



Math achievement, stereotypes, and math self-concepts among elementary-school students in Singapore



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ABSTRACT

Singaporean elementary-school students ($N = 299$) completed Child Implicit Association Tests (Child IAT) as well as explicit measures of gender identity, math–gender stereotypes, and math self-concepts. Students also completed a standardized math achievement test. Three new findings emerged. First, implicit, but not explicit, math self-concepts (*math = me*) were positively related to math achievement on a standardized test. Second, as expected, stronger math–gender stereotypes (*math = boys*) significantly correlated with stronger math self-concepts for boys and weaker math self-concepts for girls, on both implicit and explicit measures. Third, implicit math–gender stereotypes were significantly related to math achievement. These findings show that non-academic factors such as implicit math self-concepts and stereotypes are linked to students' actual math achievement. The findings suggest that measuring individual differences in non-academic factors may be a useful tool for educators in assessing students' academic outcomes.

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In many Western and the Eastern cultures, there is a prevalent stereotype among adults linking mathematics with males (Guiso, Monte, Sapienza, & Zingales, 2008; Nosek et al., 2009). This gender stereotype that “math is for males” may be one of the complex factors contributing to the underrepresentation of girls in science technology, engineering, and mathematics (STEM) and influence children's educational interests and choices (e.g., Ceci, Williams, & Barnett, 2009; Cheryan, Master, & Meltzoff, 2015).

One conjecture is that this societal *stereotype* about gender influences boys and girls differential *identification* with math at early ages (Cvencek, Meltzoff, & Greenwald, 2011). Gender stereotypes may potentially mediate learning and performance in specific academic subjects by influencing students' level of anxiety, interest, and effort they put into learning that domain (Beilock, Gunderson, Ramirez, & Levine, 2010; Steffens, Jelenec, & Noack, 2010). This, in turn, may influence how well students perform in the subject, and their interest in pursuing a career in the STEM disciplines (Denissen, Zarrett, & Eccles, 2007; Liben, Bigler, & Krogh, 2001).

However, when one looks beyond stereotypes to actual math *achievement*, boys do not consistently outperform girls. In the U.S., there is older research reporting that high-school girls score lower than boys on standardized math assessments (Dwyer & Johnson, 1997; Pomerantz, Altermatt, & Saxon, 2002); but newer findings indicate that gap is narrowing or non-existent, at least up to the final years of high school (Hyde, Lindberg, Linn, Ellis, & Williams, 2008; Hyde & Mertz, 2009). On the other hand, if one looks at achievement on international standardized math achievement tests, a gender gap favoring boys still exists among U.S. elementary-school students (Provasnik et al., 2012). In Asian countries (e.g., Japan, Singapore, and China), there is no gender gap in mathematical achievement at any age (Organisation for Economic Co-operation and Development [OECD], 2011).

Singapore is a compelling example. The mathematical achievement of students from Singapore—both male and female—is outstanding. Singapore consistently scores as one of the top-achieving countries on the international assessments of standardized math achievement, such as the Trends in International Mathematics and Science Study (TIMSS) or the Program of International Student Assessment (PISA; OECD, 2011). The country's math curriculum is celebrated for its effectiveness and emulated world-wide (Bybee & Kennedy, 2005). On the most recent TIMSS assessment, the male–female difference in average math scores of

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Singaporean boys and girls in Grade 4 was not measurably different (Provasnik et al., 2012). Contrary to what one might expect given these data, however, Cvencek, Meltzoff, and Kapur (2014) found that: (a) Singaporean elementary-school students hold the math–gender stereotype, and (b) Singaporean boys identify more strongly with math than do girls.

Studying the relationship between math achievement, math–gender stereotypes and self-concepts in Singaporean children presents an interesting opportunity for at least two reasons. From a theoretical viewpoint, it is not apparent why—in the absence of any detectable boy superiority in math—Singaporean children would hold the stereotype that “*math = boys*,” nor why Singaporean boys would identify with math more strongly than girls. From a more methodological viewpoint, a centralized common curriculum for Singaporean K–12 students enables testing of the relationship between students’ beliefs and actual math achievement (on which past research has remained silent), by allowing researchers to use standardized math achievement scores for each grade.

1. Role of non-academic factors in math achievement

When examining students’ beliefs about math and their math achievement, it is useful to distinguish three interrelated constructs. One is *gender identity*, that is, how strongly a child identifies with being either *boy* or *girl*. A second is the child’s belief about the link between math and gender (i.e., a belief about a social group and “who does math”), which can be called a *math–gender stereotype*. The third is how strongly the child connects *me* and *math* (a belief about the self; whether “I identify with math”), which can be called a *math self-concept*.

The current research is motivated by the concept of cognitive balance or consistency in social psychology and developmental psychology. The general idea is that the child and adult usually tend towards a state of psychological equilibrium and minimize dissonance (Festinger, 1957; Gawronski & Strack, 2012; Greenwald et al., 2002; Heider, 1946)—a process related to what Piaget called psychological “equilibration” in human development and education (Piaget, 1970). These general ideas about cognitive consistency and balance can be operationalized and made more precise, particularly about issues of identity (Greenwald et al., 2002). To be fully “in balance” a child who thinks *me = boy*, and *boy = math*, should experience a psychological pressure (conscious or unconscious) towards *me = math*. Such a pressure toward cognitive balance has been hypothesized to operate in young children and to motivate behavioral change and strivings even during elementary-school years (Cvencek et al., 2011, 2014).

As part of investigating cognitive balance in the current study, we specifically examine the role of gender identity and its relation to gender stereotypes and math self-concepts. Gender identity is an early developing aspect of a child’s sense of self (Ruble, Martin, & Berenbaum, 2006; Stipek, Gralinski, & Kopp, 1990). We believe that the strength of gender identity (*me = boy* or *me = girl*) could be one factor that works to strengthen (in case of boys) or weaken (in case of girls) a child’s identification with mathematics. If *me = girl*, and *girls ≠ math* (according to cultural stereotypes), then cognitive balance may pressure girls in a direction away from math (*me ≠ math*), by changing interest, motivation, choice, and so forth. Of course, in the real-world there are also many other issues that will come into play, but according to social-developmental theory, cognitive balance may be of interest.

2. Stereotypes, self-concepts, and math achievement

When stereotypes are measured in socially sensitive domains, such as gender stereotypes, both implicit and explicit measurement

methods have been used. This distinction is based on the idea that human behavior is not only guided by deliberative, conscious processes, but also by more automatic, non-deliberate, and faster processes, which can be captured by two corresponding types of measures, termed *explicit* versus *implicit* measures (Fazio, 1990; Greenwald & Banaji, 1995; Jacoby, 1991; Strack & Deutsch, 2004).

In explicit measures, participants are often asked to provide verbal self-reports and are aware of what is being assessed. For example, this can correspond to an explicit belief about the group with regard to a particular academic ability (e.g., selecting answers on a questionnaire about how much “I believe that boys like math more than girls do?”). In contrast, implicit measures require no self-report and participants are not necessarily informed about what is being assessed. For example, this can correspond to a more unconscious *math = boy* association (e.g., using the same response key to sort stimuli belonging to categories *math* and *boys* in a computerized categorization task that requires fast responses). Few studies have examined both implicit and explicit math–gender stereotypes in the same students, and fewer still have related this to the students’ actual math achievement. Three studies and their limitations will be mentioned.

Ambady, Shih, Kim, and Pittinsky (2001) showed that 5-year-old Asian-American girls performed significantly worse on a math test, when their gender identity was activated (by being asked to color a picture of a girl holding a doll) relative to a control group. These girls demonstrated math–gender stereotypes on implicit, but not on explicit measures, suggesting that the implicit math–gender stereotypes may have contributed to the observed math performance decrements.

Galdi, Cadinu, and Tomasetto (2014) activated a negative in-group stereotype for 6-year-old Italian girls by asking them to color a picture of a boy who correctly solves a math problem on a blackboard (while a girl fails to respond). Six-year-old Italian girls already possessed implicit math–gender stereotypes (without explicitly endorsing them) and the activation of such stereotypes lead to performance deficits. However, it would be desirable to evaluate the relationship between math–gender stereotypes and math achievement in the absence of experimentally activated identities and without experimentally activating the stereotypes themselves immediately before the math test. This would show that pervasive cultural stereotypes can impact math achievement without salient activation *within the test situation*.

Steffens et al. (2010) used adolescents to examine the relationship between implicit and explicit math–gender stereotypes and math achievement. In their study of German students (Grades 7 and 9), implicit math–gender stereotypes predicted self-reported math grades above and beyond explicit math–gender stereotypes. Potentially, however, the children’s self-reports of their latest class test and grades in math (Steffens et al., 2010) are susceptible to inaccuracies in memory, and the social relationship between teacher and student and other factors are known to influence students’ grades (Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2005).

So far we have discussed the relation between math–gender stereotypes and math achievement. Such stereotypes are a belief about math and a social group (*math = boys*), but we can also examine beliefs about math and the *self* (*math = me*)—i.e., children’s math self-concepts. It is well established using explicit measures that, during elementary school, girls rate themselves lower than boys in mathematics (Herbert & Stipek, 2005), but not in reading or writing (Pajares, Miller, & Johnson, 1999).

What is known about the interrelationship between math self-concepts and math-related outcomes? The emerging evidence can be summarized as follows: First, gender differences in math self-concepts can be independent from actual math achievement, which is often found to be comparable between male and female

students in elementary school (Herbert & Stipek, 2005). Second, in some Western countries, positive math self-concepts seem to be more relevant to boys' math achievement than to those of girls (Lindberg, Linkersdörfer, Ehm, Hasselhorn, & Lonnemann, 2013). Third, if explicit perceptions of an academic discipline are at odds with one's identity ("not-me"), this discourages students from choosing and identifying with the field (Cheryan et al., 2015; Frome, Alfeld, Eccles, & Barber, 2006).

3. Distinctive goals of this study

The goals of the current study are to assess math achievement, math self-concepts, and math–gender stereotypes in the same children using a high-achieving sample of elementary-school students. This is the first study to examine these issues using *both* implicit and explicit measures in the same students, *while at the same time measuring mathematical achievement* using standardized test scores. Even though in Singapore both boys and girls are high-achieving when it comes to math, boys are the positively stereotyped group and girls are the negatively stereotyped group. We will pay special attention whether the relationships between math–gender stereotypes, math self-concepts, and math achievement differ as a function of gender—that is, based on who is expected to do well in math.

In doing so, we will test four hypotheses: First, boys will have stronger math self-concepts than girls, even in absence of any difference in standardized math achievement. Second, stronger math–gender stereotypes will be associated with stronger math self-concepts for boys and weaker math self-concepts for girls. Third, stronger math–gender stereotypes will be associated with stronger math achievement (at least for boys). Fourth, the theorized influence of gender identity and math–gender stereotypes on math self-concepts will be observed in high-achieving Singaporean children. The combined use of implicit and explicit measures will allow for a more robust examination of how membership in a stereotyped social group shapes the acquisition and development of both implicit and explicit representations of self, potential gender differences in these representations, and their relationship to math achievement.

4. Method

4.1. Participants

All participants for the implicit, explicit, and math-achievement measures were drawn from the sample of students attending the 1st, 3rd, and 5th grade math classes at six participating elementary schools serving Grades 1–5 in Singapore.

A total of 299 children (152 girls, 147 boys) participated. Of these 299 children, 165 were participants in Cvencek et al.'s (2014) study, and 134 participants were recruited later. The mean age for children attending Grade 1 was 7.37 years ($SD = .33$), the mean age for children in Grade 3 was 9.38 years ($SD = .29$), and the mean age for children in Grade 5 was 11.38 years ($SD = .31$). None of the children tested had repeated a grade. The sample sizes and gender breakdown for our test sample were as follows: Grade 1, $n = 104$ (53 boys; 51 girls), Grade 3, $n = 95$ (48 boys; 47 girls), and Grade 5, $n = 100$ (46 boys; 54 girls). According to the school records, the students in our sample were 84.9% Chinese, 7.0% Malay, 6.0% Indian, and 1.3% belonged to more than one ethnic group (ethnic background data was not available for 1 student).

4.2. Procedure

For the implicit and explicit measures, children were tested individually in a quiet room outside of their classroom. The test

session began with a 3–5 min description of the study, during which children were familiarized with the test apparatus. The children were told that they would be "asked some questions" and then "play a computer game." For the math achievement measure, children were administered a standardized math test by their teachers during their math class at the end of the school year. The methods and testing protocol used in the current study followed those previously used with a Singaporean sample (Cvencek et al., 2014).

4.3. Child implicit cognition measures: Child IAT

The Child Implicit Association Test (IAT) (Cvencek et al., 2011) was used to obtain implicit measures of gender identity, math–gender stereotype, and math self-concept. IAT measures were developed within social psychology (Greenwald, McGhee, & Schwartz, 1998), but are now becoming increasingly used in educational research on students' and teachers' stereotypes and identities (e.g., Steffens et al., 2010; van den Bergh, Denessen, Hornstra, Voeten, & Holland, 2010). The IAT is based on the principle that it is easier to give the same response to items from two categories if the two categories are associated than if they are not. For example, children with the math stereotype (i.e., *math = boys*) should respond faster when math words and boy names share a response key (i.e., congruent task) than when math words and boy names are mapped on different response keys (i.e., incongruent task). Fig. 1 gives a pictorial representation of the two categorization tasks in a math–gender stereotype IAT.

During the math–gender stereotype IAT, children classified the words representing *math*, *reading*, *boy*, and *girl*. In one task, *math* words and *boy* names shared one response key, with *reading* words and *girl* names sharing the other response key (stereotype–congruent task). A second task switched the key assignments for the *math* and *reading* words (stereotype–incongruent task). Positive scores indicated stronger association of *math* with *own gender* than with *opposite gender*.

During the gender identity IAT, children classified the words representing *me*, *not-me*, *boy*, and *girl*. In one task, *me* words and *boy* names shared a response key, with *not-me* words and *girl* names sharing the other response key (congruent task for boys). In another task, two of the response assignments were reversed: *Me* and *girl* names shared one key while *not-me* and *boy* names shared the other key (incongruent task for boys). Positive scores indicated stronger association of *me* with *boy* than with *girl*.

During the math self-concept IAT, children classified the words representing *me*, *not-me*, *math*, and *reading*. In one task, *math* words and *boy* names shared a response key, as did *reading* words and *girl* names. In another task, left versus right assignment of *me/not-me* words was reversed. Positive scores indicated stronger association of *me* with *math* relative to *reading*.

The scoring algorithm developed by Greenwald, Nosek, and Banaji (2003), which results in the IAT score—called a *D* score—constrains the resulting measures to have bounds of -2 and $+2$.

4.4. Explicit self-report measures

The self-report measures of gender identity, math–gender stereotype, and math self-concepts were administered as six Likert-scales based on Harter and Pike's (1984) pictorial scale measure. Measures assessing each of the three constructs consisted of two questions each. For each question, children were shown two pictures of a child character and reported: (a) which of the two characters (boy or girl) they believed possessed an attribute (e.g., liking math) to a greater degree, and (b) whether the character possessed the attribute "a little" or "a lot."

The gender identity measure asked children to select which character (boy or girl) was more like themselves. Positive values

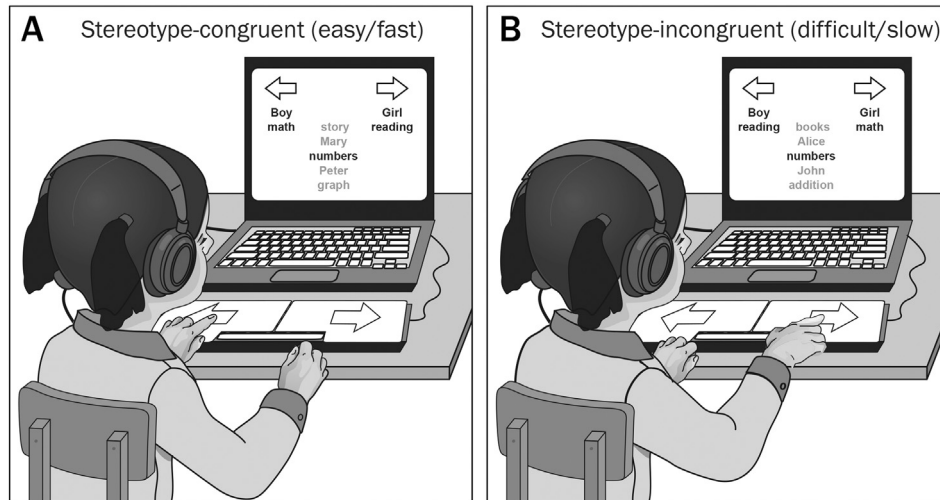


Fig. 1. Stereotype-congruent (A) and stereotype-incongruent (B) tasks of a math–gender stereotype IAT. Word stimuli at the center are presented one at a time. Children who have acquired the implicit math–gender stereotype (*math = boy* association) should respond faster to the task A than B.

indicated that the child picked the boy character as being more like the self. The math–gender stereotype measure requested selection of the boy or girl character as “liking to do math more.” Positive values indicated that the child picked the same-sex character as liking to do math more. The math self-concept measure asked children to select whether a same-sex character—engaged either in math or reading—was more like the self. Positive values indicated that the same-sex character that was doing math was picked as being more like the child.

4.5. Math achievement measures

A Singaporean math curriculum expert with 30+ years of experience was hired to develop grade-appropriate math achievement tests for each of the 1st, 3rd, and 5th grades. All the items were selected from the item banks developed for a cluster of five representative elementary schools in Singapore (sample sizes varied from 120 to 650 students). A facility index of each item (i.e., percent of students who give the right answer as an indicator of item difficulty) ranged from 30% to 80%.

The math achievement test for Grade 1 consisted of 24 items (short answer), yielding a total of 48 possible points. Topics covered by this test were: Whole numbers, measurement, geometry, and data analysis. The math achievement test for Grade 3 consisted of 25 items (10 multiple choice; 15 short answer), yielding a total of 55 possible points. Topics covered by this test were: Whole numbers, measurement, geometry, data analysis, and fractions. The math achievement test for Grade 5 consisted of 25 items (15 multiple choice; 10 short answer), yielding a total of 57 possible points. Topics covered by this test were: Whole numbers, measurement, geometry, data analysis, fractions, decimals, percentages, and ratio.

Math achievement was measured by the number of points earned for correct answers divided by the total number of points available. These *accuracy* scores could range from 0 (indicating all incorrect responses) to 100% (indicating perfect score), with an accuracy score of 50% being the lowest passing score in Singaporean Grades 1–6.

4.6. Internal consistency and data reduction

For implicit measures, Cronbach's alpha was calculated from two *D* measures computed for matched 24-trial subsets of each IAT. For the self-report measures, Cronbach's alpha was calculated from

the two items for each of the scales. Cronbach's alphas for the three implicit measures were all in the acceptable range, all $\alpha > .70$. The Cronbach's alphas for the explicit measures of gender identity and math self-concept were in the acceptable range as well, both $\alpha s > .70$. (The two items of the explicit math–gender stereotype scale measured two distinct constructs: Gender stereotype towards math vs. gender stereotype towards reading; Cronbach's alpha for this measure is therefore not particularly meaningful). For the math achievement tests, Cronbach's alpha was calculated from all of the test items at each of the three school grades, and each was in the acceptable range, all $\alpha > .79$.

Consistent with procedures commonly used in Child IAT literature (Cvencek et al., 2011), IAT data were discarded for excessively fast and/or slow responding (19 participants, 6.4%). Self-report data were discarded for 8 participants (2.7%) for excessively slow responding. Of the 299 students enrolled in the study, five were absent on the days on which the math achievement test was administered, resulting in missing achievement data for five students (1.7%). This left $N = 267$ for the analysis (127 boys and 140 girls). The analyses following data reduction provided increased power compared to analyses of the full sample, but the pattern of significant results and the conclusions drawn from them remained unchanged.

4.7. Analysis strategy

The data from this study were analyzed to examine four inter-related questions. First, we examined gender differences in the mean levels of each of the constructs by comparing boys to girls using independent samples *t*-tests. Tests of the gender differences on each of the three implicit, three explicit, and one achievement measure were conducted using Bonferroni adjusted alpha levels of .007 per test.

Second, the relationships among math achievement, math–gender stereotypes, and math self-concept measures were examined. In one series of regressions, math achievement was entered as a criterion. The predictor variables were participants' implicit and explicit math-self-concepts.¹ This analysis evaluated whether

¹ Given the correlational nature of our data, causal interpretations are not indicated. Thus, the phrase “predictor variable” here and elsewhere in this paper is used only in its statistical sense (i.e., a variable that is used to explain variance in the criterion measure in a hierarchical regression procedure).

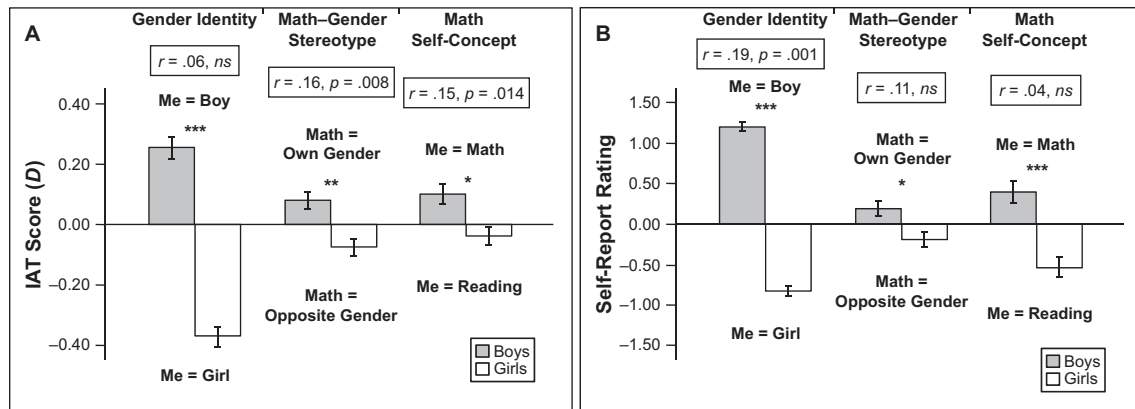


Fig. 2. Results for implicit (A) and explicit (B) measures of three constructs in elementary-school Singaporean children. Error bars = ± 1 SE. $N = 267$. Asterisks indicate significant differences between boys and girls. *** = $p < .00001$, ** = $p < .0001$, * = $p < .01$. Coefficients at the top of each construct are correlations (r s) with standardized math achievement.

implicit math–gender stereotypes are associated with math-related outcomes (standardized math achievement and math self-concepts) over and above explicit math–gender stereotypes. In another series of regressions, math achievement and math self-concepts were entered as criteria. The predictor variables were participants' implicit and explicit math–gender stereotypes. These analyses evaluated whether implicit math self-concepts were linked to math achievement, over and above any relationships that explicit math self-concepts may exhibit with math achievement.

Third, we examined whether implicit and explicit stereotypes were connected to math self-concepts and math achievement, using a statistical approach developed by Nosek, Banaji, and Greenwald (2002). In line with Nosek et al.'s (2002) approach, hierarchical regression analyses tested models explaining variance in (a) implicit math self-concepts, (b) explicit math self-concepts, and (c) math achievement. The rationale underlying these analyses is that stereotypes should be associated with opposite effects for boys and girls. Therefore, the main predictor variables of interest were the interactions of participant gender and stereotypes.

Finally, we were interested in the interrelationships among the constructs of gender identity, math–gender stereotypes, and math self-concepts. Greenwald et al. (2002) described a statistical method that can be used to examine whether the interrelations among gender identity, math–gender stereotype, and self-concept reflected the theorized balanced configuration. This statistical procedure, known as a 4-test method, can be used to evaluate a pure multiplicative model, namely whether the multiplicative product of two variables is the sole predictor of some effect. This 4-test method uses a two-step hierarchical linear regression: The measure of each of three constructs was predicted solely from the multiplicative product of the other two in Step 1, with the two predictors added individually in Step 2. If a balanced configuration exists among three constructs, the theoretical expectation is that: (a) the product of two predictor variables should be statistically significant at Step 1 and (b) the increase in criterion variance explained when the two predictors are added at Step 2 should not be statistically significant (see supplemental materials for details). This method intentionally sidesteps the standard statistical procedure of first entering the component variables as predictors before testing a product term.²

The 22nd version of the SPSS® program was used for the analysis of the results.

² Validity of this 4-test method as a procedure for testing a pure multiplicative theoretical model has been justified in detail by Greenwald et al. (2002) and Greenwald, Rudman, Nosek, and Zayas (2006).

5. Results

Preliminary analyses that justify collapsing the results across student background variables (gender, ethnic group, age), school background variables (SES level, school, grade and classroom) and experimental design factors (data collection year, counterbalancing, order of implicit and explicit measures, order of combined task within each IAT measure, and experimenter) can be found in the supplemental material. Aside from students' gender, none of the factors influenced students' responses on implicit or explicit measures, thus allowing collapsing across them.

5.1. Implicit and explicit measures

Fig. 2 displays the results for both the implicit and explicit measures separately for boys and girls.

Gender identity. As expected, boys associated *me* with *boy* more strongly than did girls on both the implicit, $t(265) = 13.30$, $p < .001$, $d = 1.63$, and explicit measure, $t(265) = 23.41$, $p < .001$, $d = 2.87$. The implicit (Child IAT) and explicit (self-report) measures of gender identity were strongly correlated, $r = .54$, $p < .001$.

Math–gender stereotype. On the implicit measure of math–gender stereotypes, boys associated *math* with *own gender* significantly more than did the girls, $t(265) = 4.00$, $p < .001$, $d = .49$. Similarly, on the explicit measure boys were more likely to pick the same gender character as “liking to do math more” than were girls, $t(265) = 2.92$, $p = .004$, $d = .36$. These results show that both boys and girls associated math more strongly with boys than with girls (Fig. 2). The implicit–explicit correlation for the math–gender stereotype measure was not significant, $p > .21$. This lack of a correlation between implicit and explicit measures is common in IAT literature for adult assessments of stereotypes (Greenwald, Poehlman, Uhlmann, & Banaji, 2009) and is thought to be due to social desirability concerns that come into play when giving self-reports about socially sensitive topics such as stereotypes.

Math self-concept. On the implicit measure, boys associated *me* with *math* more than did girls, $t(265) = 3.17$, $p = .002$, $d = .39$, and on the explicit measure boys identified more with the same gender character who was solving a math problem than did girls, $t(265) = 5.32$, $p < .001$, $d = .65$. The implicit–explicit correlation for the math self-concept measure was not significant, $p > .12$.

5.2. Math achievement

Both boys and girls performed well on the math test (Boys: $M = 77\%$, $SD = 17\%$; Girls: $M = 73\%$, $SD = 19\%$), and above the lowest

passing score of 50%, $t(126) = 18.68, p < .001, d = 1.66$ for boys, and $t(139) = 14.31, p < .001, d = 1.21$ for girls. This indicated that the overall math achievement of Singaporean elementary-school boys and girls was satisfactory. Comparing the math achievement of boys to that of girls using an independent samples t -test revealed no significant gender difference ($p > .08$).

5.3. Relationships among self-concepts, stereotypes, and math achievement

The relationships among math achievement, math–gender stereotypes, and math self-concept measures were examined. Reported first are the analyses examining the relationship between achievement and math self-concepts, followed by the report of how these two constructs (math achievement and math self-concepts) may relate to math–gender stereotypes.

Math self-concepts and math achievement. Implicit, but not explicit math self-concepts were positively related to math achievement. The regression of implicit math self-concepts on math achievement demonstrated a positive effect, $R^2 = .02, \beta = .15, p = .014$; the regression of explicit math self-concepts on math achievement did not, $p > .46$ (see the rightmost bars in panels A and B of Fig. 2).

To unpack this relationship further, a follow-up hierarchical regression was conducted. The math achievement score was entered as a criterion. The participant gender was entered as a predictor variable at Step 1. The implicit math self-concept score was added as a predictor at Step 2, and the Implicit Math Self-concept \times Gender interaction term was entered at Step 3. The effect of gender was not significant at any regression steps (all $ps > .08$). The effect of the implicit math self-concept was significant both at Step 2 ($\beta = .13, p = .030$) and Step 3 ($\beta = .14, p = .026$). The interaction term was not significant at Step 3, $p > .17$, suggesting that the positive relationship between implicit math self-concepts and math achievement occurred for both boys and girls. Taken together, the results indicated that the implicit, but not explicit, math self-concepts were positively related to math achievement of Singaporean boys and girls.

Math–gender stereotypes relate to math self-concepts and math achievement. To test whether implicit and explicit stereotypes were related to math self-concepts and math achievement, we used a statistical approach developed by Nosek et al. (2002) to examine similar relationships in adults. Table 1 presents the beta weights for five predictors that were entered into each of the three hierarchical regressions. This approach gives explicit measures the greatest opportunity to explain variance in the dependent variables, by entering explicit stereotypes, participant gender, and the Explicit Stereotype \times Gender interaction in Step 1. The implicit stereotype and Implicit Stereotype \times Gender interaction were entered in Step 2. Negative beta weights for the two interactions would indicate that stronger *math = boy* associations were related to more positive math self-concepts or higher math achievement for boys compared with girls, consistent with our hypotheses.

As shown in Table 1, results indicate that the Implicit Stereotypes \times Gender interaction showed robust predictions for implicit math self-concepts: For boys, stronger implicit stereotypes corresponded with stronger implicit math self-concepts; for girls, stronger implicit stereotypes corresponded with weaker implicit math self-concepts (See the top row of Table 1). The Explicit Stereotypes \times Gender interaction showed similar, robust predictions for explicit math self-concepts; the relationship was positive for boys and negative for girls (See the middle row of Table 1). Explicit stereotypes were not predictive of math achievement at Step 1, but implicit stereotypes were at Step 2 (See the bottom row of Table 1).

5.4. Statistical evaluation of cognitive balance in children

Given the (a) absence of significant gender differences in students' math achievement and (b) the demonstration of gender differences in students' math self-concepts, we examined whether cognitive balance plays a role in relation to gender identity, gender-related math stereotypes, and the emergence of math self-concepts. According to social psychological balanced identity theory (see Cvencek, Greenwald, & Meltzoff, 2012; Greenwald et al., 2002 for a review), math–gender stereotypes, together with gender identity, are predicted to influence how strongly one identifies with *math* (math self-concept). If cognitive balance exists among the constructs of gender identity, math–gender stereotype, and math self-concept, then scores on all three measures should be in the same direction. For boys who identify themselves with male gender (*me = boy*), stronger cultural stereotypes about math (*math = own gender*) should be related to stronger math self-concepts (*me = math*). For girls who identify themselves with female gender (*me = girl*), stronger cultural stereotypes about math (*math \neq own gender*) should be related to weaker math self-concepts (*me \neq math*). Fig. 2 is consistent with this prediction, as seen by the *direction* of results. These predictions can be tested statistically using a mathematical procedure developed by Greenwald et al. (2002), known as a 4-test-method. Details of these analyses are provided in the supplemental materials. The main conclusions of interest for theory were that: (a) the balanced identity configuration was strongly confirmed in the data for both the implicit and explicit measures, and (b) the evidence for cognitive balance became stronger over the three school grades.

6. Discussion

In Singaporean elementary-school children, we evaluated gender identity, math–gender stereotypes, and math self-concepts, using both implicit and explicit measures of the same students, and also obtained measures of math achievement in those students. As expected from previous work in Singapore, there were no significant gender differences on the standardized math achievement test. The results suggest that individual differences in students' implicit math self-concepts are significantly related to variations in

Table 1
Beta weights from hierarchical multiple regressions showing relations among implicit and explicit measures of math–gender stereotypes and math self-concepts.

Dependent measures	Adj R ²	Step 1			Step 2				
		Gender	Explicit stereotype	Gender \times Explicit stereotype	Gender	Explicit stereotype	Gender \times Explicit stereotype	Implicit stereotype	Gender \times Implicit stereotype
Implicit math self-concept	.07	.17**	-.08	.12	.13*	-.08	.12	-.04	.17**
Explicit math self-concept	.12	.28****	.02	.18**	.26****	.01	.18**	.08	.08
Math achievement	.04	.09	.12	.07	.11	.12	.07	.15*	-.07

Note. * $p < .05$. ** $p < .01$. *** $p < .001$. **** $p < .0001$.

students' math achievement and to sensitivity to prevailing cultural stereotypes, even in a high-achieving culture like Singapore. First, we discuss the empirical findings about the relationships among math–gender stereotypes, math self-concepts, and math achievement. Second, we discuss the theoretical relevance of these findings for human learning and development. Third, we will discuss the limitations of the current study. We conclude by discussing broader implications of this pattern of findings for educational practices.

6.1. Reflections on empirical findings

Three new empirical findings emerged from this research. First, math achievement of Singaporean students was positively correlated with their implicit (but not explicit) math self-concepts. Second, students' math self-concepts were correlated with their math–gender stereotypes on both implicit and explicit measures: As expected, for boys, stronger math–gender stereotypes corresponded to stronger math self-concepts, whereas, for girls, stronger math–gender stereotypes corresponded to weaker math self-concepts. Third, students' math achievement was positively correlated with their implicit (but not explicit) math–gender stereotypes.

Math self-concepts and achievement. The present results provide the first evidence that stronger implicit math self-concepts correspond to higher standardized math achievement for both boys and girls in elementary-school. These findings fit with theories about domain-specific self-concepts (Dweck, 2002; Marsh & Yeung, 1998). According to the *specificity-matching principle* (Swann, Chang-Schneider, & Larsen McClarty, 2007), specific aspects of self-concept should predict domain specific (rather than broader) outcomes. Research with college students demonstrated that the specificity-matching principle operates implicitly (McWilliams, Nier, & Singer, 2013). The current study shows that the implicit operation of the specificity matching principle occurs much younger than previously demonstrated. In a related framework, Denissen, Zarret, and Eccles (2007) used the term *coupling* to indicate the intra-individual association between domain-specific self-concepts and domain-specific academic achievement in K–12 students. Denissen et al. found that boys had a higher level of coupling than girls in math (see also Reeve & Hakel, 2000). Here we found that the “coupling” also operates at an *implicit* level, inasmuch as we found a: (a) higher math self-concept in boys than in girls and (b) significant correlation between domain-specific self-concepts and domain-specific academic achievement.

Why would implicit, but not explicit math self-concept measures predict children's standardized math achievement? Some theorists have posited that implicit measures tap highly overlearned associations whose activation has become automatic over the course of long-term experiences (Rudman, 2004). If so, this might have played a role in our finding of implicit self-concepts being related to math achievement: Implicit associations have a long history of being rehearsed in students' minds and are more likely to be unconsciously linked with their own achievement. Such implicit cognitions may not only form the groundwork for later learning, but may also serve as a foundation for learning from instruction.

The current findings show that Singaporean girls, who are high-achieving, have weaker math self-concepts than Singaporean boys. This suggests that—even in the absence of any significant differences in math achievement—viewing boys as “liking math more” may have implications for how girls construe their own liking, interest, and identification with math.

Math self-concepts and math–gender stereotypes. For boys, stronger math–gender stereotypes of *math = boys* were correlated with stronger math self-concepts. For girls, stronger math–gender

stereotypes were correlated with weaker math self-concepts. The differential relationship is consistent with findings from U.S. and German middle-school children and adults (Nosek et al., 2002; Steffens et al., 2010). The present results extend this past work in two ways. First, they demonstrated that *both* implicit and explicit stereotypes are differentially related to boys' and girls' math self-concepts at earlier school grades than has been demonstrated before. Second, these differential results are obtained in a high-achieving sample in which, crucially, there are *no gender differences* in standardized math achievement. (Both Nosek et al. and Steffens et al. obtained their evidence for these differential relationships with American and German samples; both countries in which boys outperform girls on standardized math tests during elementary-school; Provasnik et al., 2012).

These findings suggest that even before young children's math achievement becomes strongly affected, their understanding of themselves in relation to math is *already beginning to be affected* by socio-cultural factors or stereotypical behaviors that may be prevalent in their community (i.e., gender differences in math self-concepts).

How stereotypes about one's social group can influence self-concepts can be understood from a social-developmental viewpoint. If young girls think that others “like-me” (other girls) are not linked with math (math–gender stereotype), then they may be more likely to apply this to themselves. Meltzoff's (2007, 2013) “Like-me” developmental framework provides multiple domains in which young children act as though what applies to others “like-me” applies to the self, and this may be the avenue by which societal stereotypes are internalized to influence their developing self-concepts. Likewise, Steffens et al. speculated that holding a math–gender stereotype plays a role in determining time girls spend studying math: If a girl holds a strong math–gender stereotype that girls don't do math, she may feel that it is not culturally expected for her to excel in math. Nosek et al., (2002) articulated a related viewpoint about how cultural stereotypes could affect the self, from the point of view of social psychology.

Math achievement and math–gender stereotypes. For both boys and girls, stronger implicit math–gender stereotypes were significantly associated with higher math achievement. The finding for boys fits with past empirical research (Nosek et al., 2002; Steffens et al., 2010).

However, the result with girls is somewhat surprising. Why would the Singaporean girls who have stronger math–gender stereotypes also be the ones with higher math achievement scores? Research has shown that under *some* circumstances the activation of stereotypes can actually *increase* quality of performance—an effect dubbed *stereotype reactance* (Kray, Thompson, & Galinsky, 2001). Such effects tend to occur when individuals are already high achieving and are motivated to prove a strongly and explicitly instantiated stereotype as wrong. Past research has demonstrated stereotype reactance about math in Asian female college students, and has specifically shown the absence of detrimental effects of stereotypes on math achievement of female students from Asian countries (Tsui, Xu, & Venator, 2011). This fits with the idea that, at least for some people and in some contexts, societal stereotypes are actively challenged or resisted (Way, Hernández, Rogers, & Hughes, 2013). The developmental mechanism and support for such resistance are of interest.

6.2. Broader theoretical relevance of these findings

The current paper provides the first evidence that children's implicit math–gender stereotypes and math self-concepts exhibit a systematic relationship with students' actual math achievement. Research with college students shows that the cognitive balance among math self-concepts, gender identity and math–gender

stereotypes is associated, in female college students, with their: (a) weaker identification with math and (b) reduced performance on the mathematical portion of the Scholastic Aptitude Test (Nosek et al., 2002). The current evidence suggests an influence on children's academic achievement even in elementary school and in absence of any significant gender differences in achievement.

The present research shows that group membership—while opening each student to the options and choices available to the group—also leaves the student vulnerable to applying the cultural expectations about the group (stereotypes) to their own individual identities (math self-concepts). In this study, identifying with *girl* (a category not necessarily related to *math*) corresponded with reduced math self-concept. For girls, development of a math self-concept that supports high math achievement may require opposing the effects of having acquired the societally stereotypical connection between *math* and *boys* (Nosek et al., 2002). Once stereotypes are internalized, students may begin to devalue particular school subjects; not because they have experienced difficulties with those subjects in the past, but because the stereotypes connote that they may experience difficulties in the future (Skaalvik & Rankin, 1990). A tendency to organize social knowledge in a way that is cognitively “balanced,” implicates the math–gender stereotypes as an early developing belief or “mental filter” that differentially influences boys' versus girls' developing math self-concepts.

This is especially relevant to understanding the Singaporean context. Singapore and U.S. have similar gender gaps in STEM educational choices: In Singapore, 68% of bachelor's or higher degrees in STEM are awarded to males (Lin, 2012), and in the U.S. the percentage of bachelor's or higher STEM degrees awarded to males is at 73% (Snyder & Dillow, 2012). Even if young girls excel in elementary-school mathematics, as in Singapore, the stereotype that *math = boys* (or *math ≠ me*), might bias girls not to pursue mathematics in the long run. Since there is already a relationship between math self-concepts and achievement in Singaporean elementary-school girls, there may be a similar relationship between math self-concepts and educational interests and career choices of those same girls in future (e.g., Cheryan et al., 2015; Simpkins, Davis-Kean, & Eccles, 2006; Weisgram, Bigler, & Liben, 2010), which might contribute to the underrepresentation of females in STEM fields in Singapore.

6.3. Limitations

There are several limitations to the current study. First, the relatively modest magnitude of the findings suggests that there may be other variables beyond those measured in this study that can account for math achievement. Testing for other moderating influences for girls' achievement (e.g., a relationship with teacher/parent who successfully counters available cultural stereotypes) will be an important consideration to explore in future research. Second, our findings were obtained with students who were in elementary-school—a time during which gender differences in standardized math achievement can be relatively small for the students from some countries (Cerdeira, Pérez, & Ortega-Ruiz, 2014; Ee, Wong, & Aunio, 2006). There may be greater differences in motivation-related variables (including math self-concepts) emerging during the elementary-school years, which can channel male and female students into different pathways via gendered choices in educational and occupational domains (Ee et al., 2006; Kessels, Heyder, Latsch, & Hannover, 2014). In the current study, actual math achievement of Singaporean boys and girls was comparable, yet differences in students' math self-concepts were already detectable. These patterns may play out differently in other countries, in which students may not be as high-achieving as the Singaporean students. Future research will profit from targeted

large-scale studies that focus on a representative subsamples of students from multiple cultures and grade levels, and administer implicit and explicit measures of math–gender stereotypes and math self-concepts to these same students, allowing large samples to examine the development of, and the interrelation between, stereotypes, math self-concepts, and achievement across many cultures. Third, we emphasize that the data from the current study are correlational. The causal relations among math stereotypes, math self-concepts, and actual achievement are likely to be bidirectional and complex. In this paper, we have described a “simple view” (consistent with past data) that gendered math stereotypes are present in the cultural environment in which children are raised, even before an individual student forms an identification with mathematics (math self-concept) and begins receiving systematic results on tests in mathematics. The initial correlational findings reported in the current study pave a way for future longitudinal studies that can begin to tease apart developmental influences and to design interventions suited for exploring causal relations by using randomized controlled trials.

6.4. Practical implications

The findings of this study provide information that may be of use to teachers regarding assessment in learning contexts. First, there is substantive psychological and education research on how beliefs influence learning. For example, Dweck's (2002, 2006) work suggests that students who attribute under-performance in a subject to their lack of ability do not achieve as much as those who attribute to a lack of effort. Perhaps gender stereotypes about math contribute to the attribution that students, especially girls, lack ability in math, and in turn, put in less effort into learning math. If so, a direct and practical implication of our work is to not only design valid and reliable ways in which such early emerging beliefs can be identified, but also design efficient and effective interventions to change unproductive beliefs.

On designing ways of identifying, it is of interest that implicit measures are easily administered, psychometrically-sound, sensitive to individual differences, and do not require specific curriculum to have been completed. Notwithstanding the fact that much work is still needed to establish their predictive and consequential validity, implicit measures that correlate with children's academic performance have the potential to be used alongside other tools to identify students who are at risk for lower academic performance.

On designing interventions, one could target students' own beliefs, their actual math skills/performance, or both. Interventions designed to change the math skills/performance component by tutoring on math are time-consuming and costly. However, changing students' beliefs and attitudes about math may be more cost-efficient.

According to Steele's (1997) prominent *stereotype threat* model, identification with math (or lack thereof) is an important factor that can either facilitate students' motivation to do well in math (when students' identification with math is strong) or it can impede their motivation to do well in math (when their identification with math is weak). One possible way to strengthen students' identification with math is to have them “approach” math (Seibt & Förster, 2004). At the most basic level, approach behaviors can be conceptualized as pulling something or someone toward one's body (Förster, Grant, Idson, & Higgins, 2001). Recent research by Kawakami, Steele, Cifa, Phillips, and Dovidio (2008) found that training people who initially had weak math self-concepts to approach math by pulling a joystick toward themselves increased their implicit math self-concepts relative to those who were trained to avoid math by pushing a joystick away. Such “approach math” and “avoid math” behavior is generally compatible with the educationally relevant

ideas of “performance approach goals” (e.g., wanting to demonstrate competence) and “performance avoidance goals” (e.g., wanting to avoid demonstrating incompetence), as articulated in the *achievement goal theory* (Ames, 1992; Dweck & Leggett, 1988; Maehr & Midgley, 1991; Nicholls, 1984). It might be possible to design an intervention to change negative math self-concepts in elementary-school children, which could in turn influence how children respond to instruction, and consequently their math achievement.

Another possible intervention comes from targeting students' beliefs about the nature of their math ability, especially that it can be enhanced through hard work. Dweck and colleagues (Blackwell, Trzesniewski, & Dweck, 2007) showed that even short-term intervention sessions that target such beliefs in students were effective.

From an educational perspective, it would also be useful if future interventions addressing gender stereotyping and self-concepts in math can be integrated into a classroom pedagogy that embodies sociomathematical norms consistent with productive mathematical thinking and promotes norms that reward effort and persistence (Kapur, 2013; Kapur & Bielaczyc, 2012; Yackel & Cobb, 1996). An integrated effort of this type would afford greater ecological validity of the intervention.

Finally, at the broader national curriculum level, efforts to redesign curricular resources might be particularly impactful during early elementary school, when interventions may be most effective due to the malleability of stereotypes and emerging self-concepts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.learninstruc.2015.04.002>.

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