tasks was based on agreements with the schools participating in the study. In particular, the tasks were administered as part of a broad study promoted by the Department of Education, Psychology, Communication at the University of Bari Aldo Moro in Italy regarding the relation between academic achievement and teaching methods and strategies. The children were tested in October, one month after the start of school, in three collective sessions. Students were tested in different phases: (a) two group sessions in their classroom that lasted approximately one hour each: In the first group session, General Cognitive Abilities and Math Anxiety measures were assessed, while in the second group session Multidimensional Self-concept Scale and Student-Teacher Relationship Questionnaire measures were assessed; and (b) one group session in which we assessed mathematics achievement. During the first group session, the intelligence tests and the math anxiety questionnaire were administered in a fixed order (Cattell, PMA-V, PMA-S, PMA-R, VPTA and MeMa Test); in the second group

session, the self-esteem subscales (quality of interpersonal relationships, emotional competencies, and environment capability) were also administered in a fixed order.

### Data analytic approach

The R program [117] with the “psych” [118] and “lavaan” [119] libraries were used to perform exploratory and confirmatory analyses. Model fit was assessed using various indexes according to the criteria suggested by Hu and Bentler (1999) [120]. We considered the chi-square ( $\chi^2$ ), the comparative fit index (*CFI*), the non-normed fit index (*NNFI*), the standardized root mean square residual (*SRMR*), and the root mean square error of approximation (*RMSEA*); the chi-square difference ( $\Delta\chi^2$ ), and the Akaike information criterion (*AIC*) were also used to compare the fit of alternative models [121].

### Results

The principal descriptive statistics and the correlation matrix are reported in [Table 1](#).

#### Exploratory Factor Analysis (EFA)

We used a two-step modelling approach. In a first set of analyses, we used EFA to investigate the factorial structure of all our indicators. EFA was used to determine the adequate number of latent factor structures and to identify the number of factors underlying (conceptually and statistically) the set of items in each construct. The results from the EFA provided a clear estimation of the factor structure of the variables. We used Cattell’s scree plot test to identify the number of factors. Based on the results of the scree plot, five factors were clearly distinguishable. We named these factors according to the previous literature, specifically: general cognitive abilities, math anxiety, self-esteem, quality of student-teacher relationship, and mathematics achievement ([Table 2](#)). Confirmatory analyses were subsequently used to confirm the results of the EFA. Overall, about half of the variance (49.4%) was explained by these five factors.

#### Confirmatory Factor Analysis (CFA)

Having established the factorial structure of our tasks, we attempted to confirm the factor structure using CFA ([Table 3](#)). In this model, the relationship between general cognitive abilities, math anxiety, self-esteem, the quality of the student-teacher relationship, and mathematics achievement were investigated. Based on the results of the EFA, we hypothesized the existence of five factors: general cognitive abilities (g), mathematics achievement (MATH), math anxiety (MA), self-esteem (SE), and the quality of the student-teacher relationship (QSTR). All loadings were statistically significant. The fit of this model (CFA-01) was adequate,  $\chi^2(109) = 178.71, p < .001, RMSEA = .06, SRMR = .07, CFI = .93, NNFI = .92, AIC = 18191$  ([Fig 1](#)). This model was therefore used for subsequent analyses.

#### Structural Equation Modelling (SEM)

In Model SEM-01, all factors in CFA-01 were simultaneously predicting MATH ([Fig 1](#)). As for the correlations between exogenous factors, correlations that were not statistically significant in our measurement model (CFA-01) were not included. The fit of this model was adequate,  $\chi^2(109) = 178.71, p < .001, RMSEA = .06, SRMR = .07, CFI = .93, NNFI = .92, AIC = 18191$ . The average variance extracted (AVE) was .33, .60, .66, .67, .63 for g, MATH, MA, SE, and QSTR respectively. Overall, this model shows that only g and MATH are predicting unique portions of the variance. Such a finding might indicate that the relationship with MATH



**Table 1. Correlations, means (M), and standard deviations (SD), for all measures.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
01. CAT	1																
02. PMA-S	.33	1															
03. PMA-R	.43	.29	1														
04. PMA-V	.36	.13	.33	1													
05. VPTA	.43	.37	.35	.18	1												
06. MA-MLA	-.15	.10	-.19	-.16	-.09	1											
07. MA-MEA	-.18	-.07	-.19	-.16	-.18	.69	1										
08. MA-SGA	-.03	.03	-.14	-.15	.09	.49	.46	1									
09. MCS-A	.01	-.06	.08	-.01	-.05	-.16	-.11	.00	1								
10. MCS-B	.06	-.02	.09	.11	-.08	-.22	-.19	-.18	.65	1							
11. MCS-C	.05	-.06	.09	.15	-.02	-.24	-.27	-.14	.63	.70	1						
12. QSTR-AFF	-.07	.19	-.01	-.05	.04	.39	.27	.24	-.19	-.22	-.27	1					
13. QSTR-DIS	.08	-.07	.16	.06	-.11	-.30	-.22	-.22	.32	.48	.42	-.42	1				
14. QSTR-BS	.06	-.08	.09	.17	-.04	-.25	-.28	-.20	.29	.39	.46	-.57	.65	1			
15. MATH-WC	.15	.12	.41	.24	.22	-.09	-.06	-.04	.03	.08	.05	.02	.17	.11	1		
16. MATH-REA	.26	.17	.28	.39	.27	-.33	-.33	-.19	-.02	.11	.12	-.04	.13	.13	.34	1	
17. MATH-NUM	.39	.19	.29	.28	.29	-.35	-.35	-.20	.05	.16	.12	-.07	.15	.16	.40	.62	1
M	28.07	10.33	12.8	16.72	125.22	25.17	19.71	11.64	77.57	76.04	75.68	6.56	18.01	25.61	6.17	16.43	19.86
SD	4.9	12.45	5.91	5.06	21.53	7.34	5.68	3.17	9.38	9.77	10.05	2.35	3.08	3.98	1.63	3.24	4.03

All coefficients > .15 are significant at .05 level. CAT: Cattell; PMA-S: Primary Mental Ability–Spatial; PMA-R: Primary Mental Ability–Reasoning; PMA-V: Primary Mental Ability–Verbal; VPTA: Visual Pattern Test–Active; MA-MLA: Mathematical Learning Anxiety; MA-MEA: Mathematical Evaluation Anxiety; MA-SGA: School Generalized Anxiety; MCS-A: Multidimensional Self-Concept Scale–Quality of interpersonal relationships; MCS-B: Multidimensional Self-Concept Scale–Emotional Competencies; MCS-C: Multidimensional Self-Concept Scale–Environment Capability; QSTR-AFF: Student-Teacher Relationship Questionnaire–Scale Affiliation with Teacher; QSTR-DIS: Student-Teacher Relationship Questionnaire–Scale Dissatisfaction with Teacher; QSTR-BS: Student-Teacher Relationship Questionnaire–Scale Bonds with School; MATH-WC: AC-MT–Written Calculation; MATH-REA: AC-MT–Mathematic reasoning; MATH-NUM: AC-MT–Number knowledge.

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seems to be more articulated. Based on this finding and on the fact that MA, SE, and QSTR are highly intercorrelated we decided to run an additional model in which the relationship between SE and QSTR was mediated by MA. This model is also supported by the literature, which indicates that SE and QSTR are related to other constructs, such as MA [59, 122].

In Model SEM-02, math anxiety mediated the effects of both self-esteem and QSTR on mathematics achievement (Fig 2). In the model, general cognitive ability and math anxiety were allowed to correlate. This model had a good fit,  $\chi^2(113) = 179.73, p < .001, RMSEA = .06, SRMR = .07, CFI = .94, NNFI = .92, AIC = 18184$ , and a lower AIC compared to model SEM-01 ( $\Delta AIC = 7$ ), meaning that this model should be retained. In this model, the proportion of variance explained by mathematics achievement was high (i.e., 50% of the variance). In this model, it was also possible to calculate indirect effects from QSTR and SE on MATH, with the mediation of MA. Notably, when tested, only the indirect effect of QSTR was statistically significant ( $\beta = -.13, p = .009$ ), while the effect of SE was not ( $\beta = .03, p = .433$ ). We decided to perform this analysis again using maximum likelihood estimation with robust (Huber-White, MLR) standard errors and a scaled test statistic that is (asymptotically) equal to the Yuan-Bentler test statistic. The fit of the model using this method,  $\chi^2(113) = 174.88, p < .001, RMSEA = .06, SRMR(Bentler) = .07, CFI = .94, NNFI = .93$ , was very similar to the fit calculated with the traditional ML method. This method also allowed us to adjust and correct SEs, providing more reliable estimates; results using this method are very similar to those obtained with the traditional ML and are not reported due to redundancy.

Table 2. Factor loadings for the measurement model.

	Factor1	Factor2	Factor3	Factor4	Factor5
01. CAT	.68				
02. PMA-S	.50				
03. PMA-R	.57				
04. PMA-V	.32				
05. VPTA	.61				
06. MA-MLA		.92			
07. MA-MEA		.68			
08. MA-SGA		.51			
09. MCS-A				.76	
10. MCS -B				.84	
11. MCS -C				.77	
12. QSTR- AFF					-.54
13. QSTR-DIS					.55
14. QSTR-BS					.95
15. MATH-WC					.41
16. MATH-REA					.78
17. MATH-NUM					.63

CAT: Cattell; PMA-S: Primary Mental Ability–Spatial; PMA-R: Primary Mental Ability–Reasoning; PMA-V: Primary Mental Ability–Verbal; VPTA: Visual Pattern Test–Active; MA-MLA: Mathematical Learning Anxiety; MA-MEA: Mathematical Evaluation Anxiety; MA-SGA: School Generalized Anxiety; MCS-A: Multidimensional Self-Concept Scale–Quality of interpersonal relationships; MCS-B: Multidimensional Self-Concept Scale–Emotional Competencies; MCS-C: Multidimensional Self-Concept Scale–Environment Capability; QSTR-AFF: Student-Teacher Relationship Questionnaire–Scale Affiliation with Teacher; QSTR-DIS: Student-Teacher Relationship Questionnaire–Scale Dissatisfaction with Teacher; QSTR-BS: Student-Teacher Relationship Questionnaire–Scale Bonds with School; MATH-WC: AC-MT–Written Calculation; MATH-REA: AC-MT–Mathematic reasoning; MATH-NUM: AC-MT–Number knowledge.

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### Additional analyses

General cognitive ability encompasses a series of important constructs, such as working memory (WM). Working memory is a highly related but separable construct from intelligence ([123] for a review). In fact, some of the tasks included in this paper as measures of general cognitive abilities could be defined as WM tasks. These tasks include: the VPTA, which requires the subject to maintain and manipulate information for a short period of time and, to a lesser extent, the PMA-S, which requires the subject to mentally hold and mentally manipulate visual objects. For this reason, we decided to run model SEM-02 again without including these tasks in the model. In a similar vein, School Generalized Anxiety, which was included in the MA factor, is probably measuring some anxiety components related to general anxiety rather than being specific to math anxiety. For all these reasons, we decided to perform a new model SEM-03, very similar to model SEM-02, but in which some measures (i.e., VPTA, PMA-S and School Generalized Anxiety) were excluded. This gave us the opportunity to have measures of General Cognitive Abilities less dependent on WM, and measures of Math anxiety less influenced by other factors such as general anxiety. The fit of model SEM-03,  $\chi^2(71) = 118.12$ ,  $p < .001$ , RMSEA = .06, SRMR = .06, CFI = .95, NNFI = .93, AIC = 14324, was very similar to, and slightly better than, model SEM-02. The model's parameters were very similar to those in model SEM-02, and all the patterns that were statistically significant in model SEM-02 remained statistically significant in model SEM-03. Model SEM-03 is presented in Fig 3.

Table 3. Confirmatory factor analysis.

	GCA	MA	SE	QSTR	MATH
01. CAT		0.71			
02. PMA-S		0.46			
03. PMA-R		0.62			
04. PMA-V		0.48			
05. VPTA		0.59			
06. MA-MLA			0.85		
07. MA-MEA			0.81		
08. MA-SGA			0.57		
09. MCS-A				0.75	
10. MCS -B				0.85	
11. MCS -C				0.85	
12. QSTR- DIS					-0.63
13. QSTR-BS					0.75
14. QSTR-AFF					0.87
15. MATH-WC					0.75
16. MATH-REA					0.84
17. MATH-NUM					0.47
GCA	1				
MA	-0.26*	1			
SE	0.07	-0.30*	1		
QSTR	0.07	-0.42*	0.57*	1	
MATH	0.62*	-0.48*	0.16 <sup>+</sup>	0.21*	1

GCA: General Cognitive Abilities; MA: Math Anxiety; SE: Self-Esteem; QSTR: Quality of Student-Teacher Relationship; MATH: Mathematic Achievement; CAT: Cattell; PMA-S: Primary Mental Ability–Spatial; PMA-R: Primary Mental Ability–Reasoning; PMA-V: Primary Mental Ability–Verbal; VPTA: Visual Pattern Test–Active; MA-MLA: Mathematical Learning Anxiety; MA-MEA: Mathematical Evaluation Anxiety; MA-SGA: School Generalized Anxiety; MCS-A: Multidimensional Self-Concept Scale–Quality of interpersonal relationships; MCS-B: Multidimensional Self-Concept Scale–Emotional Competencies; MCS-C: Multidimensional Self-Concept Scale–Environment Capability; QSTR-AFF: Student-Teacher Relationship Questionnaire–Scale Affiliation with Teacher; QSTR-DIS: Student-Teacher Relationship Questionnaire–Scale Dissatisfaction with Teacher; QSTR-BS: Student-Teacher Relationship Questionnaire–Scale Bonds with School; MATH-WC: AC-MT–Written Calculation; MATH-REA: AC-MT–Mathematic reasoning; MATH-NUM: AC-MT–Number knowledge.

\*  $p < .05$ , two tails

<sup>+</sup>  $p < .05$ , one tail

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## Discussion

The current study was devoted to investigate the relationship between general cognitive abilities, math anxiety, self-esteem, the quality of the student-teacher relationship, and their joint effects on mathematics achievement. The influence of general cognitive abilities on mathematics achievement has been widely explored in the literature [22]. The role of math anxiety and self-esteem, among the non-cognitive factors, has also been considered by several studies [20]. In addition, there is an increasing body of research suggesting that the quality of the student-teacher relationship plays an important role in mathematics achievement [69, 124, 125]. However, with the present study we tried to overcome some of the pitfalls of previous studies; indeed, although these constructs have been widely explored for kindergarten [126] and primary school [81], further research seems necessary for middle school [127]. Additionally, to our knowledge, no study has explored the joint effects of these factors for adolescents transitioning to middle school.

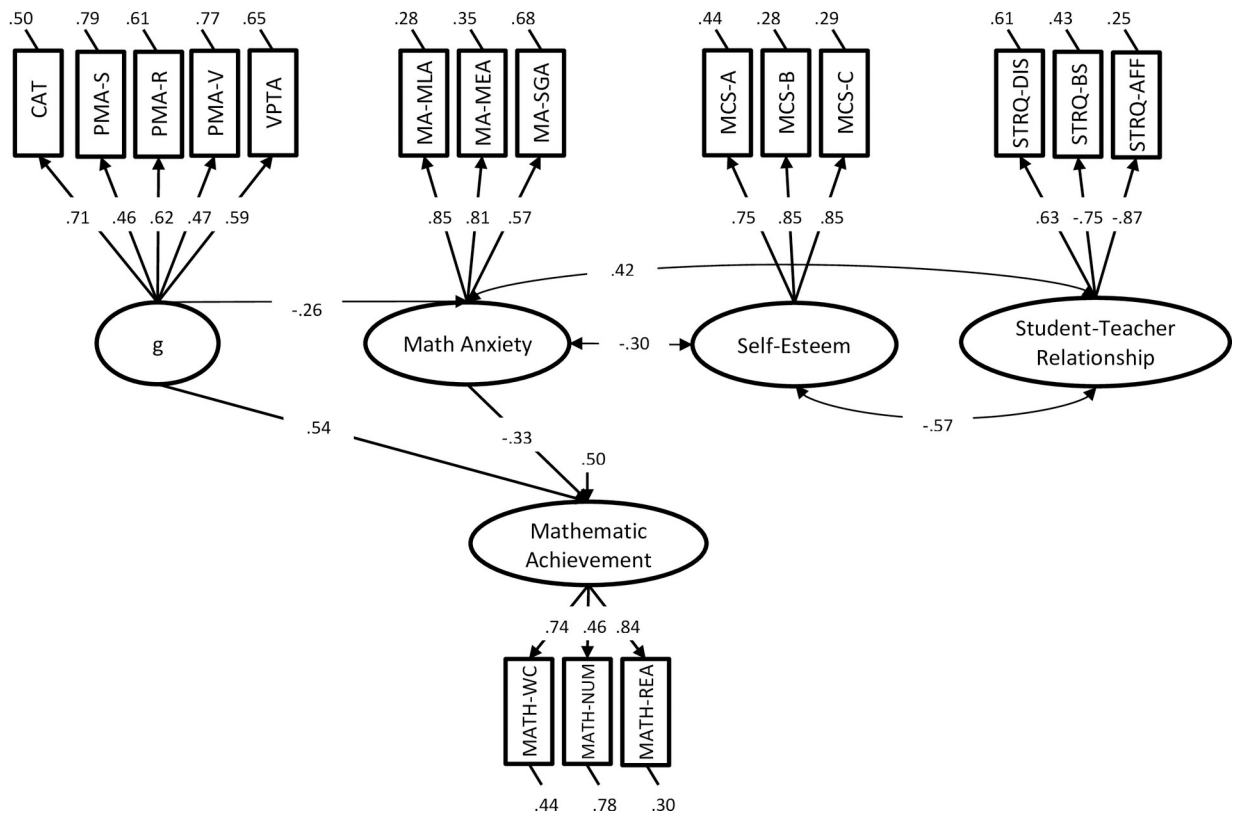


Fig 1. Model SEM-01.

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As expected, mathematics achievement and general cognitive abilities were very closely linked yet distinguishable from each other, as they only shared about half of the variance [20, 128]. Several studies corroborate these results, identifying general cognitive abilities as a relevant predictor of mathematics achievement (e.g. [128–132]). In stages of transition in schooling, such as the transition from elementary to middle school, general cognitive abilities play a more relevant role for mathematics learning, helping students to acquire the new skills and abilities required to learn new academic subjects and topics [132]. Notably, although we considered the influence of general cognitive ability on mathematics achievement, general cognitive ability explains only a portion of the mathematical variance, meaning that other variables also seem to play a role in mathematics achievement. For example, non-cognitive factors (e.g., math anxiety and self-esteem, among several others) tend to be consistently associated with mathematics achievement. With this respect, in line with previous evidence, we found a strong negative relationship between math anxiety and mathematics achievement [133–138]. The widespread findings of a negative relationship between math anxiety and performance could be interpreted in the light of studies that showed how, in this age group, students tend to implement avoidance behaviors towards mathematics [35]. This avoidance might cause students to fall even further behind in their math understanding; therefore, our findings suggest the importance of addressing math anxiety in order to improve math performance in this particular age group [139]. Efforts to curb math anxiety need to include ways to treat it in those who are already experiencing it, as well as ways to prevent it in the first place; this is why recent literature tends to focus on other factors, such as self-esteem [59, 140].

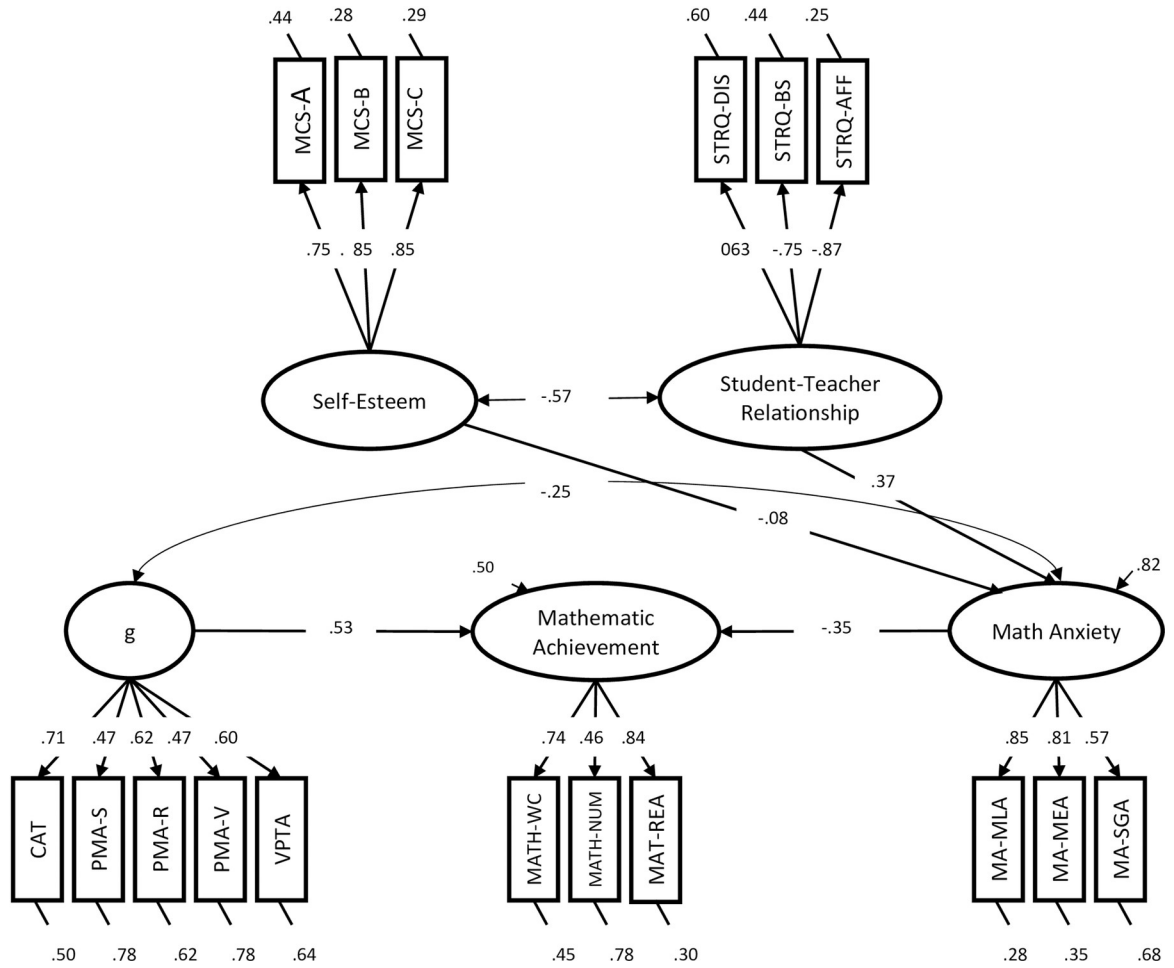


Fig 2. Model SEM-02.

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Our results showed, also, that the effects of self-esteem and the quality of the student-teacher relationship on mathematics achievement was mediated by math anxiety. As to the role played by self-esteem, the nonsignificant indirect effects on mathematics achievement were in continuity with other studies [141, 142]. This finding should be interpreted in light of the joint effects of the other variables of the model. In fact, analyzing the correlation table the relation between self-esteem and math anxiety was moderate, while the association between self-esteem and mathematics achievement was small. This effect could be interpreted in the light of the association between self-esteem and the quality of student-teacher relationship. Indeed, the correlation table showed a strong association between these measures. Therefore, the quality of student-teacher relationship explained a greater variance of the model, also absorbing the effects of self-esteem. Our results highlighted the need for further studies to disentangle the complex nature of the construct and its relation with other measures. This finding seems to indicate that other non-cognitive factors are involved, and, among others, the student-teacher relationship seems to be a prominent factor.

The quality of the student-teacher relationship is associated with mathematics achievement, through the mediation of math anxiety, thus a good quality of the relationships with the teachers dampens math anxiety, leading to effective math performances. There is growing research suggesting that student-teacher relationships may be important for mathematics achievement

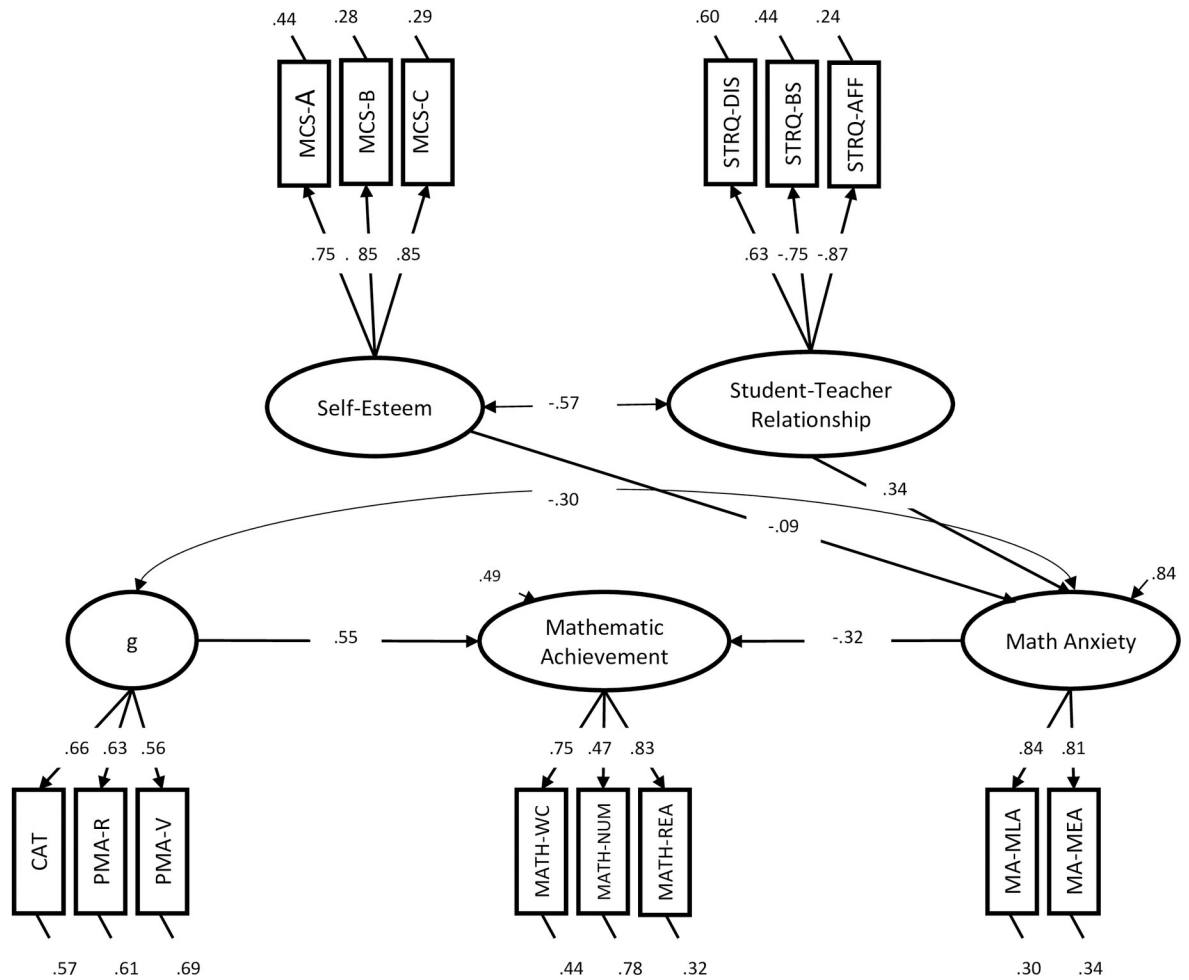


Fig 3. Model SEM-03.

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[84, 143]. However, to the best of our knowledge, this is the first study supporting such indirect pathway. It can be argued that a teacher’s emphasis on the expression of warmth, responsiveness, trust, and accessibility could support students in regulating appropriately their math anxiety, leading to a positive impact on mathematics performance. In accordance with predictions from the attachment framework, teachers act as secure bases for their students, by increasing the child’s confidence in exploring new learning materials and regulating anxiety when facing novelties, thus contributing to reducing math anxiety and positively predicting math achievement [62]. Our results thus confirm that a positive student-teacher relationship could influence mathematics achievement [65].

This study may have important implications for teacher training and professional development. For a start, the teacher’s role in promoting an emotionally supportive context and creating warm, respectful relationships with all students by empowering their socio-emotional skills should not be overlooked in favor of concerns about curriculum and direct instruction. Our findings suggest the importance of emphasizing the formation and the maintenance of close relationships between students and teachers for younger, as well as older, children (e.g., those included in the current study). This study provide evidence that teachers who build emotionally supportive relationships with their students may have an important impact on their

mathematics achievement. This type of closeness may be particularly important for improving mathematics achievement, which for children requires continued engagement with the academic material and continued practice of those competencies outside of the school context [144].

Though it contains some insightful findings, the present study also has some limitations that should be addressed by future studies. Firstly, the cross-sectional design does not allow to draw conclusions about causal relations and ways of causation. Longitudinal studies are needed to analyze how the correlations between all the variables shift over time, and especially how they influence children's performance in general and mathematical achievement specifically. Future studies should consider how the form of the relationship might vary across time. For example, it might be that student-teacher relationships are most important in the 6<sup>th</sup> grade but become less important in the transition to higher levels of education. In fact, this age group was chosen based on the observation that early genetic influences on cognition are amplified over time, and innovative genetic influences seem to arise with time [145]. However, these findings are currently under debate, and more research is needed to understand these changes over time. Future studies should also consider methods for examining the causal effects of student-teacher relationships and the impact of closeness and conflict on other subjects of the academic curriculum (e.g., reading literacy). Notably, in the present paper, half of the mathematics achievement variance was explained by the factors included in the present report, meaning other factors may also play a significant role in mathematics performance. For example, resilience seems to be positively associated with mathematics performance but was not included in the present report. Furthermore, the overall school climate also seems to play a significant role in academic performance [146]. It is also noteworthy that a convenience sample was employed in the current research and that our agreement with the schools only allowed us to test each child for a limited amount of time. Therefore, these results should be replicated with a larger sample of the population and using a broader assessment, e.g., including more tasks, and tapping executive functions, working memory, and other important aspects usually subsumed under the g-factor. Finally, using CFA and SEM does not permit the testing of the complex interlinks that might exist between factors included in the current research; therefore, these results must be considered only preliminary.

Notwithstanding these limitations, this is the first study that testing the joint influence of general cognitive abilities, math anxiety, self-esteem and the quality of student-teacher relationship on mathematics achievement. Furthermore, we decided to focus on objective and standardized measures to assess mathematics achievement, and not on an evaluation provided by the teachers (e.g., grade point average) that could be influenced by personality and other non-cognitive factors. Lastly, we decided to use a latent modelling approach, which gave us the possibility of modeling complex dependencies and structural models and of reducing the measurement errors typical in more traditional approaches. To summarize, the present study has shown that several factors, both cognitive and non-cognitive, play an important role in mathematics achievement; furthermore, the results seem to indicate that the quality of the student-teacher relationship may have an effect on mathematics achievement. These findings have a number of strengths that could help to build upon the research on student-teacher relationships and mathematics achievement.

## Author Contributions

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**Project administration:** Rosalinda Cassibba.

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**Writing – original draft:** Cristina Semeraro.

**Writing – review & editing:** David Giofrè, Gabrielle Coppola, Rosalinda Cassibba.

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