

Development of Math Attitudes and Math Self-Concepts: Gender Differences, Implicit–Explicit Dissociations, and Relations to Math Achievement

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Three hundred and ninety-one children (195 girls; $M_{\text{age}} = 9.56$ years) attending Grades 1 and 5 completed implicit and explicit measures of math attitudes and math self-concepts. Math grades were obtained. Multilevel analyses showed that first-grade girls held a strong negative implicit attitude about math, despite no gender differences in math grades or self-reported (explicit) positivity about math. The explicit measures significantly predicted math grades, and implicit attitudes accounted for additional variance in boys. The contrast between the implicit (negativity for girls) and explicit (positivity for girls and boys) effects suggest implicit–explicit dissociations in children, which have also been observed in adults. Early-emerging implicit attitudes may be a foundation for the later development of explicit attitudes and beliefs about math.

Children’s learning of mathematics is linked not only to their academic skills, but also to their attitudes (“I enjoy math”) and their beliefs about math (“I am a math person”). Early attitudes and beliefs about math have been identified as powerful longitudinal predictors of later achievement and academic choices in science, technology, engineering, and mathematics (STEM; Ceci, Ginther, Kahn, & Williams, 2014; Gunderson, Ramirez, Levine, & Beilock, 2012; Master & Meltzoff, 2020). Early gender differences in children’s attitudes and beliefs about math are important to understand because they are thought to be one stream of development that feeds into current societal inequities. The particular inequity raised here concerns the underrepresentation of women in STEM at later educational stages and in the workforce (Ceci et al., 2014).

Robust gender differences in children’s attitudes and beliefs about math are well-established in older children (late elementary school and early middle school; Cvencek, Meltzoff, & Kapur, 2014; Else-Quest, Hyde, & Linn, 2010), with boys demonstrating more positive attitudes and beliefs about math

than girls on a variety of measures (Hyde, Fennema, Ryan, Frost, & Hopp, 1990; Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2005). Such differences exist despite the fact that girls generally receive higher classroom grades than boys in mathematics at this age (Lindberg, Hyde, Petersen, & Linn, 2010). It is currently unknown when gender differences in children’s attitudes and beliefs about math first become evident, and this is relevant for theories of social–cognitive development, as well as for informing the design of interventions directed at improving STEM interests and achievement in the United States and internationally (Cvencek et al., 2020; Master & Meltzoff, 2020).

Studies that simultaneously investigate *both* attitudes and beliefs about math in the same children are rare. The few studies that have assessed both in the same children are confined to older children, well beyond elementary school (Ganley & Vasilyeva, 2011; Vandecandelaere, Speybroeck, Vanlaar, De Fraigne, & Van Damme, 2012). In part, this is due to the scarcity of appropriate instruments to differentially assess these constructs during elementary school (Adelson & McCoach, 2011). In this article, we report a novel measure of children’s attitudes toward math that can be used with

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children as young as Grade 1 and in conjunction with other measures on the same children.

Children's attitudes can be measured in many ways and at many levels of complexity (Vandecandelaere et al., 2012). At the simpler level are children's views corresponding to general emotional reactions toward math (Haladyna, Shaughnessy, & Shaughnessy, 1983), or associations between *math* and *positivity* versus *negativity* (Nosek, Banaji, & Greenwald, 2002). At the higher levels of complexity are multidimensional models that include broader beliefs and feelings about what math is, and perceptions of one's own math competence (Di Martino & Zan, 2010). Here, we combine multiple methods to capture children's attitudes toward math. With each participant, we use both simple attitudinal measures such as *math = good*, as well as multidimensional constructs involving children's verbally stated evaluations about their own feelings toward math. Measuring attitudes at both simple and multifaceted levels in the same children will allow for a richer operationalization of children's developing attitudes pertaining to math.

Alongside attitudinal measures, researchers have also been interested in assessing children's self-concepts about math, such as "I am a math person." Researchers acknowledge that math self-concepts can be defined and measured in different ways (Gunderson et al., 2012). At the simpler level are self-perceptions and identities such as children's judgments of their own personal ability in math (Harter, 1982), or an association of *self* with *math* (Cvencek, Meltzoff, & Greenwald, 2011). At higher levels of complexity are multidimensional integrative schemas informed through experience and feedback from others, conceptions of one's own self-worth in the context of being a math student, and future expectancies about one's competence in math (Eccles & Wigfield, 2020; Marsh et al., 2005). In this study, we included two measures of math self-concepts, one at the simpler level of complexity and the other at the higher level.

Over the last two decades, empirical evidence has accumulated to suggest that two types of processes need to be considered when examining children's developing attitudes and beliefs (Fazio & Olson, 2003). One type of process is characterized by introspection, awareness, and control (Kahneman, 2011). These *explicit* processes are measured in children by asking them verbal questions or having them respond to a scale or fill out a checklist. Traditionally, these involve children's self-reports and require some level of deliberation. Asking a student how much they agree with the statement "I have

always believed that mathematics is one of my best subjects" requires the child to be able to introspect about his or her thoughts, and then accurately translate that assessment into a response, often mapping their thoughts onto a Likert-like scale.

However, significant portions of the mind are not easily accessed by direct introspection in both adults and children, and even when they are accessible, children's reports of their attitudes or beliefs can often be distorted based on the "social desirability" of what they think the adult experimenter wants to hear. Therefore, one also needs ways to measure processes that are characterized as non-deliberative, unconscious, and more automatic in adults (Greenwald & Banaji, 2017) and children (Baron & Banaji, 2006; Cvencek et al., 2011). These *implicit* processes are typically measured by assessing children's attitudes and beliefs indirectly, without requiring introspection on the child's part. Implicit measures often involve simple sorting tasks in which children indicate which concepts "go together" in the child's mind. By combining both explicit and implicit measures with the same children, we can probe children's mental framework in a more comprehensive manner than is possible using one method alone.

While the explicit and implicit processes are not fully separate from one another, there is robust evidence for a dissociation between explicit and implicit attitudes and beliefs in adults (Greenwald, Poehlman, Uhlmann, & Banaji, 2009) suggesting that deliberative, conscious verbal responses (explicit) may be tapping something different from more automatic, unconscious (implicit) reactions. Moreover, work in social psychology in adults suggests that explicit and implicit measures each provide independent predictive power in explaining adult behavior (Greenwald et al., 2009). Most relevant to this study, even when they are dissociated, explicit and implicit measures have *both* been shown to be useful for predicting math-related outcomes in students (Cvencek, Kapur, & Meltzoff, 2015; Steffens, Jelenec, & Noack, 2010).

This distinction between explicit and implicit probes of children's cognition is relevant to questions in child development. Specifically, it bears on the question of whether implicit, unconscious attitudes and beliefs develop before their explicit counterparts do. Some theories hold that implicit attitudes and beliefs about math are established by formative experiences that occur prior to formal education, and that they may, in turn, play a role in the development of more explicit beliefs and attitudes (Baron & Banaji, 2006; Cvencek, Greenwald,

& Meltzoff, 2016; DeHart, Pelham, & Tennen, 2006). Empirical work that partially supports this view derives from reports that implicit math self-concepts (detectable in Grades 2–3) precede their explicit counterparts (detectable in Grades 4–5; Cvencek et al., 2011). However, to our knowledge, there are no studies examining children's *implicit attitudes toward math* as early as Grade 1. Here, we report a new measure that allows us to examine children's implicit math attitudes in younger ages than has been possible before and enables us to combine this attitudinal measure with explicit measures of math attitudes, as well as with measures of math self-concepts, in the *same* children.

From a theoretical standpoint, the conceptual distinction between attitudes and self-concepts about math also maps roughly onto the so-called "affect-competence distinction" in educational science (Arens, Yeung, Craven, & Hasselhorn, 2011). Some theorists consider affective and cognitive aspects of academic motivation to be distinguishable, but highly related constructs (Bong & Skaalvik, 2003). For example, the Self-Description Questionnaire (SDQ) has been widely used to test Marsh's (1990) multidimensional, hierarchical model of academic self-concept. In the SDQ instrument, the math self-concept assessment includes items such as "I look forward to math" and "I enjoy doing work in math." In contrast, from an Expectancy Value Theory perspective, affective and cognitive aspects of academic motivation are viewed as differentiable constructs, with clear conceptual distinctions between children's cognitive (academic self-concept) and affective (value and enjoyment) components (Eccles & Wigfield, 2020). Tests of these theories have been conducted exclusively with explicit measures, showing an age-related increase in the links between students' cognitive and affective aspects of math motivation during elementary school years (Marsh & Ayotte, 2003; Wigfield et al., 1997). It is currently unknown how separable and developmentally stable affective versus cognitive components of young children's *implicit* cognition is about math. Thus, there is a need for empirical studies measuring both cognitive and affective aspects of children's orientation to math in the same students during early elementary school using both implicit and explicit measures.

Beyond examining math attitudes and self-concepts, we also examined both of these in relation to a measurable behavioral attainment, namely school grades in math. School grades and standardized test scores are the two most commonly used indicators of students' achievement in math. We have

specifically chosen school grades in math as indicators of math achievement for four reasons. First, school grades constitute major criteria to evaluate children's academic progress in elementary school (Metsäpelto, Zimmermann, Pakarinen, Poikkeus, & Lerkkanen, 2020). Second, school grades drawn from official school records, as we have done here (as opposed to self-reported grades; Kuncel, Credé, & Thomas, 2005), represent particularly valuable information about students' achievement and are shown to be among the best longitudinal predictors of future performance in primary education (Arens et al., 2017). Third, school grades are highly salient to elementary school students: They are directly communicated and easy to compare among classmates (Arens et al., 2017). Fourth, school grades capture other aspects of student learning, such as effort, motivation, interest, and classroom behavior, all of which are also relevant to future development and success (Master & Meltzoff, 2020; McMillan, Myran, & Workman, 2002).

This study took place in the Greater Metropolitan Area of Zagreb, Croatia, which includes Zagreb, the Croatian capital and largest city, and its surrounding counties. Croatia was purposely selected for three reasons. First, Croatia has established clear evaluation criteria and national standards for grading students' achievement (Bušljeta & Kardum, 2019), which provides a level of consistency in the meaning of math grades that are not easily found in other countries (such as the United States where grading practices vary by state and locality). Second, even though Croatia has begun to close gender gaps in some STEM fields (United Nations Educational, Scientific, and Cultural Organization, 2015), large gender gaps still exist in computer science and other math-intensive fields (Croatian Bureau of Statistics, 2018). We were interested in potential gender differences in math attitudes and self-concepts, which can be measured at earlier ages than reactions to computer science. Third, in response to recent discussions about the need for broadening child study populations beyond North American samples in order to build more generalizable theories (Nielsen, Haun, Kärtner, & Legare, 2017; Wang, Fong, & Meltzoff, 2020), this study contributes useful data from Croatia.

Current Study

How early children begin to form math *attitudes*—positive versus negative affective reactions to math—is currently understudied due to the scarcity of developmentally appropriate instruments for use

with children as early as Grade 1. Here, we report a novel measure of children's implicit math attitudes and compare those to explicit math attitudes measured by self-report. We also examine math attitudes in relation to math self-concepts and math achievement in the *same* children.

The following two hypotheses were tested. First, we expected that gender differences will be evident on implicit measures at a younger age than they can be detected with explicit measures. Second, we expected that both implicit and explicit measures of attitudes and self-concepts will be associated with math achievement, and implicit and explicit measures will have unique roles. These two hypotheses were tested using a multilevel, exploratory linear regression approach. The potential contributions of the study are that it is the first to examine the relations among (a) implicit and explicit assessments (b) of both math attitudes and beliefs, (c) as well as a measure of math achievement, (d) in the same children. This is accomplished by testing independent groups of children in both Grade 1 and Grade 5 in Croatia, a country that has put substantial effort into developing a nationalized and standardized grading system.

Method

Participants

The Croatian Ministry of Education connected the researchers with eight local schools. The sample consisted of first- and fifth-grade children from Croatian, middle- and working-class families (90%) living in the Greater Metropolitan Zagreb Area, including the City of Zagreb, as well as the nearby counties (Krapina–Zagorje, Karlovac, and Varaždin counties). The elementary schools sampled thus included students raised in both urban and rural environments. Permission forms were sent to all parents of Grade 1 and Grade 5 students in the schools. A total of 391 elementary school students (195 girls) were given permission to participate (74% consent rate). Mean age of the Grade 1 students ($N = 192$; 98 girls) was 7.53 years ($SD = 0.34$). Mean age of the Grade 5 students ($N = 199$; 97 girls) was 11.53 years ($SD = 0.59$). Consistent with other studies conducted in Croatian schools (e.g., Kim & Burić, 2020), we did not ask for children's race and ethnicity since Croatians are largely homogeneous (i.e., European White).

Materials and Procedure

All testing took place between March 5, 2019 and May 7, 2019, which was partway through the

second semester of the school year. Students were tested individually in a quiet room in their school using a tablet (25 cm-diagonal screen). The experimenter provided verbal instructions to the students throughout the test, including a short introduction in which the students were told they would be playing a game on the tablet and answering some questions.

Explicit Measures

Every child completed two explicit (i.e., self-report) measures.

Explicit math attitude. Students completed the "Students Like Learning Mathematics, 4th Grade" survey from the TIMSS 2015 student questionnaire (TIMSS and PIRLS International Study Center, 2014). TIMSS items capture both "confidence" as well as "liking" dimensions of math attitudes (Martin et al., 2016). The survey asked students to indicate (by circling the appropriate option) how strongly they agreed or disagreed with specific statements about math. There were nine items. Sample items included "I enjoy learning mathematics" and "Mathematics is boring" (individual items appear in Supporting Information, Section 1.1). Possible responses on a Likert-like scale were 1 (*disagree a lot*), 2 (*disagree a little*), 3 (*agree a little*), and 4 (*agree a lot*). Items in which agreement equated to negative math attitude were reverse coded before all items were averaged. The final explicit math attitude measure was the average of the nine items and was centered around zero with upper and lower bounds of ± 2 . Thus, positive values indicated more agreement with positive statements about math, negative values indicated more agreement with negative statements about math, and a score of zero indicated equal agreement with positive and negative statements about math. Cronbach's alpha for the explicit math attitude measure in our sample was $\alpha = .93$, which is identical to the published Cronbach's alpha from the official TIMSS 2015 results for Croatia, also $\alpha = .93$ (Martin et al., 2016).

Explicit math self-concept. Students completed items from the "Mathematics Self-Concept (SCMAT)" survey from the PISA 2012 student questionnaire (Organization for Economic Co-operation and Development [OECD], 2012b). PISA items capture multiple dimensions of students' beliefs about math, such as interests, motivation, and self-concepts (OECD, 2012a). The survey asked students to indicate by circling the appropriate option how strongly they agreed or disagreed with specific

statements about math. There were five statements. Sample items included “I learn mathematics quickly” and “I am just not good at mathematics” (see Supporting Information, Section 1.2). The possible responses were 1 (*strongly disagree*), 2 (*disagree*), 3 (*agree*), and 4 (*strongly agree*). Items in which agreement equated to dis-identifying with math were reverse coded. The final explicit math self-concept measure was the average of the five items and was centered around zero with upper and lower bounds of ± 2 . Positive values indicated more agreement with statements about identifying with math, negative values indicated more agreement with statements about dis-identifying with math, and a score of zero indicated equal agreement with statements about identifying and dis-identifying with math. Cronbach’s alpha for the explicit math self-concept measure was $\alpha = .77$, which is slightly lower than the published Cronbach’s alpha for Croatia, $\alpha = .88$ (OECD, 2012a), but is still well within the acceptable range.

Implicit Measures

Every student also completed two child-friendly Implicit Association Tests (Child IAT), one assessing implicit math attitudes and the other math self-concepts. There are several child adaptations of the adult IAT (Baron & Banaji, 2006; Cvencek et al., 2011). For the current Child IAT procedures, we followed the block structures and algorithms described by Cvencek et al. (2011) for use with this age group. All stimuli used in the Child IATs were presented simultaneously as text and audio recordings in Croatian language.

The Child IAT is a sorting task in which students rapidly sort stimuli belonging to four categories using two response buttons. The underlying principle of the Child IAT is that students will respond faster when the paired categories are mentally associated (or “congruent”) versus when they are not (“incongruent”). For example, the pairing of *sky* with *birds* and *ocean* with *fish* would be congruent, whereas the pairing of *sky* with *fish* and *ocean* with *birds* would be incongruent, and children would be expected to respond more quickly to the congruent pairings. The faster the children’s responses, the stronger the presumed underlying association between the two categories (for a discussion about the reliability and validity of the Child IAT, see Cvencek et al., 2016). The speed of response was automatically measured via touch screen technology. The relevant measure used for statistical analysis was the difference (in milliseconds) between

response times when faced with congruent versus incongruent stimuli. Both Child IATs were scored using the *D*-score (Greenwald, Nosek, & Banaji, 2003), an effect-size-like index of association strength that converts the raw response times into a standardized metric of association strength, as has also been done in previous uses of a Child IAT (Baron & Banaji, 2006; Cvencek et al., 2011).

Implicit math attitude. A new Child IAT measuring math attitude was developed for this study following the techniques described in Cvencek et al. (2011). This Child IAT assessed the evaluative association of *math = good* or *math = bad*. It included the categories of *math*, *reading*, *good*, and *bad*. Sample words belonging to the *math* and *reading* categories were “count” and “books,” and sample words belonging to categories *good* and *bad* were “happy” and “mad” (see Supporting Information, Section 2.1 for individual stimuli). In one task of the Child IAT, *math* and *good* words shared a response button, and *reading* and *bad* words shared the other response button. In another task, the *good* and *bad* categories were switched so that *math* and *bad* shared a response button and *reading* and *good* shared the other. Students who hold a positive math attitude should respond faster when *math* and *good* are paired together. The math attitude Child IAT score (*D*) was calculated by first (a) computing the difference between the mean response latencies of the *math = good* and *math = bad* tasks for each subject, then (b) dividing that difference by the pooled standard deviation (Greenwald et al., 2003). Positive *D* scores indicated a stronger association of *math* with *good* (upper bound: +2), and negative *D* scores indicated a stronger association of *math* with *bad* (lower bound: -2). The math attitude Child IAT had a rational value of 0, which indicated an equally strong association of *math* with both *good* and *bad*. Cronbach’s alpha for the implicit math attitude measure was $\alpha = .71$.

Implicit math self-concept. The Child IAT measuring math self-concept assessed the identity association of *self = math* or *self = reading*. The math self-concept Child IAT included the categories *self*, *other*, *math*, and *reading*. Stimuli in the *math* and *reading* categories were the same as those used in the math attitude Child IAT. Sample words belonging to categories *self* and *other* were “my” and “them” (see Supporting Information, Section 2.2 for individual stimuli). In one task of the Child IAT, *self* and *math* words shared a response button, and *other* and *reading* words shared the other response button. In another task, the *self* and *other* categories were switched so that *other* and *math* shared a

response button, and *self* and *reading* shared the other. Students who hold a positive math self-concept should respond faster when *self* and *math* are paired together. Implicit math self-concept was scored so that positive values indicated a *self* = *math* association, negative values indicated a *self* = *reading* association, and a score of zero indicated an equally strong association of *self* with both *math* and *reading*. Cronbach's alpha for the implicit math self-concept measure was $\alpha = .66$.

All measures were counterbalanced to account for three factors: (a) the order of the measures (explicit vs. implicit; 2 orders), (b) the order of the constructs (math attitude vs. math self-concept; 2 orders), and (c) the order of the IAT tasks (congruent task vs. incongruent task within both IATs; 4 orders), resulting in 16 unique conditions. Detailed analyses showing that none of the counterbalancing factors had any effects on either implicit or explicit measures (all $ps > .31$) can be found in the Supporting Information, Section 3.1. In addition, evidence for the validity of the explicit and implicit measures can be found in the Supporting Information Section 4.1.

Achievement Measure

Math grades for students were provided by teachers in both Grades 1 and 5. As is standard across all Croatian elementary schools, achievement was rated on a national grading scheme that uses a scale of 1 (*insufficient*), 2 (*sufficient*), 3 (*good*), 4 (*very good*), or 5 (*excellent*). Because some students were given three grades, some were given four, etc., a given child's school grades in math were averaged to arrive at an index of *math achievement* (range 1–5) for each child.

Data Reduction

Students' data were excluded from analyses if they met any of three standard exclusion criteria on either of the two implicit measures. Meeting these criteria indicates a lack of focus or a lack of understanding by the student on the implicit assessment procedure. On each measure, data were excluded if a student (a) responded too quickly to too many of the trials ($> 10\%$ of trials under 300 ms), (b) responded too slowly (average response latency 3 *SDs* above the mean), or (c) made too many ($> 35\%$) errors (Cvencek et al., 2011). These criteria resulted in excluding data for 23 students. Data were excluded for an additional 13 students for whom school grades were not available, resulting

in a final sample of $N = 355$ (182 girls) with complete, valid data.

Data Analytic Approach

We employed three-level linear regression models to test hypotheses, with students (Level 1, $n = 355$) nested within classrooms (Level 2, $n = 31$), within schools (Level 3, $n = 8$). This multilevel approach allows for testing predictor effects at their appropriate levels with correct degrees of freedom (i.e., testing grade effects at the classroom level), as well as decomposing lower-level predictor effects into within- and between-classroom components because relations can differ at different levels (Hamaker & Muthén, 2020).

Our models were focused on three research questions: First, what are the mean values for the explicit and implicit math attitudes and self-concepts for boys and girls in early and late elementary grades (Grades 1 and 5)? Second, do boys and girls differ in their math attitudes and self-concepts, and does this vary by grade? Third, do *implicit* math measures predict math achievement over and beyond *explicit* math measures and do effects vary by grade or gender?

Prior to testing our research questions, intercept-only models (i.e., estimating variance components) were conducted to evaluate the degree of nonindependence in student data present due to classrooms and schools. Classroom differences explained 18% of the variance in math achievement, and school differences explained an additional 5%, for a total of 23%. For the two explicit measures, the school did not explain any variation, but the classroom explained 12% of math attitude and 10% of math self-concept. For the implicit measures, the classroom explained 3% of the variance in math attitude and none in math self-concept; no variance was explained by the school. For consistency and brevity, we retained a three-level structure for all models, which were conducted using *R* lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages; the latter provides Satterthwaite degrees of freedom for fixed effects tests. Effect sizes for model coefficients were computed as follows: d equals coefficient divided by pooled *SD*, where the pooled *SD* is the square root of the sum of the model variance components. For our final model, approximate R^2 was computed as the variance of the predicted values divided by the total variance, which, in turn, was computed as predicted variance plus model variance components.

Results

We provide unadjusted descriptive statistics for all measures by grade and gender in Table 1. For math attitudes, positive scores indicate positive attitudes toward math and negative scores indicate negative attitudes. For self-concepts, positive scores indicate identifying oneself more with math; negative scores indicate the opposite. For both measures, zero indicates neutrality.

Explicit and Implicit Measures

For both explicit and implicit measures of math attitude and self-concept, we used three-level models to test for main effects due to classroom grade level (Level 2), student gender (Level 1), and their interaction. Next, to gauge students' positivity, we conducted three-level intercept-only models for each grade-gender combination to test whether means were significantly different from zero (neutral). Last, as a follow-up, we conducted three-level models for each grade level separately to test whether boys and girls differed significantly within their respective grade levels. Figure 1, Panel A illustrates the results of these tests for the explicit measures; Panel B shows the results for the implicit measures. We discuss the findings below.

Explicit Math Attitude

Our overall multilevel model results (with grade, gender, and grade-by-gender interaction tests) showed a significant effect of grade level on explicit math attitude, $t(21) = -6.93, p < .001$, with Grade 5 averaging 0.68 points lower than Grade 1 (across genders), and a significant grade-by-gender interaction, $t(353) = 2.07, p = .039$. There was no significant main effect of gender, $p = .328$. As shown in the left four bars in Figure 1, Panel A, both girls and boys across grade levels reported positive attitudes toward math. On the explicit math attitude measure, girls had significantly positive math attitudes in Grade 1, $p < .001, d = 0.87$, and in Grade 5, $p < .001, d = 0.85$. Boys also had significantly positive math attitudes in Grade 1, $p < .001, d = 2.11$, and in Grade 5, $p = .002, d = 0.53$. Finally, in Grade 1, boys had more positive math attitudes than girls, $p = .009, d = 0.41$, but the difference was not significant in Grade 5, $p = .510$.

Explicit Math Self-Concept

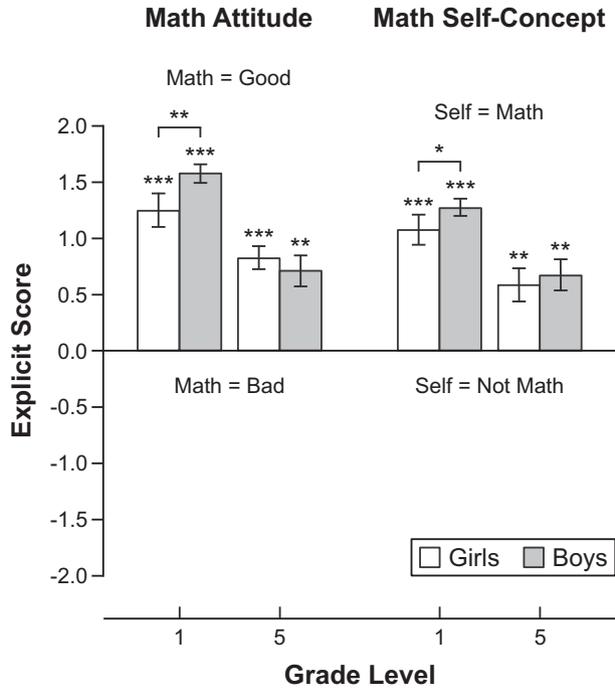
Our overall multilevel model results showed a significant effect of grade level on explicit math self-concept, $t(27) = -5.60, p < .001$, with Grade 5 averaging 0.54 points lower than Grade 1 (across

Table 1
Descriptive Statistics for All Explicit, Implicit, and Achievement Measures for Girls and Boys in Grade 1 and Grade 5

Measure	Cronbach's α	Girls				Boys			
		<i>M</i>	<i>SD</i>	Min	Max	<i>M</i>	<i>SD</i>	Min	Max
Explicit math attitude	.93	1.06	0.94	-1.70	2.00	1.12	1.01	-2.00	2.00
Grade 1	.92	1.31	0.84	-1.41	2.00	1.58	0.76	-1.41	2.00
Grade 5	.92	0.82	0.97	-1.70	2.00	0.75	1.03	-2.00	2.00
Explicit math self-concept	.77	0.81	0.92	-1.73	2.00	0.97	0.88	-1.47	2.00
Grade 1	.64	1.09	0.76	-0.67	2.00	1.28	0.69	-0.67	2.00
Grade 5	.81	0.55	0.98	-1.73	2.00	0.71	0.93	-1.47	2.00
Implicit math attitude	.71	-0.14	0.34	-1.09	1.06	-0.02	0.34	-0.77	0.89
Grade 1	.70	-0.12	0.33	-0.90	0.63	-0.03	0.33	-0.68	0.73
Grade 5	.71	-0.17	0.35	-1.09	1.06	-0.01	0.34	-0.77	0.89
Implicit math self-concept	.66	-0.09	0.29	-0.74	0.71	0.002	0.31	-0.82	0.70
Grade 1	.63	-0.09	0.29	-0.74	0.51	-0.01	0.33	-0.82	0.66
Grade 5	.69	-0.09	0.29	-0.67	0.71	0.01	0.29	-0.61	0.70
Math achievement	—	4.45	0.80	1.00	5.00	4.47	0.76	2.00	5.00
Grade 1	—	4.74	0.55	3.00	5.00	4.78	0.47	3.00	5.00
Grade 5	—	4.17	0.90	1.00	5.00	4.22	0.85	2.00	5.00

Note. Bold font indicates significant difference from the scale midpoint (unadjusted for classroom and school), $p < .05$. Cronbach's α for math achievement (classroom grades) not available.

A. Explicit Measures



B. Implicit Measures

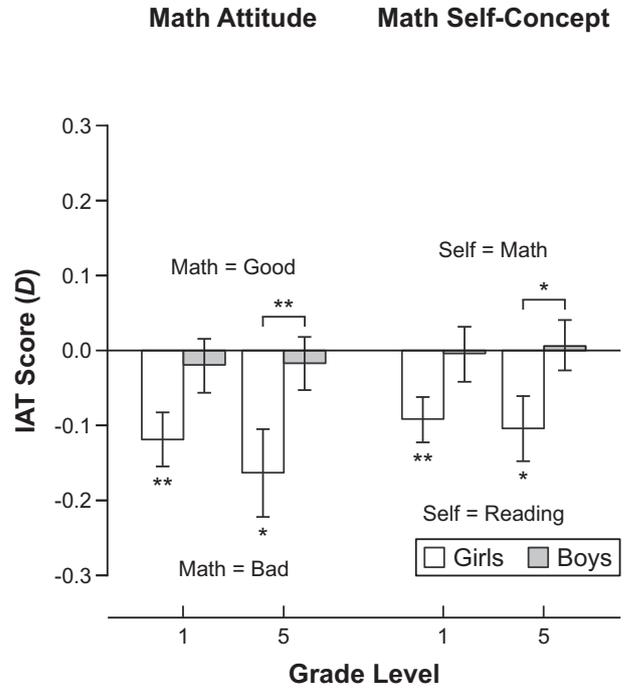


Figure 1. Model-adjusted means for explicit (A) and implicit (B) measures, split by gender. Asterisks above or below bars indicate significant difference from zero. Brackets indicate significant difference between genders. Error bars = model-estimated standard errors. * $p < .05$. ** $p < .01$. *** $p < .001$.

genders), but no significant gender effect, $p = .056$, and no significant grade-by-gender interaction, $p = .78$. As can be seen from the right four bars in Panel A, both girls and boys across grade levels reported positive math self-concept. On the explicit math self-concept measure, girls had positive identification with math in both Grade 1, $p < .001$, $d = 0.84$, and Grade 5, $p < .004$, $d = 0.41$. Boys also had significantly positive identification with math in Grade 1, $p < .001$, $d = 1.83$, and Grade 5, $p < .002$, $d = 0.50$. Similar to our finding for explicit math attitude, boys and girls only differed significantly in Grade 1, with boys again higher than girls, $p = .046$, $d = 0.31$; there was no difference in Grade 5, $p = .27$.

Implicit Math Attitude

On the implicit math attitude measure, positive scores indicate *math = good* associations, and negative scores indicate *math = bad* associations. In contrast with the explicit measure of math attitude, our overall multilevel model results showed no significant effect of grade level on implicit math attitude, $p = .67$, but there was a significant gender effect, t

(353) = -3.41 , $p < .001$, with girls lower by 0.12 points (across grades). No significant grade-by-gender interaction was detected, $p = .52$. As shown in the left four bars in Figure 1, Panel B, implicit math attitudes were significantly negative for girls across grades, but boys did not differ from zero (neutral). Specifically, implicit math attitude was significantly negative for girls in Grade 1, $p = .005$, $d = -0.35$, and it was also significantly negative in Grade 5, $p = .025$, $d = -0.29$. It was not significantly negative or positive for boys in either grade, $ps > .57$. (Additional post hoc examination of neutral math attitudes in boys can be found in the Supporting Information, Section 5.1) Unlike the finding for explicit math attitude, on implicit math attitude, boys and girls differed significantly in Grade 5 only, with boys having more positive math attitudes than girls, $p = .006$, $d = 0.41$, but no difference was found in Grade 1, $p = .054$.

Implicit Math Self-Concept

On the implicit math self-concept measure, positive scores indicate *self = math* associations, and negative scores indicate *self = reading* associations.

The right four bars in Figure 1, Panel B show that girls connected themselves more strongly with reading (and thus negatively with math), whereas boys demonstrated no strong preference in their associations of themselves with math or reading (thus close to zero). In contrast with the explicit measure of math attitude, our overall multilevel model results showed no significant effect of grade level on implicit math attitude, $t(355) = 0.23$, $p = .82$, but there was a significant gender effect, $t(355) = -2.93$, $p = .004$, with girls lower by 0.10 points (across grades). No significant grade-by-gender interaction was detected, $t(355) = -0.16$, $p = .87$. When we examined each grade-gender combination, our level models showed that girls associated *self* with *reading* significantly more than with *math* in both Grade 1, $p < .003$, $d = -0.32$, and Grade 5, $p = .042$, $d = -0.25$; in contrast, boys did not, $ps > .79$. The difference between girls and boys was only significant in Grade 5, $p = .025$, $d = 0.33$; there was no difference detected in Grade 1, though there was a trend in the same direction, $p = .066$.

Academic Achievement (Math Grades)

Examining the unadjusted frequencies of students' math grades at each of the five levels of achievement revealed left skew, as follows: "insufficient" (0.3%), "sufficient" (2%), "good" (10%), "very good" (27%), and "excellent" (61%). Nevertheless, in our statistical models, we found that modeling log-transformed grades showed substantively similar results. More importantly, model residual errors did not exhibit significant skew or kurtosis; hence, we retain the original grade metric throughout for brevity and ease of interpretation.

Table 2
Correlations Among All Measures

Measure	1	2	3	4	5
1. Explicit math attitude	—	.70***	.16**	.09	.40***
2. Explicit math self-concept		—	.18***	.03	.57***
3. Implicit math attitude			—	.16**	.14**
4. Implicit math self-concept				—	.05
5. Math achievement (grades)					—

Note. Pearson's r for all explicit, implicit, and achievement measures; correlations are unadjusted for classroom and school membership.

** $p < .01$. *** $p < .001$.

Unadjusted Relations Among Math Attitude, Self-Concept, and Achievement

Table 2 shows unadjusted correlations between all explicit, implicit, and achievement measures. Both explicit measures were positively related to grades for both genders, $rs > .37$, $ps < .001$, $ds > 0.82$. In addition, implicit math attitude was positively related to explicit math attitude and explicit math self-concept, $rs > .15$, $ps < .04$, $ds > 0.31$. Finally, implicit math attitude was positively related to implicit math self-concept and grades for boys, $rs > .17$, $ps < .03$, $ds > 0.35$, but not for girls, $ps > .16$. (See Supporting Information, Section 6.1, Tables S2 and S3 for correlations within each grade, and Table S4 for correlations within each gender.) This pattern of correlations shows that: (a) both explicit and implicit measures are positively correlated with math achievement, and (b) explicit measures are more correlated with math achievement than implicit measures.

Predicting Math Grades: The Contribution of Implicit Measures Beyond Explicit Measures

Given the observed pattern in the correlations, our remaining question of interest for theory and practice is whether implicit measures provide any additional contribution to predicting math achievement beyond the (already predictive) explicit measures. To explore this question, we conducted a three-level analysis predicting math grades with three blocks (models) analogous to a sequential regression analysis. Block 1 predictors included classroom grade, student gender, and their interaction. In Block 2, we added *explicit* math attitude and math self-concept, as well as their interactions with grade and gender. Lastly, in Block 3, we added *implicit* math attitude and math self-concept, along with their interactions with grade and gender. Across Blocks 2 and 3, we decomposed the math attitude and self-concept measures into their classroom and student levels in order to tease apart potential aggregate classroom effects from student-level individual differences. Our focus in the present study is on student-level individual differences, especially given that we did not measure all students in each classroom.

Grade and gender effects (Block 1). Results from Block 1 revealed a significant grade effect (Grade 5 students had significantly lower grades than Grade 1 students), but no gender effect, $p = .720$, or grade-by-gender interaction, $p = .790$; approximate $R^2 = .19$.

Explicit effects (Block 2). The likelihood ratio test comparing Block 2 (explicit math attitude and self-concept predictors, and their interactions with grade and gender) with Block 1 (grade and gender effects) revealed a significantly better model fit with explicit measures added, $\chi^2(16, N = 355) = 183.10$, $p < .001$; approximate $R^2 = .49$. In other words, 30% more variance in math grades was explained by the explicit measures. Within this block, student math self-concept and its interaction with grade were uniquely positively related with grades (discussed below).

Implicit effects (Block 3). The likelihood ratio test comparing the contribution of Block 3 variables to the prediction of math grades above that of Blocks 1–2 was also significant, $\chi^2(16, N = 355) = 28.90$, $p = .025$, indicating that implicit measures of math attitude and self-concept and their Grade Level \times Gender interactions contributed to the prediction of math grades above and beyond explicit effects alone; approximate $R^2 = .52$, showing that an additional 3% variance in grades was explained by the implicit measures. Combined, the explicit and implicit measures (and associated interactions) accounted for 33% of the variance in math grades, controlling for gender and grade level effects. Given that implicit measures were correlated with explicit measures, we endeavored to untangle the unique and shared contributions of each. To this end, we entered implicit measures as Block 2 (instead of Block 3) and found the approximate $R^2 = .32$, 13% more variance explained than Block 1. Taken together, 10% of the variance explained in math grades is shared by both implicit and explicit measure effects; explicit effects uniquely predict 20% of the variance in math grades and implicit effects uniquely predict 3%.

Individual predictor effects. Table 3 displays the fixed effects results for the final model with all predictors entered. As can be seen, grade level significantly negatively predicted math achievement, with Grade 5 students 0.19 points lower than average and 0.38 points lower than Grade 1 students, but there was no main effect of gender or Grade Level \times Gender interaction.

Within the *explicit* measures, student math attitude interacted with grade level and gender in a three-way interaction: follow-up tests showed that, within each Grade Level \times Gender Subgroup, explicit math attitude did not show any significant relation with math grades, $ps > .05$, although a trend was observed for Grade 1 girls' explicit math attitude to correlate positively with math grades, $p = .077$, $d = 0.23$. As shown in Table 3, explicit

(student-level) math self-concept had an overall positive relationship with math grades but also interacted with grade level. Follow-up tests of the interaction showed that it positively predicted math grades for Grade 5 students, $p < .001$, $d = 0.93$, but not Grade 1 students, $p = .304$.

Within the *implicit* measures, there were significant interactions among math attitude and gender at both the classroom aggregate and individual student levels, as well as a significant interaction between classroom aggregate math self-concept and grade level. At the individual level (our focus for this study), students' implicit math attitude was positively predictive of math grades for boys, $p = .010$, $d = 0.21$, but not girls, $p = .204$ (see Figure 2).

Discussion

A new, child-friendly implicit measure of math attitudes was developed for use with children as young as Grade 1. This allowed us to uncover evidence that, by first grade, girls have already developed a strong implicit negativity about math (*math = bad*), and that this implicit, unconscious negativity exists in the absence of gender differences in math achievement or explicit self-reports about math attitudes. The striking contrast between the direction of the implicit and explicit findings on attitude and self-concept measures (see Figure 1, Panels A vs. B) suggests an early emerging implicit–explicit dissociation in children, which mimics similar findings of implicit–explicit dissociations in adults (Greenwald et al., 2009) and raises important issues for developmental theory. We also found evidence that positive explicit math attitudes and self-concepts were associated with higher math achievement more strongly than corresponding implicit measures were. However, implicit measures did account for unique variance for boys.

Early Acquisition of Implicit Negativity About Math in Young Girls

One central finding from the current work is that, as early as Grade 1, girls had significant negative implicit math attitudes, and boys did not. This is among the earliest demonstrations of a strongly negative attitude toward math by girls. We believe that there are two likely contributing factors to this early arising negativity. The first is math anxiety (which is held by certain adult role models) and the second is math–gender stereotypes (which are

Table 3
 Multilevel Model Fixed Effects Results Predicting Math Achievement (Grades)

Fixed effects	Coefficient	(SE)	<i>t</i>	(<i>df</i>)	<i>p</i>	<i>d</i>
Intercept (mean achievement)	4.52	(0.11)	39.60	(11)	< .001	7.91
Grade (+1 = Grade 5, -1 = Grade 1)	-0.19	(0.06)	-2.97	(235)	.003	-0.34
Gender (+1 = girl, -1 = boys)	-0.03	(0.05)	-0.63	(348)	.528	-0.05
Grade × Gender	0.04	(0.05)	0.80	(347)	.424	0.07
Explicit measures						
Classroom math attitude (Z)	0.00	(0.10)	-0.01	(268)	.992	0.00
Grade × Classroom MA	0.01	(0.08)	0.17	(348)	.862	0.03
Gender × Classroom MA	-0.07	(0.07)	-1.02	(346)	.309	-0.13
Grade × Gender × Classroom MA	0.04	(0.07)	0.61	(348)	.541	0.08
Student math attitude (Z)	0.02	(0.04)	0.64	(346)	.525	0.04
Grade × Student MA	-0.01	(0.04)	-0.21	(346)	.833	-0.01
Gender × Student MA	-0.01	(0.04)	-0.25	(348)	.801	-0.02
Grade × Gender × Student MA	-0.08	(0.04)	-2.12	(347)	.034	-0.14
Classroom math self-concept (Z)	0.12	(0.08)	1.57	(327)	.119	0.22
Grade × Classroom MSC	0.14	(0.07)	1.92	(345)	.056	0.24
Gender × Classroom MSC	0.08	(0.06)	1.22	(346)	.224	0.14
Grade × Gender × Classroom MSC	-0.10	(0.06)	-1.55	(347)	.123	-0.18
Student math self-concept (Z)	0.31	(0.04)	8.11	(346)	<.001	0.54
Grade × Student MSC	0.26	(0.04)	6.85	(346)	<.001	0.46
Gender × Student MSC	0.06	(0.04)	1.47	(349)	.141	0.10
Grade × Gender × Student MSC	0.04	(0.04)	1.11	(347)	.270	0.07
Implicit measures						
Classroom math attitude (Z)	-0.03	(0.06)	-0.43	(310)	.668	-0.04
Grade × Classroom MA	-0.07	(0.06)	-1.17	(314)	.244	-0.12
Gender × Classroom MA	0.15	(0.05)	3.01	(347)	.003	0.26
Grade × Gender × Classroom MA	-0.03	(0.05)	-0.62	(347)	.536	-0.05
Student math attitude (Z)	0.04	(0.03)	1.33	(346)	.186	0.07
Grade × Student MA	0.01	(0.03)	0.23	(346)	.821	0.01
Gender × Student MA	-0.07	(0.03)	-2.49	(348)	.013	-0.13
Grade × Gender × Student MA	0.03	(0.03)	0.95	(347)	.343	0.05
Classroom math self-concept (Z)	-0.03	(0.06)	-0.48	(351)	.630	-0.05
Grade × Classroom MSC	0.14	(0.06)	2.49	(353)	.013	0.24
Gender × Classroom MSC	-0.11	(0.05)	-2.09	(349)	.037	-0.19
Grade × Gender × Classroom MSC	0.04	(0.05)	0.81	(348)	.419	0.07
Student math self-concept (Z)	0.01	(0.03)	0.35	(346)	.730	0.02
Grade × Student MSC	0.02	(0.03)	0.62	(346)	.538	0.03
Gender × Student MSC	0.05	(0.03)	1.62	(348)	.106	0.08
Grade × Gender × Student MSC	-0.03	(0.03)	-0.89	(347)	.372	-0.05

Note. Bold font indicates $p < .05$. Z = z-score; MA = math attitude; MSC = math self-concept.

pervasive societal views about “who does math”). These have been previously demonstrated by Grade 2, respectively, by Beilock, Gunderson, Ramirez, and Levine (2010) and Cvencek et al. (2011).

One can distinguish negative math attitudes from the related construct of “math anxiety.” Strictly speaking, one can have a negative math attitude without it rising to the level of math anxiety, which tends to involve more severe, sometimes uncontrollable negative emotional reactions in situations that involve numerical activities,

tension in testing situations, and autonomic reactions (Dowker, Sarkar, & Looi, 2016). It has been reported that there is a higher prevalence of math anxiety in adult women than in adult men (Ferguson, Maloney, Fugelsang, & Risko, 2015). Additionally, elementary-school children with higher math anxiety tend to have lower math achievement (Harari, Vukovic, & Bailey, 2013). Interestingly, research with elementary-school girls has shown that girls (especially) are susceptible to “catching” math anxiety from math-anxious female

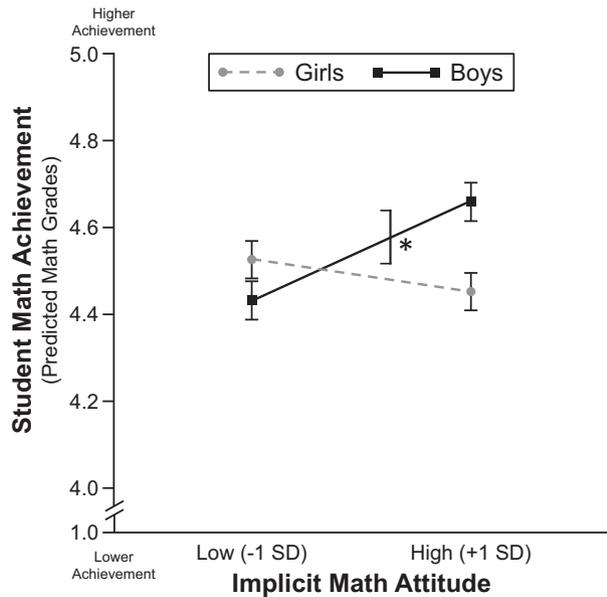


Figure 2. More positive student implicit math attitude relates to higher achievement (predicted math grades) in boys but not in girls. Bracket indicates significant slope. Error bars = model-estimated standard errors.

* $p = .01$.

teachers (Beilock et al., 2010). We thus conjecture that young girls could develop negative math attitudes (*math = bad*, as reported in the current work) through the teacher-to-student transfer of affect from math-anxious teachers (Casad, Hale, & Wachs, 2015).

Another possible contributor to girls, as early as Grade 1, having strongly negative attitudes toward math involves the societal stereotypes. In many countries, including Croatia, there is a prevalent math-gender stereotype among adults that associates math with males (Nosek et al., 2009). Adults' stereotypes are early sources of children's own beliefs about "who does math" (del Río, Strasser, Cvencek, Susperreguy, & Meltzoff, 2019; del Río et al., 2020; Tomasello, Alparone, & Cadinu, 2011). If a girl registers the pervasive adult stereotypes about *boys = math*, she may develop her own stereotype that "girls don't do math" and begin to feel that she does not like math because math is not something that is done by other "like-me" individuals (Meltzoff, 2007). Our results with explicit measures are consistent with this speculation, but we did not directly assess stereotypes in this study. Future research should incorporate a more comprehensive battery of measures to elucidate the emergence of negativity toward math in young girls.

Differences in Implicit Versus Explicit Cognition

Given the growing attention to implicit attitudes in children, implicit-explicit dissociations are beginning to be documented in elementary school in a variety of domains (del Río et al., 2019; Dunham, Baron, & Banaji, 2006). This typically involves non-significant correlations between implicit and explicit measures of the same construct, such as measures of race attitudes (Baron & Banaji, 2006; Qian et al., 2016). This article adds to this literature by extending to the domain of math, and by finding different patterns of results with implicit and explicit measures. As shown in Figure 1, one would draw different conclusions if one were presented with only explicit data (Panel A) or only implicit data (Panel B).

We believe the early-arising dissociations between the implicit and explicit measures may be, in part, due to their different origins and development. The experiences a person has early in life have a particularly important role in shaping "automatic," implicit processing (DeHart et al., 2006). Although there is interindividual and cross-cultural variation, many adult women across the cultures tested to date show an implicit negativity toward math (*math = bad*; Nosek et al., 2002), and this is strongly the case in both the United States and Croatia. Here, those patterns were found on implicit measures as early as Grade 1. This suggests that the adult state (gender-linked negativity toward math) is evident on implicit measures before such differences emerge on explicit measures. We believe that children first form implicit attitudes about math via influence from the prevailing attitudes of adults in their culture, perhaps through implicit observational learning (Lee, Meltzoff, & Kuhl, 2020). These early-emerging, gender-linked implicit attitudes about math then form the groundwork for and guide the later development of explicit attitudes about math (see Baron & Banaji, 2006, for related reasoning about implicit racial attitudes).

Implicit Attitudes Contribute Unique Variance to Math Achievement Beyond Explicit Attitudes for Boys

The current work also addresses issues relevant to the understanding of children's achievement. In line with previous work with explicit measures (Marsh & Ayotte, 2003; Wigfield et al., 1997), the measures of explicit math attitudes and explicit math self-concepts were (a) weakly correlated with each other, but (b) both were strongly related to math achievement (see Table 2). In the

case of implicit math attitudes, this relation was evident over and above the variance accounted for by explicit math attitudes in boys. The reason for this incremental effect in boys may lay in the fact that, in many cultures, boys are the positively stereotyped group when it comes to math, that is, *math = male gender* (Nosek et al., 2009). Research shows that when parents display implicit math-gender stereotypes, those stereotypes are evident earlier in their sons than in their daughters (del Río et al., 2019). Croatia still has STEM gender gaps, particularly in math-intensive technological and computer sciences. For example, 73% of PhD degrees awarded in technology in Croatia are awarded to males (Croatian Bureau of Statistics, 2018). Just as stereotypes may discourage young girls from developing positive attitudes and beliefs about math (see above), these same stereotypes may also serve to “buffer” young boys from developing negative attitudes about math, and indeed motivate them to engage in math-related activities more often (Martin, Ruble, & Szkrybalo, 2002; Master & Meltzoff, 2020). Because implicit attitudes involve simple memory links and are consistent with prevailing cultural stereotypes, they will be frequently rehearsed or reinstated in boys’ minds. After repeated reinstatements, boys’ implicit attitudes may become unconsciously connected with their own math efforts, behaviors, and achievement. For girls, this may not occur because pervasive cultural stereotypes work against the strengthening of these attitude–achievement connections.

A related finding involves the difference in effect sizes for the effect of attitudes compared to self-concept on math grades, perhaps indicating that implicit attitude is established earlier and present more strongly than students’ math self-concept is. This is also consistent with other research showing that implicit math self-concepts emerge relatively later in development (Grades 4–5; Cvencek et al., 2014). From the perspective of developmental theory, we, therefore, regard it as more plausible that math attitudes have a stronger influence on math self-concepts than the reverse because it is relatively implausible that the weaker and less stable effect produces the stronger and more stable one. (This would also be consistent with our observation that the implicit math attitude measure showed higher internal consistency for both grades than the implicit math self-concept measure; see Table 1.) However, further longitudinal research is needed to pinpoint the causal pathway.

Limitations

While this study has several notable strengths, the findings should be interpreted with several limitations in mind. First, the study utilized a cross-sectional design, which limits our ability to investigate causal relations among variables. Generally, longitudinal studies suggest that the relations between children’s attitudes and beliefs and their actual achievement are bidirectional: Prior attitudes and beliefs affect subsequent achievement, and prior achievement affects subsequent attitudes and beliefs (Marsh & Craven, 2006). Longitudinal studies that incorporate designed interventions are the most powerful way of examining causal links in development, and this study was not designed to do this, though it provides data that are relevant to such designs in elementary school in the future.

Second, it has been suggested that attitudes and self-concepts about math may engender different types of math-related outcomes (Arens et al., 2011). Self-concepts are reported to influence immediate outcomes (e.g., actual performance on a test), whereas attitudes are believed to be more strongly related to long-term educational choices (e.g., course enrollment and future aspirations). Future studies could use our measures and additionally include a broader scope of achievement indicators within the same study to examine both immediate (school grades, standardized test results), as well as long-term outcomes (future interest, career aspirations).

Third, a fuller battery might be desirable (although we already measured four constructs plus achievement). This battery might require multiple test sessions with each child, but it could involve a combination of several implicit and explicit measures. For example, one could combine the currently used Child IAT with a Draw-A-Scientist Task (Miller, Nolla, Eagly, & Uttal, 2018) or the Affective Misattribution Procedure (Williams, Steele, & Lipman, 2016), both of which have been used as early as elementary school. Similarly, qualitative approaches grounded in student interviews (Di Martino & Zan, 2010) or explicit questionnaires such as the SDQ (Marsh & Craven, 2006) also have a history of productive use in the assessment of attitudes and self-concepts.

Fourth, the study was conducted in Croatia, and further tests will be needed to check whether the results generalize beyond the culture tested. To date, the lion’s share of publications on children’s math beliefs and attitudes have been done on U.S. samples, and the call for extending studies of child development in other cultures outside the United States is

increasing. We have fulfilled this aim here, but testing outside the United States raises the reciprocal issue of whether the Croatian results would generalize to the United States. The present data provide results from a country that has the advantage of a standardized grading system, and we fully acknowledge that it would be beneficial to replicate this study in other cultures (including in the United States), and particularly other countries that show different patterns of adult beliefs and attitudes about gender and math (del Río et al., 2019).

Fifth, the foregoing discussion about children's developing implicit math attitudes and implicit math self-concepts has been phrased in terms of mathematics. We acknowledge, however, that it is possible that the results reported here could, at least in part, be due to the positivity of girls about reading (rather than just their negativity about math). Given the relative nature of the Child IAT measures, it is difficult to untangle whether girls have generally negative attitudes about math, generally positive attitudes about reading, or relatively more positive attitudes about reading compared to math. Measurement of single-category attitudes may require using a different measurement tool designed for such purposes.

Conclusion

How children feel and what they think about math is related to their math achievement during elementary school. As early as Grade 1, girls have developed an implicit negativity about math, even in the absence of gender differences in math achievement or self-reported (explicit) positivity about math. While the explicit math attitude and self-concept measures uniquely explained 20% of math achievement variance, the implicit measures explained an additional 3%. Furthermore, for boys, differences in the implicit measure of math attitude were predictive of math grades. Implicit attitudes may be acquired rapidly, effortlessly, and without explicit instruction. Such early-emerging implicit attitudes may not only form the groundwork for the development of explicit attitudes, but may also serve as a foundation for interests (where students spend time), choices (what classes and clubs they join), learning, and their emerging implicit and explicit sense of identity.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

- Appendix S1.** Items for Explicit Questionnaires
- Appendix S2.** Child IAT Stimuli
- Appendix S3.** Counterbalancing
- Appendix S4.** Construct Validity and Predictive Validity
- Appendix S5.** More Detailed Examination of Group-Level Neutral Math Attitudes in Boys
- Appendix S6.** Supplemental Correlational Results
- Appendix S7.** Supplemental References

Supporting Information for

“Development of Math Attitudes and Math Self-Concepts: Gender Differences, Implicit–Explicit Dissociations, and Relation to Math Achievement”

1. Items for Explicit Questionnaires

1.1. Explicit Math Attitude. Items from the “Students Like Learning Mathematics, 4th Grade” survey from the TIMSS 2015 student questionnaire (TIMSS and PIRLS International Study Center, 2014).

Item		Agree a lot	Agree a little	Disagree a little	Disagree a lot
1	I enjoy learning mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	I wish I did not have to study mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Mathematics is boring.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	I learn many interesting things in mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	I like mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	I like any schoolwork that involves numbers.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	I like to solve mathematics problems.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	I look forward to mathematics lessons.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Mathematics is one of my favorite subjects.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

1.2. Explicit Math Self-Concept. Items from the “Mathematics Self-Concept (SCMAT)” survey from the PISA 2012 student questionnaire (OECD, 2012).

Item		Strongly agree	Agree	Disagree	Strongly disagree
1	I am just not good at mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	I get good grades in mathematics.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	I learn mathematics quickly.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	I have always believed that mathematics is one of my best subjects.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	In my mathematics class, I understand even the most difficult work.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. Child IAT Stimuli

2.1. Implicit Math Attitude. Math attitude Child IAT included the following categories/stimuli.

Math	Reading	Good	Bad
addition	books	friendly	awful
count	letters	good	bad
graph	read	happy	mad
math	sentence	nice	mean
numbers	story	smart	naughty

2.2. Implicit Math Self-Concept. Math self-concept Child IAT included the following categories/stimuli.

Self	Other	Math	Reading
I	other	addition	books
me	theirs	count	letters
my	them	graph	read
myself	they	math	sentence
		numbers	story

3. Counterbalancing

3.1. No Significant Effects for Counterbalanced Factors. All measures were counterbalanced to account for three factors: (a) the order of the measures (explicit vs. implicit; 2 orders), (b) the order of the constructs (math attitude vs. math self-concept; 2 orders), and (c) the order of the IAT tasks (congruent task vs. incongruent task within both IATs; 4 orders). The result of counterbalancing was 16 unique conditions to which all students were randomly assigned (see Table S1). To test for an effect of IAT task order, two one-way ANOVAs were conducted with either implicit math attitude or implicit math self-concept entered as the dependent variable, and the IAT task order entered as a between-subjects factor. There was no effect of the IAT task order on either IAT, $ps > .31$. A repeated-measures ANOVA with implicit construct entered as a within-subjects factor and IAT task order entered as a between-subjects factor reinforced these results, $p = .85$. Finally, a repeated-measures ANOVA with measure and construct entered as within-subjects factors, and experimental condition entered as a between-subjects factor, revealed no main effect of experimental condition, $p = .76$.

Table S1

Percentage of Students Assigned to Counterbalanced Factors

Grade	Gender	First Measure		First Construct		IAT Task Order			
		Explicit	Implicit	Attitude	Self-Concept	Con, Con	Con, Inc	Inc, Con	Inc, Inc
1	Girls	51.0	49.0	50.0	50.0	25.5	19.4	25.5	29.6
	Boys	48.9	51.1	46.8	53.2	23.4	25.5	26.6	24.5
5	Girls	52.6	47.4	51.5	48.5	20.6	23.7	25.8	29.9
	Boys	53.9	46.1	55.9	44.1	23.5	20.6	27.5	28.4

Note. Con = Congruent IAT. Inc = Incongruent IAT.

4. Construct Validity and Predictive Validity

4.1. Validity of the Explicit and Implicit Measures in the Current Study. The current study used a combination of both established measures (explicit math attitudes and math self-concepts; implicit math self-concepts) as well as one newly developed (implicit math attitudes) measure. The three existing measures have been shown to meet psychometric and construct validity standards for individual difference measures in past research. The material below provides a brief summary of the evidence of validity of these measures.

The explicit math attitude measure used in the current study derives from the TIMSS, which was validated using item response theory (IRT; Hooper, 2016) with 111,194 students from 43 countries, and was used in the TIMSS 2015 assessment with more than 324,000 students (Lee & Chen, 2019). This math attitude measure correlated with math achievement, $r_s \geq .224$ (Lee & Chen, 2019). The explicit math self-concept measure derives from the PISA and was also validated using IRT (OECD, 2005, p. 271) prior to being included in PISA 2012 with nearly 500,000 students from 64 countries (Stankov & Lee, 2017). This math self-concept measure was correlated with math achievement, $r = .26$, in 2012 (Stankov & Lee, 2017).

The implicit math self-concept measure has been initially validated with 247 elementary-school children (Cvencek et al., 2011), as well as 234 preschool children (Cvencek et al., 2016, p. 55), and has been subsequently used in research on math self-concepts with more than 1,000 elementary-school students from the United States (Cvencek et al., 2011), Singapore (Cvencek et al., 2015) and Chile (del Río et al., 2019), including the grade levels tested in the current study. In these subsequent studies, implicit math self-concept measures exhibited theoretically expected relations to implicit measures of gender identity and math–gender stereotype according to principles of “affective–cognitive consistency” (Cvencek et al., 2011, 2014), as well as expected positive relations to children’s performance on a standardized math achievement test (Cvencek et al., 2015).

The current results provide three types of evidence bearing on the validity of the measures used. First, both explicit and implicit measures correlated with math grades to the extent that was comparable (or higher) than previous published reports (Cvencek et al., 2015; Stankov & Lee, 2017) suggesting a form of criterion-validity. Second, Cronbach’s alpha levels for the four measures suggests that they are internally consistent/cohesive – although to a lesser extent for the implicit math self-concept measure (which we speculate reflects the later developmental emergence of this construct; see main text section “Implicit attitudes contribute unique variance to math achievement beyond explicit attitudes for boys,” which expands on this point). Third, all four measures (including the newly developed implicit math attitude measure) were resistant to order effects (reported in detail above in Section 3.1).

5. More Detailed Examination of Group-Level Neutral Math Attitudes in Boys

5.1. More Boys Than Girls Have Positive Math Attitudes. Neutral math attitudes for boys could be due to either (a) majority of boys having neutral attitudes (i.e., Child IAT scores around 0), or (b) some boys having positive attitudes (Child IAT scores above 0) and some having negative attitudes (Child IAT scores below 0). A post hoc examination more strongly supports the latter view: 45% of boys had positive math attitudes ($n = 78$) and 55% of boys had negative math attitudes ($n = 95$). This is in contrast to girls: 36% of girls had positive math attitudes ($n = 65$) and 64% of girls had negative math attitudes ($n = 117$). This difference in percent of boys versus girls who had positive versus negative attitudes was statistically significant by chi-square analysis, $\chi^2(1, N = 355) = 3.24, p = .045$.

6. Supplemental Correlational Results

6.1. Relations Among Math Attitudes, Math Self-Concepts, and Math Achievement. Correlations between all explicit, implicit, and achievement measures separately for Grade 1 and Grade 5 students are displayed using parametric (Pearson r , Table S2) as well as non-parametric (Spearman r_s , Table S3) tests. The results were highly consistent across both. In addition, Table S4 presents the correlations (Pearson r) separately for boys and girls, showing very similar patterns for both genders. As shown in Table S4, the relatively low implicit–explicit correlations (referred to as an implicit–explicit dissociation) are evident in boys, as well as in girls.

Table S2 – Pearson r

Correlations Among Measures Separately for Grade 1 and Grade 5 Students

Measure	1	2	3	4	5
1. Explicit Math Attitude	—	.62***	.14	.13	.04
2. Explicit Math Self-Concept	.70***	—	.17*	.03	.13
3. Implicit Math Attitude	.18*	.19**	—	.07	.04
4. Implicit Math Self-Concept	.07	.04	.24***	—	-.03
5. Math Achievement	.45***	.68***	.20**	.11	—

Note. Correlations for Grade 1 students are presented above the diagonal, and correlations for Grade 5 students are presented below the diagonal. *** $p < .001$. ** $p < .01$. * $p < .05$.

Table S3 – Spearman r_s (non-parametric)

Correlations Among Measures Separately for Grade 1 and Grade 5 Students

Measure	1	2	3	4	5
1. Explicit Math Attitude	—	.65***	.15*	.11	.06
2. Explicit Math Self-Concept	.72***	—	.18*	.07	.14
3. Implicit Math Attitude	.20**	.22**	—	.06	.06
4. Implicit Math Self-Concept	.06	.03	.18*	—	-.03
5. Math Achievement	.49***	.69***	.20**	.08	—

Note. Correlations for Grade 1 students are presented above the diagonal, and correlations for Grade 5 students are presented below the diagonal. *** $p < .001$. ** $p < .01$. * $p < .05$.

Table S4

Correlations Among Measures Separately for Girls and Boys

Measure	1	2	3	4	5
1. Explicit Math Attitude	—	.71***	.15*	.06	.38***
2. Explicit Math Self-Concept	.70***	—	.18*	-.01	.58***
3. Implicit Math Attitude	.16*	.16*	—	.10	.10
4. Implicit Math Self-Concept	.11	.04	.17*	—	.07
5. Math Achievement	.43***	.56***	.19*	.02	—

Note. Correlations for girls are presented above the diagonal, and correlations for boys are presented below the diagonal. *** $p < .001$. * $p < .05$.

7. References

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