Children's and Adults' Math Attitudes Are Differentiated by Number Type

Pooja G. Sidney, Clarissa A. Thompson, Charles Fitzsimmons & Jennifer M. Taber

View supplementary material ↗

Published online: 12 Sep 2019.

Submit your article to this journal ↗

View related articles ↗

View Crossmark data ↗

Routledge
Taylor & Francis Group

Check for updates

LEARNING, INSTRUCTION, AND COGNITION

Children's and Adults' Math Attitudes Are Differentiated by Number Type

Pooja G. Sidney[a]* (iD), Clarissa A. Thompson[b]* (iD), Charles Fitzsimmons[b], and Jennifer M. Taber[b] (iD)

[a]University of Kentucky, Lexington, KY, USA; [b]Kent State University, Kent, OH, USA

ABSTRACT

People's attitudes toward mathematics are multifaceted. Across four studies, we found that children and adults have different attitudes about mathematics when asked specifically about whole numbers, as opposed to fractions. The vast majority of children and adults reported negative attitudes toward fractions despite having positive attitudes toward whole numbers. Across both children and adults, the difference in fraction and whole-number attitudes was present across levels of math achievement, indicating that it was not just participants who were worse at math whose attitudes differed by number type. These findings may have important implications for how children and adults engage with numerical information when presented as fractions.

PEOPLE ENCOUNTER FRACTIONS in many everyday contexts. Reasoning with fractions and other ratios underlies common tasks including measuring and scaling (e.g., when calculating a discount, measuring a length, or following a recipe) and is often necessary for complex decision making (e.g., evaluating health-risk information at the doctor's office or comparing interest rates at the bank). Furthermore, fractions are an essential facet of the development of mathematical skills. Fraction proficiency uniquely predicts concurrent academic achievement in the sixth and eighth grades (Torbeyns, Schneider, Xin, & Siegler, 2015), students' readiness to learn Algebra I (the "gatekeeper" to higher mathematics; Booth & Newton, 2012), and high school mathematics achievement (over and above early whole number skills and general cognitive ability, Siegler et al., 2012). Despite their importance, fractions are difficult for children to master (e.g., Siegler, Fazio, Bailey, & Zhou, 2013), and these difficulties can persist into adulthood (e.g., Fazio, DeWolf, & Siegler, 2016; Opfer & DeVries, 2008).

Given the importance of fractions in everyday life and mathematics development, a great deal of research has focused on the cognitive-developmental aspects of fraction understanding (e.g., Fazio, Kennedy, & Siegler, 2016; Fuchs, Malone, Schumacher, Namkung, & Wang, 2016; Hamdan & Gunderson, 2017; Siegler et al., 2013; Torbeyns et al., 2015) and adults' competency with ratios in probability tasks (e.g., Cuite, Weinstein, Emmons, & Colditz, 2008; Lipkus, 2007; Sinayev, Peters, Tusler, & Fraenkel, 2015; Waters, Fagerlin, & Zikmund-Fisher, 2016). However, students' attitudes toward mathematics in general are tightly linked to their mathematics achievement (Denissen, Zarrett, & Eccles, 2007; Ma & Kishor, 1997; Singh, Granville, & Dika, 2002), yet little

is known about students' attitudes *toward fractions*, specifically. Furthermore, adults need both sufficient competence and motivation to use given numeric information to make complex decisions in everyday contexts (e.g., Etchegary & Perrier, 2007; see also Petty & Briñol, 2014).

In the current studies, we examined the relationships between the attitudes of children and adult toward mathematics in general, their specific attitudes toward highly familiar and well-practiced numbers (i.e., whole numbers, Alibali & Sidney, 2015), and their specific attitudes toward fractions. People's specific attitudes toward fractions may predict when and how they engage in fraction learning and reasoning in the classroom and in everyday contexts. We sought, as a first step toward understanding the role of fraction attitudes in fraction learning and reasoning, to examine whether children's and adults' attitudes toward fractions diverged from their attitudes toward mathematics in general and mathematics with whole numbers. Second, we examined whether there was variability in the *extent* to which children's and adults' attitudes concerning fractions diverged from their attitudes toward other facets of mathematics. Finally, we examined the relationships between children's and adults' specific attitudes and other math-related individual differences.

Math attitudes, learning, and proficiency

Researchers have long been interested in measuring students' attitudes toward mathematics with the goal of better understanding the role of attitudes in children's mathematics learning (e.g., Aiken, 1974; Fennema & Sherman, 1976; Neale, 1969). To date, most studies examining children's and adults' attitudes toward mathematics focus on attitudes toward mathematics in general—for example, "How much do you like doing math?" "How important is it to you to get good grades in math?" (Cooper, Sidney, & Alibali, 2018; Eccles & Wigfield, 1995). This body of work has demonstrated that holding more-positive attitudes toward mathematics in general is related to higher general mathematics achievement among children (e.g., Ma & Kishor, 1997; Singh et al., 2002) and improved learning and problem-solving among adults (e.g., Cooper et al., 2018; Hattikudur, Sidney, & Alibali, 2016). Students with more-positive attitudes toward a learning domain, or a specific topic, are more interested in new learning (Ainley & Ainley, 2011); take better advantage of cognitive supports during learning and problem-solving (Cooper et al., 2018; Hattikudur et al., 2016); and persist in the face of difficulty (Ainley, Hidi, & Berndorff, 2002; Pajares & Graham, 1999).

Little research has directly examined how people's attitudes toward mathematics in general are related to their attitudes about specific facets of mathematics, such as attitudes toward fractions or whole numbers. Attitudes more strongly predict specific behaviors when they are measured with a comparable level of specificity (e.g., Ajzen & Fishbein, 2005; Davidson & Jaccard, 1979; Pajares, 1996; Weigel, Vernon, & Tognacci, 1974). For example, students' beliefs about solving mathematical problems are a better predictor of their actual problem-solving success than beliefs about other mathematical activities (Pajares, 1996). Similarly, the first aim of the current research was to assess whether children's and adults' attitudes toward mathematics differed by number type (whole numbers versus fractions versus percentages). If this were the case, then measuring mathematics attitudes with greater specificity may better elucidate the relationships between children's and adults' attitudes about critically important facets of numerical cognition, such as fractions, and their developing proficiency in those domains.

Prior research does suggest that attitudes about academics are multifaceted. In this brief review, we have considered "attitudes" in a general sense, however, academic attitudes include multiple distinct motivational constructs that predict student behavior in unique ways. In working to understand how students' attitudes toward and beliefs about mathematics affect learning and motivation, several researchers examined the factor structures of broad measures of mathematics attitudes (Cooper et al., 2018; Eccles, Wigfield, Harold, & Blumenfeld, 1993) and found that these

broad measures do indeed include multiple distinct motivational constructs. Attitudes toward mathematics include people's preferences and interest (Ainley et al., 2002), as well as self-perceived abilities, expectations of success, and their values (Wigfield & Eccles, 2000). These constructs have different developmental patterns (Eccles et al., 1993) and have separable effects on mathematics problem solving (Cooper et al., 2018). For example, Cooper and colleagues argue that interest and value beliefs may affect trigonometry problem solving through distinct, though overlapping, mechanisms. A full theoretical account of how students' attitudes toward mathematics affects mathematics achievement must attend to these distinct constructs and their individual mechanisms.

However, although these motivational constructs are theoretically and empirically distinct, we did not seek to predict behavior from attitudes in the current study. In this first foray into the relations between general and specific attitudes about math, we had no specific hypothesis about how general and specific attitudes may vary by motivational construct (i.e., interest, perceived ability, and value). To adequately represent the overarching construct of attitudes, we included questions tapping all three distinct constructs in our measure of mathematics attitudes to capture these multiple components of attitudes when examining the relationships between attitudes about mathematics in general and attitudes toward specific facets of mathematics.

Integration of knowledge and attitudes about fractions and whole numbers

Here, we focus primarily on specific attitudes toward two facets of mathematical knowledge: math with fractions and math with whole numbers. The primary reason for focusing on children's and adults' attitudes toward fractions concerns their importance in the development of mathematical skills and in understanding ratios in everyday contexts, as described above. Furthermore, we suggest that examining the extent to which people's attitudes toward fractions are similar to or differ from their attitudes toward whole numbers may reveal whether fraction and whole-number concepts and beliefs are sufficiently integrated.

One foundational aspect of mathematics development is understanding the fundamental similarities between whole-number concepts and fraction concepts (e.g., Fazio, Bailey, Thompson, & Siegler, 2014; Siegler, Thompson, & Schneider, 2011). For instance, according to the *integrated theory of whole number and fractions development* (Siegler, 2016; Siegler et al., 2011), one fundamental achievement in mathematics development is realizing that whole numbers and fractions represent magnitudes that can be placed together on a single number line. However, children's mathematical reasoning reveals two ways in which their whole-number and fraction concepts are poorly integrated: they often incorrectly rely on their whole-number knowledge in mathematical tasks (*whole-number bias errors*, e.g., Ni & Zhou, 2005), and they sometimes incorrectly treat whole numbers and fractions as distinct categories of numbers (Sidney & Alibali, 2015; Vamvakoussi, Christou, Mertens, & Van Dooren, 2011; Vamvakoussi & Vosniadou, 2010).

Whole-number bias errors are errors in reasoning according to which people overextend their knowledge of whole numbers in tasks that necessitate knowledge of other types of numbers. These errors are pervasive across the lifespan; both adults and children exhibit whole-number bias errors in fraction reasoning tasks when they claim that 1/5 is greater 1/3 because 5 is greater than 3 (Fazio, DeWolf, et al., 2016; Sidney, Thalluri, Buerke, & Thompson, 2018; Siegler & Thompson, 2014; Siegler et al., 2011); when they add across numerators to choose an answer of 19, or add across denominators to choose an answer of 21 for the problem $12/13 + 7/8$ (Carpenter, Corbitt, Kepner, Lindquist, & Reys, 1980; Lortie-Forgues, Tian, & Siegler, 2015); or when they indicate that there is just one fraction, 1/5, that falls between 1/4 and 1/6 (Brown, Donovan, & Alibali, 2016; Van Hoof, Verschaffel, & Van Dooren, 2015). Adolescents also demonstrate overreliance on whole-number knowledge when asked to think generally about mathematics. For example, when eighth grade students were asked to verify arithmetic operation

statements containing inequalities (e.g., $x + 4 < x$; $x/4 < x$), they often used substitution to check accuracy, but were much more likely to substitute positive whole numbers and almost never attempted to substitute zero, rational numbers, or negative numbers into multiplication and division equations (Van Hoof, Vandewalle, Verschaffel, & Van Dooren, 2015; Van Hoof, Verschaffel, et al., 2015).

One potential source of such errors stems from people attempting to think about mathematics in a general way, wherein their knowledge of natural whole numbers is strongly activated and their other mathematical knowledge is not (see Alibali & Sidney, 2015, for a related discussion). There is preliminary evidence that some children may view whole numbers and fractions as being fundamentally dissimilar or even belonging to two different categories of number, perhaps signaling poorly integrated knowledge. For example, when asked to order a set of numbers, many young children separate natural numbers and fractions into two separate groups rather than ordering numbers by their magnitude (Hartnett & Gelman, 1998). Similarly, older children often sort arithmetic problems into two groups according to number type (i.e., containing a fraction or not) without considering conceptual similarities such as arithmetic operation (Sidney & Alibali, 2015). Students' reasoning about numerical density can also differ by the type of numbers they are asked to reason about, signaling poorly integrated knowledge (Vamvakoussi et al., 2011)—some students who accurately believed that there is an infinite set of numbers between two whole numbers still inaccurately believed that there is a finite set of numbers between two fractions. In contrast, children and adults who consistently avoid demonstrating the whole-number bias and focus less on differences between whole-number and fraction arithmetic (i.e., in a sorting task; Sidney & Alibali, 2015) may do so because their whole-number and fraction knowledge are better integrated, allowing them to both appreciate the key conceptual similarities between fraction and whole number arithmetic and to treat mathematics with *all* numbers as a single, interrelated system of mathematics.

Although here we argue that the extent to which people's attitudes about fractions diverge from their attitudes toward whole numbers, or math in general, may indicate poorly integrated knowledge, it is important to note that attitudes may reflect more than just knowledge. If people do hold very different attitudes toward fractions than to other facets of math, or math in general, this may reflect the underlying structure of their number concepts (i.e., that fractions knowledge is represented separately from other mathematical knowledge). However, it could also reflect other aspects of people's mathematical experience, including perceptions of difficulty. People experience persistent difficulty with fractions, as compared to whole numbers (see Fazio et al., 2014; Thompson & Opfer, 2010; Sidney et al., 2018; and Siegler & Opfer, 2003, for comparative evidence from number line estimation). For example, it takes people longer to estimate fractions than to estimate whole numbers likely because they are employing strategies for fractions that take time to accurately execute. People may be aware of this fluency difference and interpret fractions as being more difficult because responses are less automatic than for whole numbers. Thus, differences in attitudes could be a function of differential difficulty. We investigated this alternative hypothesis by examining whether individual differences in performance on fraction and whole-number tasks could account for individual differences in the extent to which attitudes toward fractions are different from attitudes toward whole numbers.

Individual differences in students' attitudes

In addition to examining the relationships between people's general attitudes toward math and their specific attitudes toward fractions and whole numbers, we sought to explore the relationships between key individual differences and the nature of people's attitudes. Here, we focused on educational achievement and gender. First, the nature of children's attitudes toward mathematics does change with increased experience in formal schooling across elementary and middle school

(Eccles et al., 1993; Wigfield et al., 1991, 1997). Furthermore, a preliminary cross-sectional study (Sidney & Alibali, 2015) provided suggestive evidence that students' number concepts (i.e., whole-number and fraction arithmetic concepts) become increasingly integrated with increased educational experience. For example, Sidney and Alibali found that although children in sixth grade were more likely to differentiate mathematics equations based on number type (i.e., whole-number versus fraction equations), adults were more likely to categorize based on operational structure (e.g., division equations) without differentiating by number type. Similarly, whole-number bias errors also decrease with educational experience (Braithwaite & Siegler, 2018; Vamvakoussi & Vosniadou, 2010). Although we did not have a strong hypothesis about how educational experience may be related to variability in students' specific attitudes, we expected that attitudes among people with high levels of education should reflect integrated number concepts.

Furthermore, we sought to explore whether gender would be related to variability in people's specific attitudes given that several academically relevant facets of students' attitudes, beliefs, and motivation appear to differ by gender. Although girls and boys' mathematics performance tends to be similar in early elementary and middle school (Hyde, Fennema, & Lamon, 1990), some facets of children's attitudes toward mathematics often differ by gender at these same ages (Wigfield et al., 1997). For example, in their longitudinal examination of children's mathematics attitudes and beliefs, Wigfield and colleagues (1997) found that boys tend to have more-positive beliefs about their competence and ability in mathematics than girls, and this difference is stable across elementary and early middle school. Gender differences in mathematics performance do emerge in high school (Hyde et al., 1990), along with differences in course-taking and career expectations that may be shaped, in part, by students' attitudes (see Halpern et al., 2007). For example, Lauermann, Tsai, and Eccles (2017) demonstrated that boys in high school are more likely to aspire to math- and science-related careers than girls, even after controlling for mathematics ability. Differences in high school course-taking shape later observed differences in women's and men's pursuit of science- and mathematics-related careers (Webb, Lubinski, & Benbow, 2002). Although this prior research reflects a diversity of attitudinal constructs, they all indicate ways in which differences between girls' and boys' socialization during K–12 education in the United States may contribute to less positive attitudes toward math, including self-evaluations of ability and expectancies for success, that in turn affects later performance and attainment. Thus, given these early gender differences in general mathematics attitudes, we examined whether gender plays a role in children's and adults' specific attitudes as well.

Finally, given that students' middle school fraction understanding uniquely predicts high school mathematics achievement above and beyond other facets of children's mathematics knowledge (Siegler et al., 2012), gender differences in specific attitudes toward fractions could contribute to later gender differences in mathematics achievement. Although we did not have a strong hypothesis about the role of gender in the relationships between specific attitudes toward fractions and whole numbers, we sought to explore the role of gender in specific attitudes given the prior evidence of gender differences in general mathematics attitudes, beliefs, and performance. In doing so, we aimed to contribute to the growing literature that describes gender differences that may relate to disparities in socialization between girls and boys.

Current studies

Here, we report four studies investigating people's specific attitudes toward fractions and whole numbers. We propose that people's attitudes toward mathematics may show evidence of poorly integrated knowledge; specific attitudes toward fractions may be separable from their attitudes toward whole numbers. To measure differences in attitudes by number type, we created the Math Attitude Questionnaire to assess attitudes toward mathematics in general, whole numbers specifically, and fractions specifically. Critically, this measure included multiple motivational constructs

that underlie attitudes toward mathematics. In Study 1, we examined attitudes among children in the fifth and sixth grades. Fraction symbols are introduced as early as third grade, and fraction arithmetic instruction typically begins in fifth grade and continues into sixth grade (see Common Core State Standards, National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). Thus, both fifth- and sixth-graders have experience representing and solving problems with fractions, but sixth-graders have considerably more experience with fractions and related math topics. In Studies 2 and 3, we examined attitudes in a sample of adults in the community using an online survey. In Study 4, we examined attitudes among college-aged adults using an in-person survey.

First, given the persistent difficulty that people often have with fractions (see Fazio et al., 2014; Sidney et al., 2018; Siegler & Opfer, 2003; Thompson & Opfer, 2010), we hypothesized that children's and adults' attitudes toward fractions would be less positive than their attitudes toward whole numbers (Hypothesis [H] 1). We expected differential attitudes toward whole numbers and fractions to emerge between fifth and sixth grade, as children gain more experience with fractions during intensive fraction arithmetic instruction. Second, we explored the relationships between children's and adults' specific attitudes about different number types and their general attitudes about mathematics. We expected that specific attitudes toward fractions would be related to, but distinct from, attitudes toward math in general (H2).

Third, across Studies 1 and 2 we explored whether variability in the differences between children's and adults' fraction and whole-number attitudes were related to several key individual differences in mathematics development: mathematics performance or standardized mathematics achievement, educational attainment or grade level, and gender (H3). These analyses were strictly exploratory, as we had no strong a priori hypotheses; we examined whether individual differences in factors related to mathematics attitudes could also elucidate who may be more likely to have negative attitudes toward fractions than to have negative attitudes toward whole numbers.

Finally, in Studies 3 and 4, we aimed to replicate our findings for H1 in two new adult samples. In Study 3, we used a revised Math Attitude Questionnaire to better capture the full range of attitudes toward fractions and whole numbers and extend our findings to a new, related number type: percentages. In Study 4, we aimed to replicate our findings for H1 when specific attitudes were assessed between, rather than within, subjects.

Study 1

Method

All study procedures were reviewed and approved by the Kent State University institutional review board under Protocol #14-471 entitled "Understanding of Rational Numbers."

Participants

Participants were 119 children (45% girls, M age $= 11.4$ years, $SD = 1.1$ years, 75% non-Hispanic White, 4% Hispanic, 1% Black or African-American, 1% East or Southeast Asian, 5% of mixed racial descent, and 18% not reported by parent). Children were recruited from both the sixth grade (who completed the study in the Fall 2017; $n = 51$) and the fifth grade (who completed the study in late Spring 2018; $n = 68$) from one public intermediate school in [blinded] to assess children at different points during fraction arithmetic instruction. Children in fifth grade participated after fraction addition and subtraction with unlike denominators had been introduced in their current math classroom but before they completed formal classroom lessons on fraction division. Thus, the sixth-graders had more experience with fraction arithmetic instruction than fifth graders. Approximately 20% of children at this school qualified for the free and reduced-price lunch program.

Table 1. Study 1 descriptive statistics and correlations.

	Mean (SD)	1	2	3	4	5
1. MAQ-General	3.08 (0.61)	–	–	–	–	–
2. MAQ-Whole Number	3.19 (0.52)	**.58**	–	–	–	–
3. MAQ-Fraction	2.66 (0.65)	**.59**	**.45**	–	–	–
4. Std. Math Achievement	0 (1.00)	**.42**	**.33**	**.39**	–	–
5. Grade	57% 5th	.03	.13	−.19	−.23	–
6. Gender	45% girls	.09	.06	.04	.06	−.08

Note. Correlation coefficients (in boldface) are significant at $p < .05$. MAQ scores can range from 1 to 4.

Written parental consent and child assent was obtained for each child prior to participation. Children were recruited as part of a larger study on children's use of diagrams and completed an assessment of their specific math attitudes at the end of an approximately 40-minute individual session including another mathematics task involving drawing diagrams to represent fraction problems. Each participating child received a $10 gift card at the conclusion of the larger study. The sample size was driven by the between-subjects experimental design of the larger study.

Tasks and procedure

We designed the Math Attitude Questionnaire (MAQ) to include three sections with five questions in each (15 items total). The sections, pertaining to *self-perceived ability*, *preference*, and *perceived frequency of use,* were designed to reflect the multifaceted nature of attitudes toward mathematics (e.g., Cooper et al., 2018; Eccles & Wigfield, 1995), and each included questions about mathematics in general, whole numbers specifically, and fractions specifically (see Appendix A). Each section began with one question about mathematics in general, then the remaining four questions alternated between whole number and fraction questions. Thus, two of the remaining four questions within each section asked specifically about whole numbers (e.g., How good are you at thinking about how big whole numbers [numbers like 34 or 57] are?) and two about fractions (e.g., How good are you at thinking about how big fractions [numbers like 3/4 or 5/7] are?). Examples were consistent across questions to control for familiarity of digits (i.e., 3, 4, 5, and 7). For each question, responses were on a four-point scale with higher scores indicating more-favorable attitudes. We calculated children's attitudes toward mathematics in general as an average of their responses to the three general questions on the MAQ (MAQ-General: Items G1–G3, Cronbach's α = .74). Next, we calculated children's overall attitudes toward fractions as an average of their responses to the six fraction questions (MAQ-Fraction: Items F1–F6, Cronbach's α = .82). Finally, we calculated children's attitudes toward whole numbers as an average of their responses to the six whole-number questions (MAQ-Whole Number: Items W1–W6, Cronbach's α = .74).

Children's grade, age, gender, and race/ethnicity were reported by parents at time of consent. We obtained standardized mathematics achievement data from the previous year's end-of-year assessment for 109 participants; missing data was primarily from children who had not completed a standardized assessment since transferring into the district.

Results and discussion

Differences in specific attitudes (H1)

Overall, children's attitudes toward mathematics were somewhat positive, $M = 3.08$, with more-positive attitudes toward whole numbers, $M = 3.19$, than fractions, $M = 2.66$ (see Table 1). As expected, the majority of children (92/119) reported less positive attitudes toward fractions than whole numbers (see Table 2). The remaining children reported either equivalent attitudes (4/119) or more-positive attitudes toward fractions (23/119). Interestingly, most of the children who

Table 2. Distribution of relative attitudes among children and adults.

	Prefers fractions	Equal attitudes	Prefers whole numbers	Total N
Study 1: 5th Grade	19 (28%)	2 (3%)	47 (69%)	68
Study 1: 6th Grade	4 (8%)	2 (4%)	45 (88%)	51
Study 2: Adults	16 (4%)	46 (12%)	309 (83%)	371
Study 3: Adults	6 (8%)	6 (8%)	64 (84%)	76

reported more-positive attitudes toward fractions were fifth-graders (19/23), potentially because they had not yet been introduced to the most difficult aspect of fraction arithmetic, fraction division (Siegler et al., 2011). A dependent samples t test on children's fraction and whole-number attitude scores revealed that their attitudes toward fractions were significantly less favorable than their attitudes toward whole numbers, $M_{Diff} = -0.53$, $SE = .06$, $t(118) = -9.18$, $p < .001$, $d = -0.89$ (Borenstein, 2009; Lenhard & Lenhard, 2016). Since the MAQ includes questions spanning multiple distinct constructs (*self-perceived ability*, *preference*, and *perceived frequency of use*), we also examined the differences in specific attitudes within each construct. The magnitude of this difference was similar within each section (consisting of two items each), $ps < .01$, demonstrating that children believe they are less competent with fractions ($M_{Diff} = -0.49$), like fractions less ($M_{Diff} = -0.53$), and believe that fractions are less useful ($M_{Diff} = -0.54$) than whole numbers. Given the similarities in attitude differences across specific attitude constructs, we do not report findings separately by specific construct in subsequent sections within Study 1.

Relationships with general attitudes (H2)
We also examined the relationships between children's general attitudes toward mathematics—their average responses to the four general questions on the math attitude questionnaire (MAQ-General)—and their specific attitudes toward whole numbers and fractions. Children's fraction attitudes, $r = 0.59$, and whole number attitudes, $r = 0.58$, were correlated with general attitudes toward mathematics, $ps < .001$, and each other, $r = 0.45$. The correlations between specific attitudes and general attitudes did not differ by number type, $z = -.29$, $p = .83$, r-to-z for dependent correlation coefficients (Lee & Preacher, 2013; Steiger, 1980). Furthermore, in a regression model predicting children's general attitudes (MAQ-General) from fraction attitudes (MAQ-Fraction) and whole-number attitudes (MAQ-Whole Number), together, the predictors accounted for about half of the variance in general attitudes, total $R^2 = 47\%$. Additionally, each predictor accounted for unique variance in attitudes, $ps < .001$; whole number attitudes uniquely predicted about 12% of variance in general attitudes, $b = 0.45$, $\Delta R^2 = 12\%$, and fraction attitudes uniquely predicted about 14% of variance in general attitudes, $b = 0.39$, $\Delta R^2 = 14\%$. Taken together, these findings suggest that while children's attitudes toward fractions and whole numbers are related to their attitudes about math in general, neither children's fraction attitudes nor their whole-number attitudes were close to perfectly correlated with their general attitudes, and together fraction and whole-number attitudes predicted less than half of the variability in general attitudes. See Appendix B for all regression results for all studies.

Individual differences (H3)
Finally, we examined whether children's different attitudes toward fractions and whole numbers were related to standardized math achievement, level of current education (i.e., grade), and gender. We conceptualized the difference between children's attitudes toward fractions and whole numbers as a within-subject effect of number type (fractions versus whole numbers) on children's attitude reports and, thus, sought to examine whether achievement, grade, or gender moderated this within-subject effect of number type on attitude reporting. In other words, we examined, for example, whether the effect of number type on attitude reporting on the MAQ was greater among

children in the fifth or in the sixth grade (effect of grade on the number-type effect). To examine these interactions, we followed a statistical approach described by Judd, McClelland, and Ryan (2009) for examining interactions between a two-level–within-subject variable (number type: fractions versus whole numbers) and between-subjects predictors within a regression framework. As Judd and colleagues demonstrate, the overall effect of a two-level–within-subject variable on a continuous dependent variable can be modeled by regression of a difference score variable, comprising the scores from one level subtracted from the scores from the other level, on the dependent variable. The statistical test of the intercept in such a regression model is equivalent to the effect of the within-subject variable on the dependent variable. When a between-subjects predictor is added to the regression model, the regression coefficient can be interpreted as the effect of the between-subjects predictor on the effect of the within-subject variable; in other words, the test of this coefficient is equivalent to testing whether the between-subjects variable moderates the within-subject variable (see Judd et al., 2009, Chapters 11 and 12). Note that we did not include the distinct attitudinal constructs (self-perceived ability, preference, and perceived frequency of use) as a second within-subject variable, because patterns in specific attitudes were similar across constructs and we did not aim to examine whether the effects of number type are moderated by attitude construct.

In line with the procedure described by Judd et al. (2009), we examined whether children's different attitudes were related to individual differences by regressing difference scores ((MAQ-Whole Numbers) − (MAQ-Fractions)) on our predictors: achievement, grade, and gender. Greater difference scores reflect more-positive attitudes toward whole numbers relative to attitudes toward fractions. To further explore differences and similarities across the relationships between each predictor and MAQ-Whole Numbers and MAQ-Fractions, we ran two additional models regressing MAQ-Whole Numbers and MAQ-Fractions on all predictors. Note that this analysis is equivalent to testing the simple effects of each predictor on attitudes for each type of number (Judd et al., 2009). *Grade* was dummy coded, with fifth grade as the reference category; *gender* was coded, with girls as the reference category. The math achievement variable was rescaled for interpretation such that $M = 0$, $SD = 1$. Missing achievement data was handled with casewise deletion from the analysis. For each analysis, we report unstandardized regression coefficients.

Math achievement

Children's overall math achievement did not predict different attitudes, $b = -.05$, $SE = 0.06$, $t(104) = -0.78$, $p = .44$, $\Delta R^2 = 1\%$, controlling for grade and gender. Math achievement was related to both fraction attitudes, $p < .01$, $\Delta R^2 = 13\%$, and whole number attitudes, $p < .01$, $\Delta R^2 = 14\%$, such that students with higher levels of math achievement also held more-positive attitudes. However, differences in fraction and whole-number attitudes were present across levels of math achievement. Students with relatively low achievement in math were just as likely to have different attitudes by number type as students with relatively high achievement in math.

Gender

Children's gender also did not predict different attitudes, $b = 0.03$, $SE = 0.12$, $t(104) = 0.28$, $p = .78$, $\Delta R^2 = 0\%$, controlling for achievement and grade level. In other words, girls were just as likely as boys to have less positive attitudes toward fractions compared to their attitudes toward whole numbers. Furthermore, there was no effect of gender on fraction attitudes or whole-number attitudes; girls' and boys' attitudes toward fractions were similarly positive, $p = .84$, $\Delta R^2 = 0\%$, and their attitudes toward whole numbers were similarly positive, $p = .55$, $\Delta R^2 = 0\%$.

Grade level

Children's current grade level however was related to attitude differences, $b = 0.35$, $SE = 0.12$, $t(104) = 2.83$, $p = .006$, $\Delta R^2 = 7\%$, such that fifth-graders had considerably smaller attitude differences on average, $M = .36$, $SD = .62$, than sixth-graders, $M = .75$, $SD = .57$, controlling for gender and achievement. As shown in Table 2, one source of this effect is that a greater proportion of fifth-graders than sixth graders reported *more-favorable* attitudes toward fractions. Furthermore, among those children with more favorable attitudes toward fractions, the magnitude of that difference was smaller among sixth-graders, $M_{Diff} = 0.21$, than fifth-graders, $M_{Diff} = 0.35$ (though note that *n*s are quite low, see Table 2) In contrast, among children who reported less favorable attitudes toward fractions, the magnitude of that difference was larger among sixth-graders, $M_{Diff} = -0.86$, than fifth-graders, $M_{Diff} = -0.67$. These patterns suggest that differences in specific math attitudes begin to emerge in the middle grades, as children gain more experience with fractions. Many children in fifth grade, who have some formal classroom experience with fractions and fraction arithmetic, already have more-negative attitudes toward fractions than other, more familiar aspects of math. However, in sixth grade after intensive fraction arithmetic instruction has finished, a greater proportion of sixth-graders report negative attitudes toward fractions as compared to fifth-graders, $p = .01$, Fisher's exact test.

Study 2

In Study 2, we adapted the MAQ for use with a large, online sample of adult participants. The goal of Study 2 was to assess whether adults, like children, showed differential attitudes toward whole numbers and fractions. As with the children, we also explored whether important individual differences, such as level of educational attainment and gender, predicted different attitudes based on number type. Furthermore, we assessed adults' fraction and whole-number performance with a range of math tasks and with general math anxiety to examine their relationships with specific attitudes and to allow us to control for performance and anxiety when estimating relationships with educational attainment and gender. We added a measure of anxiety given recent studies linking adults' general math anxiety to fraction magnitude comparison and number-line estimation performance (Sidney et al., 2018). Finally, we investigated whether specific attitudes about fractions uniquely predicted performance on fraction number-line estimation and fraction arithmetic (see Supplemental Materials).

Method

All study procedures were reviewed and approved by the Kent State University institutional review board under Protocol #17-432 entitled "Effects of Attitudes and Emotions about Number on Decision-Making."

Participants

The full sample included 374 participants recruited through Amazon's Mechanical Turk (MTurk) who met our inclusion criteria: located in the United States, completion of at least 100 previous Human Intelligence Tasks (HITs) on MTurk, and at least 95% approval from other requestors for previously completed HITs. Three participants were excluded for poor quality data (see below). Of the remaining 371 participants, 54% self-identified as women, 45% identified as men, 1% identified as neither or declined to respond. Ages ranged from 21 to 76, $M = 37.4$ years, $SD = 11.4$ years. The sample was 79.9% non-Hispanic White, 5.3% Hispanic, 5.1% Black or African-American, 4.5% East or Southeast Asian, and 3.5% of mixed racial descent; 1.6% declined to respond. Most participants reported having college experience: 13.9%, a postgraduate degree;

47.1%, a college degree; 23.0%, some college experience; 0.8%, post–high school training other than college; 11.5% reported having finished high school, 0.3% reported having some high school education, and none reported having had fewer than 8 years of education; and 2.7% declined to respond.

Upon accepting the HIT, MTurk workers were given a link to the Qualtrics survey. The survey took on average 45 minutes, $M = 45.21$ m, $SD = 20.92$ m. Participants received \$6 in their MTurk account for completing the survey.

Design and tasks

Participants completed a series of tasks on Qualtrics that measured their attitudes, math anxiety, and mathematics performance. Participants provided electronic consent and took the survey on their own computers or mobile devices. The survey included four sections: (a) attitudes and math anxiety, (b) mathematics performance, (c) decision-making, and (d) demographic characteristics. Attitude, anxiety, and performance measures were always completed in the first two sections; half of the participants were randomly assigned to complete the attitude and anxiety measures first. The primary goal of this study was to examine relationships between our math attitude questionnaire (see below), anxiety, and performance and the secondary goal was to pilot new rational-number–decision-making tasks. Here, we report our results with a subset of attitude, anxiety, performance, and demographic measures.

Math attitude questionnaire

The MAQ from Study 1 was adapted for use with adults. The ability section was identical to the child version of the survey. In the preference section, children were asked about liking *learning* adults were asked about *thinking*. In the frequency section, children were asked about use outside of school and asked to predict usefulness as an adult; adults were asked about work. Finally, we include a new section on the adult questionnaire assessing adults' perceived importance of math in general, of fractions, and of whole numbers (see Appendix A). The reliability of the expanded adult questionnaire was higher than the child version for each component: general attitudes (MAQ-General: Items G1–G4, Cronbach's α = .75), fraction attitudes (MAQ-Fraction: Items F1–F8, Cronbach's α = .91), and whole-number attitudes (MAQ-Whole Number: Items W1–W8, Cronbach's α = .87).

Math anxiety measure

To measure math anxiety, participants were asked, "On a scale of 1 to 10, with 10 being the most anxious, how math anxious are you?" (Ashcraft, 2002). Response options ranged from 1 (*not anxious*) to 10 (*very anxious*).

Whole-number competence

We measured two aspects of participants' whole-number competence: understanding of numerical magnitude and arithmetic knowledge. Numerical magnitude understanding was assessed with a number-line task adapted from Landy, Charlesworth, and Ottmar (2017) and Opfer and Siegler (2007). In 22 trials, participants placed a number on a number line ranging from 0 to 1 billion (e.g., Landy et al., 2017). The set of 22 numbers was created by multiplying the set of numbers used in Opfer and Siegler (2007) in Experiment 1, which included numbers between 0 and 1,000, by 1,000,000. Numbers ranged from 2 million to 948 million. In the number-line task, participants' performance was assessed by calculating percent absolute error (PAE = (|Participants'

Answer − Correct Answer|)/Number Line Scale) × 100. For each participant, we averaged PAEs across all 22 trials; lower PAEs indicated smaller deviation from the correct location on the line.

We measured participants' whole-number arithmetic performance with the Calculation Fluency Test (Sowinski, Dunbar, & LeFevre, 2014), which measures the number of two-digit whole-number arithmetic problems completed within three minutes. The assessment included 180 problems: 60 addition, 60 subtraction, and 60 multiplication. Participants answered as many problems as they could in each section within one minute. Participants' scores were the total number of problems completed correctly.

Fraction performance

As with whole-number performance, we measured participants' understanding of fraction magnitudes and knowledge of fraction arithmetic. Fraction magnitude understanding was measured with two number-line tasks, a 0 to 1 number-line task adapted from Siegler and Thompson (2014) and a 0 to 5 number-line task adapted from Fazio, DeWolf, et al. (2016). For each task, we calculated participants' average PAE, as described above. Additionally, we administered a fraction magnitude comparison task, adapted from Fazio, DeWolf, et al. (2016), in which participants were presented with two fractions and asked to choose the larger one; percent accuracy was calculated.

We measured participants' fraction arithmetic performance across 24 fraction arithmetic problems. Participants completed six problems in each of four sections: addition, subtraction, multiplication, and division. Participants were given three minutes to solve each set of six problems. Two problems in each section involved two fraction operands (stimuli from Siegler et al., 2011) and four problems involved a whole number and a fraction (stimuli from Sidney & Alibali, 2017). Participants' scores were the total number of problems completed correctly.

Demographic information

At the end of the survey, participants reported their age, gender (coded as male identity or not, such that the two participants who reported nonbinary identities are categorized with the women), race/ethnicity, and highest grade or level of education completed (1 = *less than 8 years,* 2 = *8–11 years,* 3 = *12 years or completed high school,* 4 = *post–high school training other than college,* 5 = *some college,* 6 = *college graduate,* 7 = *postgraduate* [treated as a continuous variable in the analysis]).

Exclusion criteria

We evaluated participants' engagement in the tasks. On the number-line tasks, participants whose standard deviation was less than 10% of the length of the number line were flagged as responding with a similar location to all stimuli. On the arithmetic-knowledge tasks, participants who gave no responses or who correctly answered all questions on the Calculation Fluency Test were flagged. No participants correctly answered all questions on the Calculation Fluency Test, which helps to rule out the likelihood of calculator use on performance tasks. On the magnitude comparison task, participants who chose the option presented on one side of the screen in at least 27 out of 32 trials were flagged. Three participants were flagged in at least four of six tasks and were excluded from analysis.

Results and discussion

Overall, participants' attitudes toward mathematics were somewhat positive, with more positive attitudes toward whole numbers than fractions (see Table 3 for means, SDs, and correlations

Table 3. Study 2 descriptive statistics and correlations.

	Mean (SD)	1	2	3	4	5	6	7	8	9	10	11
1. MAQ-General	2.69 (0.67)	–	–	–	–	–	–	–	–	–	–	–
2. MAQ-Whole Number	2.74 (0.66)	.86	–	–	–	–	–	–	–	–	–	–
3. MAQ-Fraction	2.15 (0.72)	.78	.76	–	–	–	–	–	–	–	–	–
4. Math Anxiety	5.32 (2.81)	−.60	−.53	−.55	–	–	–	–	–	–	–	–
5. Whole Number Magnitude PAE	12% (11%)	−.21	−.21	−.15	.24	–	–	–	–	–	–	–
6. Fraction Magnitude PAE (0–1)	8% (7%)	−.22	−.22	−.17	.26	.43	–	–	–	–	–	–
7. Fraction Magnitude PAE (0–5)	14% (10%)	−.38	−.37	−.37	.39	.37	.66	–	–	–	–	–
8. Fraction Magnitude Comparison	86% (18%)	.29	.32	.28	−.35	−.44	−.72	−.62	–	–	–	–
9. Whole Number Arithmetic	26.70 (12.36)	.41	.37	.34	−.32	−.26	−.30	−.39	.31	–	–	–
10. Fraction Arithmetic	3.60 (1.16)	.42	.38	.41	−.47	−.35	−.50	−.60	.52	.43	–	–
11. Highest Level of Education	5.52 (1.14)	.23	.21	.29	−.18	−.01	−.01	−.12	.10	.09	.17	–
12. Gender	54% women	.09	.06	.18	−.17	−.22	−.07	−.11	.17	.12	.14	.03

Note. Correlation coefficients (in boldface) are significant at $p < .05$. MAQ scores can range from 1 to 4.

among variables). Participants' performance on the fraction magnitude tasks was in line with prior work, suggesting that participants in the MTurk sample put forth an amount of effort similar to other samples from the literature. Average fraction number-line estimation performance in the 0–5 range from the current MTurk sample (see Table 3) was similar to performance in prior college student samples (PAE = 10%, Fazio, DeWolf, et al., 2016; PAE = 12% and 14%, Sidney et al., 2018) as was magnitude-comparison accuracy ($M = 96\%$, Fazio, DeWolf, et al., 2016; $M = 91\%$ and 91%, Sidney et al., 2018).

Differences in specific attitudes (H1 and H2)

First, we examined whether adults' attitudes toward fractions were reliably less positive than their attitudes toward whole numbers (*H1*). As with the children, the vast majority of adults (306/371) reported less positive attitudes toward fractions than whole numbers. Some adults' (46/371) scores on fraction questions were equal to their scores on whole-number questions, and some adults (16/371) reported more-positive attitudes toward fractions than whole numbers (Table 2). We tested whether adults' fraction attitudes differed from their whole-number attitudes with a dependent samples t test. Indeed, in line with the attitudes among children, adults' attitudes toward fractions, $M = 2.15$, were significantly less positive than their attitudes toward whole numbers, $M = 2.74$, $M_{Diff} = -0.59$, $SE = 0.03$, $t(370) = -23.45$, $p < .001$, $d = -0.84$. Again, we examined the patterns of attitudes within each specific construct (self-perceived ability, preference, perceived frequency of use, and perceived importance). The observed pattern held within each section (consisting of two items each), $ps < .001$, demonstrating that adults believe they are less competent with fractions than with whole numbers ($M_{Diff} = -0.70$), report liking fractions less than whole numbers ($M_{Diff} = -0.53$), believe that they use fractions less often ($M_{Diff} = -0.78$) and believe that fractions are less important for being accurate when using mathematics in everyday life ($M_{Diff} = -0.34$). Again, given the similarities in attitude differences across specific attitude constructs, we do not report findings separately by specific construct in subsequent sections within Study 2.

Second, we examined the relationships between adults' general attitudes toward mathematics and their specific attitudes toward whole numbers and fractions. Both fraction attitudes, $r = 0.78$, and whole-number attitudes, $r = 0.86$, were significantly correlated with general attitudes toward mathematics. However, contrary to results for the children in Study 1, in which fraction and whole number attitudes were similarly correlated with general math attitudes, among adults the correlation of general math attitudes with whole numbers was significantly larger than the correlation with fractions, $z = 4.54$, $p < .01$, r to z for dependent correlation coefficients (Lee & Preacher, 2013; Steiger, 1980).

In a regression model predicting general attitudes (MAQ-General) from fraction attitudes (MAQ-Fractions) and whole-number attitudes (MAQ-Whole Number) separately, both predictors accounted for unique variance in attitudes, $ps < .01$, and together accounted for most of the variance, total $R^2 = 78\%$. This suggests that when we asked adults about their mathematics attitudes, in general, their responses draw on their attitudes about whole numbers, fractions, and likely other aspects of mathematics. However, in contrast to results for the children, the relationship between whole-number attitudes and general mathematics attitudes among adults was stronger, $b = 0.63$, $\Delta R^2 = 17\%$, than the relationship between fraction attitudes and general mathematics attitudes, $b = 0.29$, $\Delta R^2 = 4\%$. Taken together, these results suggest that when asked about their attitudes toward mathematics, such as how they feel about mathematics and how much they like mathematics, adults may be thinking more about whole numbers than fractions.

Individual differences (H3)

Third, we examined whether different attitudes toward fractions and whole numbers were related to math performance, math anxiety, level of education, and gender. As in Study 1, we conceptualized differential attitudes as the within-subject effect of number type on attitude responses and employed a procedure described by Judd et al. (2009) for examining the moderating effects of between-subjects predictors on a two-level, within-subject factor. We did this by regressing difference scores ((MAQ-Whole Numbers) − (MAQ-Fractions)) on all of our predictors: math anxiety; the two whole-number performance measures; the four fraction performance measures; level of education; gender; and order condition (attitude measures first or performance measures first). This analysis allowed us to examine whether variability in the magnitude of the difference between adults' whole-number and fraction attitudes was related to variability on each individual difference variable.

Given the inclusion of multiple, overlapping predictors (see Table 3 for correlations), we assessed the multicollinearity of our predictors. VIF values ranged from 1.03 to 2.69, with the greatest overlap across the fraction predictors ($VIF_{NL01} = 2.69$, $VIF_{NL05} = 2.33$, $VIF_{MagComp} = 2.47$, $VIF_{FrArith} = 1.94$), suggesting low-to-moderate correlations across these predictors that all measure fraction-magnitude knowledge to some degree (see Sidney et al., 2018; Siegler et al., 2011). Due to this overlap, we do not interpret the effects of individual performance measures; instead, we assess "whole number performance" and "fraction performance" as a set of predictors using comparison of nested models. Missing data was handled with casewise deletion from the analysis. For each analysis, we report unstandardized regression coefficients.

Order condition

First, we examined whether there were effects of our task-order manipulation. Different attitudes toward fractions and whole numbers were not related to order condition, $b = 0.04$, $SE = 0.05$, $t(350) = 0.88$, $p = .38$. Both whole-number attitudes, $b = 0.24$, $SE = 0.06$, $t(350) = 4.30$, $p < .001$, and fraction attitudes, $b = 0.20$, $SE = 0.06$, $t(350) = 3.27$, $p = .001$, were more positive when attitudes were assessed before performance. In other words, completing mathematics tasks first caused adults to report less positive attitudes toward mathematics across both number types and did not differently affect whole-number and fraction attitudes.

Performance

The difference score analysis revealed that neither whole-number performance, $F(2, 350) = 2.25$ (comparison of nested models), $p = .11$, nor fraction performance, $F(4, 350) = 1.25$ (comparison of nested models), $p = .29$, predicted different attitudes toward fractions and whole numbers. Indeed, both whole-number performance, $F(2, 350) = 5.97$, $p = .003$, $\Delta R^2 = 2\%$, and fraction

performance, $F(4, 350) = 3.41$, $p = .009$, $\Delta R^2 = 2\%$, were significantly related to adults' whole-number attitudes (MAQ-Whole Numbers). Both whole-number performance, $F(2, 350) = 3.77$, $p = .02$, $\Delta R^2 = 1\%$, and fraction performance, $F(4, 350) = 3.78$, $p = .005$, $\Delta R^2 = 3\%$, were significantly related to adults' fraction attitudes (MAQ-Fractions). In general, participants with higher performance on whole-number and fraction tasks had more-positive attitudes about whole numbers and fractions. Together with the difference-score analysis, this suggests that adults' less positive attitudes toward fractions relative to whole numbers cannot be attributed to differences in mathematics performance.

Math anxiety

The difference-score analysis also revealed that adults' math anxiety did not predict different attitudes toward fractions and whole numbers, $b = .01$, $SE = 0.01$, $t(350) = 1.13$, $p = .26$. Indeed, math anxiety predicted both whole-number attitudes, $b = -0.09$, $SE = 0.01$, $t(350) = -7.78$, $p < .001$, $\Delta R^2 = 10\%$, and fraction attitudes, $b = -0.10$, $SE = 0.01$, $t(350) = -8.15$, $p < .001$, $\Delta R^2 = 11\%$. In both cases, adults who reported greater math anxiety also reported less positive attitudes toward mathematics, regardless of number type.

Education

Different attitudes toward fractions and whole numbers were uniquely predicted by level of education, $b = -0.05$, $SE = 0.02$, $t(350) = -2.15$, $p = .03$, $\Delta R^2 = 1\%$. In other words, controlling for performance, anxiety, gender, and order condition, participants with more years of education had smaller differences between (i.e., more similar) whole-number and fraction attitudes. Education is related to adults' whole-number attitudes, $b = 0.06$, $SE = 0.02$, $t(350) = 2.53$, $p = .01$, $\Delta R^2 = 1\%$, and fraction attitudes, $b = 0.11$, $SE = 0.01$, $t(350) = 4.13$, $p < .001$, $\Delta R^2 = 3\%$. Together, these results suggest that although continued education is related to more-positive attitudes toward both whole numbers and fractions, continued education is more strongly related to fraction attitudes than whole number attitudes and is thus related to a smaller "gap" between attitudes toward fractions and whole numbers.

Gender

In contrast to the findings with children, different attitudes toward fractions and whole numbers were uniquely predicted by gender, $b = -0.18$, $SE = 0.05$, $t(350) = -3.45$, $p < .001$, $\Delta R^2 = 3\%$. The gender difference in whole-number attitudes, $b = -0.06$, $SE = 0.06$, $t(350) = -1.05$, $p = .29$, was smaller than the gender difference in fraction attitudes, $b = 0.11$, $SE = 0.06$, $t(350) = 1.87$, $p = .06$. Together, these findings reveal that women are more likely than men to hold different attitudes, and this can be partially attributed to less positive attitudes toward fractions among women than among men. Importantly, these analyses control for mathematics performance and anxiety. The findings suggest that, given a man and a woman with equal mathematics performance and anxiety, the woman may be more likely to hold negative attitudes specifically toward fractions.

Study 3

Study 3 had two aims. First, we aimed to replicate our findings that adults held different attitudes about fractions and whole numbers (*H1*) in a second sample with an adapted version of the Math Attitude Questionnaire. One limitation of the MAQ used in Studies 1 and 2 was that the four response options (e.g., *not at all good, OK, good, very good*) asked only about the extent of positive attitudes (e.g., *OK, good, very good*) and absence of positive attitudes (e.g., *not at all good*), rather than directly asking about negative attitudes. We decided not to measure explicitly

negative attitudes toward math in children because we did not want to suggest to children that they could or should "hate math" or identify as "very bad" at math at a time when their attitudes toward math, fractions, and whole numbers may still be developing (see Gunderson, Ramirez, Levine, & Beilock, 2012, for a review). However, using the MAQ from Studies 1 and 2, we could not differentiate whether participants' less positive ratings for fractions reflected truly negative attitudes. This distinction is important because negative attitudes may be more detrimental to people's engagement in math tasks than less positive attitudes. Thus, in Study 3, we changed the response options to a six-point scale (e.g., *very bad, bad, slightly bad, slightly good, good, very good*) so that we could explicitly ask adults about their negatively valenced attitudes (e.g., *very bad, bad, slightly bad*), rather than an absence of their positive attitudes. Conceptually, we choose these options to retain three levels of positive attitudes and substituted three levels of negative attitudes for the leftmost endpoint of the original scale (e.g., *not at all good*).

Second, in Study 2, we found that the relationship between whole-number attitudes and general attitudes was stronger than the relationship between fraction attitudes and general attitudes among adults. These findings were in line with whole-number bias studies suggesting that when adults are asked about math in general, whole numbers are the types of numbers that likely come to mind (e.g., Van Hoof, Vandewalle, et al., 2015). In Study 3, we extended the question of whether asking participants about general attitudes captured some variability in their attitudes toward any number types other than whole numbers by examining attitudes toward percentages. Percentages are also common in daily life (e.g., 25% off sale) and central to other measures of adults' mathematics self-perceived ability, preference, and values (Fagerlin et al., 2007). Because of the dearth of developmental research on children and adults' understanding of percentages (see Tian & Siegler, 2018), it was unclear whether people would consider percentages to be more similar to whole numbers because of their perceptual similarities (e.g., 25% and 25 involve the same numerals) or to fractions because of their conceptual similarities (e.g., 1/4 and 25% are equivalent).

Our primary aim for Study 3 was to replicate H1 and H2, so we set our sample size to have adequate power to test the differential attitudes between whole numbers and fractions (H1) and the *r* to *z* transformation analyses (i.e., Is the correlation between whole number attitudes and general attitudes stronger than the correlation between fraction attitudes and general attitudes?; H2). Thus, we focus on relationships between fraction and whole-number attitudes and do not report relationships with the individual differences variables mentioned in Study 1 (e.g., gender, educational attainment, math anxiety, competency) because we did not power for these analyses.

Method

All study procedures were reviewed and approved by the Kent State University Institutional Review Board under Protocol #17-432 entitled "Effects of Attitudes and Emotions About Number on Decision-Making."

Participants

The full sample included 76 participants recruited through Amazon's MTurk who met the same inclusion criteria as described in Study 2. Participants who completed Study 2 were not eligible to complete Study 3. Applying the criteria described in Study 2, no participants were excluded for poor quality data. In this sample, 30 participants self-identified as women and 46 identified as men. Ages ranged from 18 to 68, $M = 37.5$ years, $SD = 11.7$ years. The sample was 78.9% non-Hispanic White, 3.9% Hispanic, 3.9% Black or African-American, 5.3% East or Southeast Asian, and 6.6% of mixed racial descent; 1.3% declined to respond concerning race/ethnicity. In terms of educational experience the sample was similar to the Study 2 sample. As in Study 2, participants received $6 in their MTurk account after completing the survey.

Table 4. Study 3 descriptive statistics and correlations.

	Mean (SD)	1	2	3	4	5	6	7	8	9	10	11
1. MAQ-General	3.84 (1.07)	–	–	–	–	–	–	–	–	–	–	–
2. MAQ-Whole Number	4.14 (1.04)	.87	–	–	–	–	–	–	–	–	–	–
3. MAQ-Fraction	2.86 (1.14)	.73	.53	–	–	–	–	–	–	–	–	–
4. MAQ-Percentage	3.72 (1.14)	.83	.80	.73	–	–	–	–	–	–	–	–
5. Math Anxiety	6.01 (3.04)	−.58	−.50	−.50	−.58	–	–	–	–	–	–	–
6. Whole Number Magnitude PAE	9% (9%)	−.25	−.21	−.24	−.35	.23	–	–	–	–	–	–
7. Fraction Magnitude PAE (0–5)	13% (10%)	−.41	−.33	−.43	−.41	.43	.53	–	–	–	–	–
8. Fraction Magnitude Comparison	84% (21%)	.29	.26	.28	.36	−.39	−.48	−.58	–	–	–	–
9. Whole Number Arithmetic	26.79 (9.98)	.34	.30	.39	.41	−.40	−.33	−.43	.34	–	–	–
10. Fraction Arithmetic	3.62 (1.84)	.46	.43	.41	.45	−.49	−.44	−.58	.45	.34	–	–
11. Highest Level of Education	5.32 (1.13)	.05	.03	.21	.17	−.18	−.35	−.20	.00	.09	.20	–
12. Gender	39% women	.30	.26	.22	.37	−.42	−.25	−.21	.24	.18	.13	.13

Note. Correlation coefficients (in boldface) are significant at $p < .05$. MAQ scores can range from 1 to 6. Fraction Magnitude (0–1) was not administered in Study 2.

Design and tasks

Participants completed a subset of the Qualtrics survey questions used in Study 2: attitudes and math anxiety, mathematics performance, and demographic characteristics. The MAQ used in Study 3 had three main differences: (a) participants rated their responses on a six-point scale instead of a four-point scale; (b) participants rated their attitudes about percentages in addition to mathematics in general, whole numbers, and fractions (percentage questions always followed fraction questions within each subsection of the MAQ, see Appendix A); and (c) all participants received performance tasks before attitude tasks, given that order did not affect the relationship between whole-number and fraction attitudes. As in Studies 1 and 2, we calculated participants' attitudes toward mathematics in general (MAQ-General: Items G1–G4, Cronbach's α = .79), participants' attitudes toward fractions (MAQ-Fraction: Items F1–F8, Cronbach's α = .90), and participants' attitudes toward whole numbers (MAQ-Whole Number: Items W1–W8, Cronbach's α = .89). Additionally, we calculated participants' attitudes toward percentages as the average of participants' attitudes on the eight percentage questions (MAQ-Percentage: Items P1–P8, Cronbach's α = .91).

Performance measures were always completed before the attitudes and anxiety measure because we found that there was no effect of order in Study 2 on the relationship between participants' whole-number and fraction attitudes.

Results and discussion

Attitudes differences (H1)

Participants' attitudes toward mathematics in general were somewhat positive, with positive attitudes toward whole numbers and percentages and negative attitudes toward fractions, on average (see Table 4 for means, *SD*s, and correlations among variables).

As in Studies 1 and 2, the vast majority of participants (64/76) reported less positive attitudes toward fractions than whole numbers (see Table 2). Of this subset, most (39/64) held positive attitudes toward whole numbers and negative attitudes toward fractions. As in Studies 1 and 2, the remaining participants (12/76) reported either equivalent attitudes or more-positive attitudes toward fractions. Among participants whose attitudes were "mixed" (positive attitudes toward one number type and negative attitudes toward another), all held negative attitudes toward fractions despite reporting positive attitudes toward whole numbers (see Table 5).

We examined each pairwise comparison between responses to questions with each number type (fraction, whole numbers, and percentages) with a dependent samples *t* test. Adults' attitudes toward fractions were significantly less favorable than their attitudes toward whole numbers,

Table 5. Relative attitudes toward fractions and whole numbers.

Relative Attitude	Both Negative	Mixed	Both Positive	Total
Prefers Fractions	$n = 2$	$n = 0$	$n = 4$	$n = 6$
Fraction = Whole Number	$n = 4$	–	$n = 2$	$n = 6$
Prefers Whole Numbers	$n = 11$	$n = 39$	$n = 14$	$n = 64$

Note. Mixed = positive attitudes toward one number type with negative attitudes toward another (when fraction and whole number attitudes are equivalent, mixed attitudes cannot be observed). No participant reported negative attitudes toward whole numbers with positive attitudes toward fractions.

$M_{Diff} = -1.29$, $SE = 0.12$, $t(75) = 10.60$, $p < .001$, $d = -1.18$, and attitudes toward percentages were significantly less favorable than attitudes toward whole numbers, $M_{Diff} = -0.42$, $t(75) = 5.26$, $SE = 0.08$, $p < .001$, $d = -0.35$. Furthermore, participants' attitudes toward fractions were significantly less favorable than their attitudes toward percentages, $M_{Diff} = -0.87$, $SE = 0.10$, $t(75) = 9.03$, $p < .001$, $d = -0.76$. Notably, the effect size estimates indicate that the difference between fraction and whole number attitudes in Study 3 was greater than in Study 2. This suggests that the six-point scale allowed us to measure greater differences between fraction and whole-number attitudes, as we had aimed to do. As in Studies 1 and 2, attitude differences between whole-number and fraction items were similar across attitude constructs, self-perceived ability, $M_{Diff} = -1.38$, preference, $M_{Diff} = -1.18$, frequency of use, $M_{Diff} = -1.56$, and perceived importance, $M_{Diff} = -1.03$.

Second, we aimed to replicate our finding (H2) from Study 2 that adults' general attitudes toward mathematics were more closely related to adults' attitudes toward whole numbers than to adults' attitudes toward fractions. As in Study 2, both fraction attitudes, $r = 0.73$, and whole-number attitudes, $r = 0.87$, were significantly correlated with general attitudes toward mathematics. However, the correlation with whole numbers was significantly larger, $z = 2.77$, $p < .01$, r to z for dependent correlation coefficients (Lee & Preacher, 2013; Steiger, 1980). Adults' attitudes toward percentages were also closely related to both general attitudes, $r = 0.83$, and whole-number attitudes, $r = 0.80$, suggesting the possibility that adults think about percentages as being highly similar to whole numbers. The correlation between percentage attitudes and general attitudes was not significantly different than the correlation between whole number and general attitudes, $z = 1.20$, $p = .23$.

Finally, we fit a regression model predicting general attitudes (MAQ-General) from fraction attitudes (MAQ-Fraction) and whole-number attitudes (MAQ-Whole Number) separately. Both predictors account for unique variance in attitudes, $ps < .001$, and together account for most of the variance, total $R^2 = 85\%$. However, as in Study 2, the relationship between whole-number attitudes and general mathematics attitudes was considerably stronger, $b = 0.69$, $\Delta R^2 = 32\%$, than the relationship between fraction attitudes and general mathematics attitudes $b = 0.36$, $\Delta R^2 = 10\%$. Adding adults' attitudes toward percentages explains no additional variance; adults' percentage attitudes did not have any unique relationship with their general attitudes over and above the other predictors, whole number: $b = 0.62$, $p < .001$, $\Delta R^2 = 13\%$; fraction: $b = 0.31$, $p < .001$, $\Delta R^2 = 5\%$; percentage: $b = 0.10$, $p = .24$, $\Delta R^2 = 0\%$.

Study 4

Although we found in Studies 1, 2, and 3 that both children and adults have less positive attitudes toward fractions than whole numbers, we considered the possibility that differences in attitudes were at least in part a function of the order of items within the MAQ. One possibility is that participants rated fractions differently than whole numbers simply because questions that differed only by number type (e.g., about fractions versus about whole numbers) appeared together in a fixed order within the MAQ. To examine this possibility, we administered a portion of the MAQ to college-aged adult participants (age range: 18 to 25 years, $M_{age} = 19.24$ years, $SD = 1.54 y$;

80% women; 76% White) who were recruited through psychology courses at a selective university in the southeastern United States.

Participants rated their attitudes at the end of another study about adults' diagram drawing. The tasks in the other study were similar to the tasks completed by children in Study 1 prior to receiving the MAQ and involved drawing diagrams to represent fraction division problems.

Some ($n = 43$) participants answered only MAQ questions about whole numbers, and other participants ($n = 33$) answered only MAQ questions about fractions. Each group answered questions just about self-perceived ability and preference on the same six-point scale used in Study 3. Because each group received questions about only one number type, this provides a more stringent test of whether adults' attitudes toward fractions are reliably more negative than their attitudes toward whole numbers.

Indeed, even when number type was manipulated across participants, rather than within participants, adults' attitudes toward fractions were less positive than their attitudes toward whole numbers, $M_{Fractions} = 3.49$, $M_{Whole\ Numbers} = 4.76$, $M_{Diff} = -1.26$, $SE = 0.24$, $t(74) = 5.23$, $p < .001$, $d = -1.22$. Thus, the magnitude of mean differences between adults' attitudes toward fractions and whole numbers was similar to differences observed with the same scale in Study 3 ($M_{Diff} = -1.29$). As in Study 3, attitude differences were observed for each measured attitude construct, self-perceived ability, $M_{Diff} = -1.04$, and preference, $M_{Diff} = -1.49$.

Thus, it does appear that differential attitudes toward fractions and whole numbers is not the result of a demand characteristic of the MAQ, which juxtaposes questions about whole numbers and questions about fractions within the same scale. Our results suggest that fractions attitudes were not rated less favorably than whole numbers just because participants saw both types of questions together within the same scale and inferred that they should respond differently to each type of question. However, there are some important limitations to consider when comparing the findings from the adults in Study 4 to the adults in Studies 2 and 3. In contrast to Studies 2 and 3, we did not recruit a community sample. Thus, the adults in Study 4 differ in many ways from the adults in Studies 2 and 3, including distributions of age, gender, and educational attainment. Their higher levels of education (i.e., all currently enrolled at a selective university) may be one reason why they held more-positive attitudes toward both fractions and whole numbers, though the "gap" in attitudes was similar in magnitude. Finally, all participants rated their attitudes after completing a challenging fraction problem-solving task, so this may have negatively impacted their attitudes about fractions. However, results from Study 2 (see "Order condition" section above) suggest that this is unlikely to be the case since both whole-number and fraction attitudes were less positive after completing earlier math tasks than if rated before math tasks were completed.

General discussion

Early-emerging differences in specific attitudes (H1)

Across four studies, we found that both children and adults often held less favorable attitudes toward fractions than whole numbers. They believed they were less competent with fractions, they reported that they liked fractions less, and they thought fractions were less important and useful in daily life than whole numbers (Studies 1, 2, and 44) and percentages (Study 3). Furthermore, in Study 3, we demonstrated that adults' fraction attitudes were not just less positive, but quite negative, despite many adults holding positive attitudes toward whole numbers. In Study 4, we demonstrated that the observed differential attitudes were not simply a function of sequentially answering questions about fractions after questions about whole numbers (and thus likely directly contrasting the different types of numbers), suggesting that our findings in Studies 1, 2, and 3 reflect true differences in people's attitudes toward fractions and whole numbers.

Importantly, the fifth- and sixth-graders who participated in our research had differing amounts of formal fraction arithmetic experience, yet even the fifth-graders who had less formal fraction arithmetic experience already showed differential attitudes between whole numbers and fractions. However, the differences in attitudes were significantly greater among children in sixth grade. Not only was the average difference between whole-number and fraction attitudes larger among sixth-graders than fifth-graders, but many more sixth-graders held differential attitudes. That is, sixth-graders were more likely to hold very positive attitudes toward whole numbers, and math in general, but held considerably less positive attitudes toward fractions. The magnitude of the difference between participants' whole-number and fraction attitudes was quite similar among children and adults who held less favorable attitudes toward fractions.

The specific direction of the differences between whole-number attitudes and fraction attitudes—that people feel more negatively toward fractions—may have significant developmental and practical implications. Developmentally, negative attitudes toward fractions are concerning because of the importance of fraction understanding in mathematics development and higher educational attainment more broadly: Early fraction learning is a critical predictor of success in algebra (Siegler et al., 2012), the "gatekeeper" to higher mathematics (Booth & Newton, 2012). Although lower mathematics achievement was related to less positive attitudes overall, we did not find that children's relative mathematics achievement before beginning fraction instruction predicted different attitudes toward fractions and whole numbers at the end of the school year. More research is necessary to determine whether the attitude differences that emerge in sixth grade contribute to poorer fraction competency at the end of sixth grade and, in turn, less success in later grades.

These findings also have important implications for how we assess attitudes toward mathematics in contexts with and without fractions and other rational numbers. One fortunate implication of the high correlation between whole number and fraction attitudes is that when researchers ask adults about their mathematics attitudes, which are closely aligned with whole-number attitudes, they can capture some of the variability in adults' attitudes toward fractions as well. However, for contexts in which attitudes toward fractions may be especially important, such as when explaining differences in adults' decision-making when given ratio information (for example, when evaluating the difference between the 1 in 16,400 risk of SIDS when sharing a bed with one's infant versus the 1 in 46,000 risk if not sharing a bed; Doucleff, 2018), asking directly about fraction attitudes has the potential to provide a more focused measure that should predict adults' propensity to engage deeply with or avoid numeric information of this type. Given the variability with which adults' fraction attitudes are in line with their whole number and general attitudes, asking simply about "mathematics" may fail to capture negative attitudes among people who have otherwise favorable attitudes toward mathematics.

Furthermore, it may be important to ask about attitudes toward both whole numbers and fractions, to index the degree to which children and adults have negative attitudes toward fractions despite positive attitudes toward whole numbers or mathematics in general. Asking people about their attitudes toward multiple subdomains of mathematics allows researchers to distinguish those with attitudes that differ by subdomain from those who feel negatively or positively toward mathematics overall. Measuring differences in *specific attitudes*, as we have here, may offer more insight into children and adults who may differentially engage in numeric tasks, both in and out of school, depending on whether the numeric information is presented as fractions, whole numbers, or in other numeric formats.

Are number concepts integrated? (H2)

Children's and adults' attitudes about math in general were correlated with both their attitudes about fractions and their attitudes about whole numbers. However, there was variability in the

extent to which people's attitudes were aligned across whole-number and fraction questions. To the extent that differences in attitudes may indicate differences in underlying number concepts, divergence in children's and adults' attitudes toward fractions and whole numbers may indicate poorly integrated fraction and whole-number knowledge. According to the integrated theory of whole number and fractions development (Siegler et al., 2011), one key component in the developmental trajectory of mathematical cognition is understanding that all rational numbers, including whole numbers, fractions, percentages, decimals, and other types of numbers belong to the same mathematical system and have fundamental commonalities. It remains an open question as to whether instructional practices that emphasize these commonalities (e.g., whole numbers and fractions are similar because they possess magnitudes that can be placed on number lines) would lead people to better integrate their knowledge and attitudes about whole numbers and fractions.

Furthermore, adults' attitudes about math in general appeared to differ from children's attitudes in two ways. First, the correlations between adults' general attitudes and their specific attitudes were much higher overall, potentially indicating that children's specific attitudes were more distinct from their general attitudes toward math compared with adults'specific attitudes. Children's concepts of what math encompasses may be more differentiated than adults' concepts. When asked about "math in general," children may think about various aspects of math in addition to whole-number and fraction arithmetic, such as geometry, data and statistics, and patterning, which are other aspects of elementary and middle grades curricula (see National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). Alternatively, adults' attitudes may have been more strongly correlated simply because many adults had just completed a broad range of fraction and whole-number tasks (whereas the children had just completed a single diagram-drawing task) or because the measure was more reliable among adults.

Second, when asked about attitudes toward mathematics generally, adults appear to be thinking more about whole numbers than fractions (Studies 2 and 3). This evidence from adults' attitudes is in line with other evidence of a whole-number bias (e.g., Ni & Zhou, 2005; Van Hoof, Verschaffel, et al., 2015), in which people who are asked to think generally about numbers (e.g., evaluating the accuracy of the statement $x + 4 < x$) often think specifically about whole numbers and fail to think about other types of numbers, such as fractions. These findings from the adult studies suggest that the differences in specific attitudes toward fractions and whole numbers may reflect the extent to which their fraction concepts remain poorly integrated with their other math concepts. Interestingly, adults' attitudes toward whole numbers were more closely aligned with their attitudes toward percentages than fractions. This may indicate that many adults perceive percentages as if they were whole numbers, ignoring the percentage sign entirely, an error commonly observed in studies of children's reasoning (see Parker & Leinhardt, 1995). Lending support to this interpretation, we found that percentage attitudes were very highly correlated with whole-number attitudes and that adding percentage attitudes to our regression model of general attitudes explained no additional variance over and above whole-number and fraction attitudes. Only a handful of adults in our Study 3 sample ($n = 10$) reported positive attitudes toward whole numbers but negative attitudes toward percentages.

In line with our interpretation, Moss and Case (1999) have argued that percentages serve as a bridge between whole numbers and fractions and have designed an educational intervention aimed at teaching children about rational numbers by introducing percentages first. They argue that children are more familiar with percentage contexts in their everyday experiences (e.g., a file loading), and thus, starting rational-number instruction with percentages allows learners to engage with ratios in a context that is both highly familiar and that allows children to draw on their whole-number knowledge (e.g., 25% is less than 50% because 25 is less than 50). More research is needed to better understand the developmental trajectory of percentage knowledge and attitudes and how percentages are perceived to be similar to and different from whole numbers and fractions (Tian & Siegler, 2018).

Attitudes, performance, and gender (H3)

In Study 2, we collected data with a large sample of adults and included measures of specific facets of fraction and whole-number performance to explore the relationships between specific attitudes, math performance, educational attainment, and gender. First, we found that educational attainment and gender predicted *how much* less favorable adults' attitudes toward fractions were in comparison to their whole number attitudes (*H3*). Adults with higher educational attainment felt more similarly toward fractions and whole numbers than adults with less educational attainment. Experience in higher education may help people to rate fractions less negatively, people who rate fractions more positively may be more likely to continue in higher education, or both. However, these correlational findings prohibit insight into causal direction.

Also, we observed that women's attitudes toward whole numbers and fractions tend to differ more than men's attitudes toward whole numbers and fractions. It is important to note the preliminary nature of this finding, as no prior research has directly indicated that women's or girls' attitudes are likely to be more differentiated than men's or boys'. However, given the importance of fraction understanding in the development of mathematics knowledge (e.g., Siegler et al., 2012), this finding raises questions about whether women's negative attitudes toward fractions might be implicated in gender differences in mathematics achievement in adolescence and adulthood (e.g., Halpern et al., 2007; Hyde et al., 1990). When people have negative attitudes toward fractions, they may disengage with mathematics tasks involving fractions. For instance, in a recent, unpublished survey of college students' fraction problem-solving ability conducted as an experiment in a research methods course, one undergraduate participant answered the mathematics problem $3/4 + 2/3 = $ ___ by typing, "This is my worst nightmare." Negative attitudes toward fractions may contribute to some women's disengagement from mathematics, regardless of their actual mathematics performance or even anxiety (see Lauermann et al., 2017; Wang, Eccles, & Kenny, 2013). However, we did not observe gender differences in attitudes among fifth- and sixth-graders, raising questions about when stronger, specific fraction attitudes emerge among girls or, alternatively, when the "gap" between fraction and whole-number attitudes closes among boys.

Gender differences in mathematics performance is a contentious topic, both in the research literature and in public debate. The current study makes an incremental contribution toward a more robust understanding of the possible mechanisms (i.e., disengagement from rational-number instruction) that could contribute to later observed gender differences in achievement and attainment.

Limitations and future directions

First, one limitation of the current line of studies is our adoption of a broad characterization of "mathematics attitudes" that subsumes multiple distinct attitudinal constructs, self-perceived ability, preference, and perceived frequency of use. Over the past several decades, a rich history of research linking facets of students' attitudes and their academic goals, performance, and achievement (e.g., Ainley et al., 2002; Cooper et al., 2018; Eccles et al., 1993; Wigfield & Eccles, 2000) has demonstrated that mathematics attitudes comprise theoretically and empirically distinct constructs. In many cases, these constructs have been shown to have unique, separable effects on development, learning, and problem-solving, and thus, it is useful to distinguish between them, both in theory and practice. However, here, we have not focused on how number type might affect the measurement of children's and adults' self-perceived ability, preference, and perceived frequency of use, and we have not measured the effects of attitude differences on targeted behavioral outcomes. Thus, we are unable to conclude whether people's negative attitudes toward fractions may matter more for some attitudinal constructs than others. Given that each construct

may have unique effects on student mathematics performance and engagement, one important future direction is to directly examine the roles that attitudes toward specific facets of mathematics may play in these unique pathways.

Second, the open questions about the relationships between gender, attitudes, mathematical performance, and educational attainment reveal a limitation: Because of the correlational nature of our data, we are unable to address whether different attitudes toward fractions and whole numbers directly affect mathematics learning, development, or engagement or, conversely, whether mathematical performance directly affects attitudes. Rather, this study is a first step in demonstrating relationships among children's and adults' attitudes about specific types of numbers and their mathematical performance. We acknowledge that it was necessary for us to conduct many analyses across four studies, though we note that our main hypothesis was supported across all studies with a variety of samples (i.e., less favorable/more negative attitudes about fractions than other types of numbers). Further work is needed to assess the developmental trajectory of gender differences in fraction attitudes; whether these attitudes are malleable; specifically when fraction performance is improved; and what role these attitude differences might play in mathematics engagement.

Third, one may wonder whether negative attitudes about fractions stem from the fact that fraction tasks are accurately perceived as more difficult and requiring more effort than whole number tasks to complete. Adults are often less accurate and precise in fraction tasks than they are with similar whole-number tasks (e.g., Fazio et al., 2014; Sidney et al., 2018; Siegler & Opfer, 2003; Thompson & Opfer, 2010, for evidence from number-line estimation), even though adults are far removed from direct instruction on either of these facets of mathematics. This difficulty with fractions may lead to both greater math anxiety and more negative attitudes toward fractions specifically. However, it is important to note that in our current sample, fraction performance *did not* predict differences in attitudes for whole numbers versus fractions in Study 2. We found that differences in attitudes cannot be attributed to differences in performance; our data suggest that given two people who are equally good with fractions, one may have very similar attitudes toward fractions and whole numbers, and one may have very different attitudes toward fractions and whole numbers. Thus, these differences in attitudes are not solely a function of the objective difficulty of whole-number and fraction tasks, though it is an open question as to whether participants' perceived effort on whole-number versus fraction tasks predicts differential attitudes about fractions and whole numbers. Furthermore, there was no effect of task order on attitude differences in our data. That is, even when participants in Study 2 completed our fraction performance measures before rating their mathematics attitudes, they did not report less positive attitudes toward fractions (relative to whole numbers) than if they rated their attitudes before completing the challenging fraction performance tasks.

Fourth, the current study does not shed light on the role that familiarity with fractions may play in attitudes toward fractions. Experience with numbers in everyday life may impact familiarity with numbers and thus attitudes about different number types. The Common Core State Standards indicates that children begin learning about whole numbers prior to learning about fractions, therefore, people may be more familiar with whole numbers than fractions, which may translate to more-positive attitudes about whole numbers than fractions. Interestingly, recent work has indicated that familiarity plays a role in adults' equivalent fraction number-line estimation performance (Fitzsimmons, Thompson, & Sidney, 2019). That is, they are more familiar, more confident, and more precise with small component fractions (1/2) than with equivalent large component fractions (15/30).

Familiarity with rational numbers may explain some of the seemingly discrepant results that we identified in our data. For example, there was a bigger difference in fraction and whole-number attitudes for sixth-graders than for fifth graders. However, our results suggested that with increasing years of formal education, this led to a smaller gap in attitudes for adults. Why might

this be the case? With increasing years of formal classroom instruction on fractions, children may begin to recognize that this topic is particularly difficult; they may be exposed to teachers' and/or parents' negative attitudes toward fractions; and they may be more capable of monitoring their own fraction competency. For adults, we do not have data on the types of majors/professions that they pursued, so it could be possible that our highly educated adults chose majors/professions that required them to use fractions and other rational numbers in their daily lives, resulting in greater familiarity. However, it may be the case that simple familiarity with fractions would not explain differences in attitudes, as adults may encounter fractions on a daily basis (e.g., following recipes, interpreting nutrition labels, measuring distance and length, filling up gas tanks, reasoning about fractional units of time and money). Future research will be necessary to tease apart the role of familiarity and experience in math attitudes.

Finally, given that children and adults report different attitudes for different facets of mathematics and that people find some facets of mathematics to be more difficult than others, one future direction of research may be to extend this finding to mathematics anxiety. Some topics in mathematics may elicit anxiety in different ways than others. For example, there is some evidence that statistics anxiety may be a separate construct from mathematics anxiety and that gender may play a different role in each (see Baloğlu, 2004). Recently, there has been a call to examine the degree to which different subdomains of mathematics elicit different degrees of mathematics anxiety (see Dowker, Sarkar, & Looi, 2016) and our findings regarding differentiated attitudes based on specific number types appear to be in line with this general idea.

Conclusions and educational implications

In conclusion, we have demonstrated that children's and adults' mathematics attitudes are multifaceted. In addition to having distinct attitudes about ability, preference, and value of mathematics (e.g., Cooper et al., 2018; Eccles & Wigfield, 1995), people also differ in their attitudes toward different types of mathematics (i.e., with fractions and whole numbers). Even when people report that they "like mathematics," they may still dislike fractions, despite the prevalence and importance of fractions in everyday life. Continued research is necessary for revealing relationships between attitudes, mathematics performance, math anxiety, educational attainment, gender, and how attitudes change or stay the same across the lifespan. Additional research about students' attitudes is needed, particularly research about students' attitudes as they are formally learning about different number types in school. Attitudes about different number types may ultimately contribute to decisions about whether students engage and persist in STEM majors and professions.

ORCID

Pooja G. Sidney 🔟 http://orcid.org/0000-0003-3719-8543
Clarissa A. Thompson 🔟 http://orcid.org/0000-0001-8758-3218
Jennifer M. Taber 🔟 http://orcid.org/0000-0003-3285-4871

References

Ainley, M., & Ainley, J. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about science. *Contemporary Educational Psychology*, *36*(1), 4–12. doi:10.1016/j.cedpsych.2010.08.001

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest, learning, and the psychological processes that mediate their relationship. *Journal of Educational Psychology, 94*(3), 545. doi:10.1037//0022-0663.94.3.545

Ajzen, I., & Fishbein, M. (2005). The influence of attitudes on behavior. In D. Albarracín, B. T. Johnson, M. P. Zanna (Eds.), *The handbook of attitudes* (pp. 173–221). Mahwah, NJ: Lawrence Erlbaum Associates.

Alibali, M. W., & Sidney, P. (2015). Variability in the natural number bias: Who, when, how, and why? *Learning and Instruction, 37*, 56–61. doi:10.1016/j.learninstruc.2015.01.003

Alken, L. R. (1974). Two scales of attitude towards mathematics. *Journal for Research in Mathematics Education, 5*(2), 67–71. doi:10.2307/748616

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science, 11*(5), 181–185. doi:10.1111/1467-8721.00196

Baloğlu, M. (2004). Statistics anxiety and mathematics anxiety: Some interesting differences I. *Educational Research Quarterly, 27*(3), 38–48.

Booth, J., & Newton, K. J. (2012). Fractions: Could they really be the gatekeeper's doorman? *Contemporary Educational Psychology, 37*(4), 247–253. doi:10.1016/j.cedpsych.2012.07.001

Borenstein, M. (2009). Effect sizes for continuous data. In H. Cooper, L. V. Hedges, & J. C. Valentine (Eds.), *The handbook of research synthesis and meta analysis* (pp. 221–237). New York, NY: Russell Sage Foundation.

Braithwaite, D. W., & Siegler, R. S. (2018). Developmental changes in the whole number bias. *Developmental Science, 21*(2), e12541.

Brown, S. A., Donovan, A. M., & Alibali, M. W. (2016, July). *Gestural schematization influences understanding of infinite divisibility*. Paper presented at the fourth annual midwest meeting on Mathematical Thinking, Madison, WI.

Carpenter, T. P., Corbitt, M. K., Kepner, H., Jr., Lindquist, M. M., & Reys, R. (1980). Results from the second NAEP mathematics assessment: Secondary school. *The Mathematics Teacher, 73*(5), 329–338.

Cooper, J. L., Sidney, P. G., & Alibali, M. W. (2018). Who benefits from diagrams and illustrations in math problems? Ability and attitudes matter. *Applied Cognitive Psychology, 32*(1), 24–38. doi:10.1002/acp.3371

Cuite, C. L., Weinstein, N. D., Emmons, K., & Colditz, G. (2008). A test of numeric formats for communicating risk probabilities. *Medical Decision Making, 28*(3), 377–384. doi:10.1177/0272989X08315246

Davidson, A. R., & Jaccard, J. J. (1979). Variables that moderate the attitude–behavior relation: Results of a longitudinal survey. *Journal of Personality and Social Psychology, 37*(8), 1364. doi:10.1037/0022-3514.37.8.1364

Denissen, J. J., Zarrett, N. R., & Eccles, J. S. (2007). I like to do it, I'm able, and I know I am: Longitudinal couplings between domain-specific achievement, self-concept, and interest. *Child Development, 78*(2), 430–447. doi:10.1111/j.1467-8624.2007.01007.x

Doucleff, M. (2018, May 21). Is sleeping with your baby as dangerous as doctors say? *National Public Radio*. Retrieved from https://www.npr.org/sections/goatsandsoda/2018/05/21/601289695/is-sleeping-with-your-baby-as-dangerous-as-doctors-say

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? *Frontiers in Psychology, 7*, 1–16. doi:10.3389/fpsyg.2016.00508

Eccles, J. Wigfield, A., Harold, R. D., & Blumenfeld, P. (1993). Age and gender differences in children's self- and task perceptions during elementary school. *Child Development, 64*(3), 830–847.

Eccles, J. S., & Wigfield, A. (1995). In the mind of the actor: The structure of adolescents' achievement task values and expectancy-related beliefs. *Personality and Social Psychology Bulletin, 21*(3), 215–225. doi:10.1177/0146167295213003

Etchegary, H., & Perrier, C. (2007). Information processing in the context of genetic risk: Implications for genetic-risk communication. *Journal of Genetic Counseling, 16*(4), 419–432. doi:10.1007/s10897-006-9082-z

Fagerlin, A., Zikmund-Fisher, B. J., Ubel, P. A., Jankovic, A., Derry, H. A., & Smith, D. M. (2007). Measuring numeracy without a math test: Development of the Subjective Numeracy Scale (SNS). *Medical Decision Making, 27*(5), 672–680. doi:10.1177/0272989X07304449

Fazio, L. K., Bailey, D. H., Thompson, C. A., & Siegler, R. S. (2014). Relations of different types of numerical magnitude representations to each other and to mathematics achievement. *Journal of Experimental Child Psychology, 123*, 53–72. doi:10.1016/j.jecp.2014.01.013

Fazio, L. K., DeWolf, M., & Siegler, R. S. (2016). Strategy use and strategy choice in fraction magnitude comparison. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*(1), 1–16. doi:10.1037/xlm0000153

Fazio, L. K., Kennedy, C. A., & Siegler, R. S. (2016). Improving children's knowledge of fraction magnitudes. *PLoS One, 11*(10), e0165243. doi:10.1371/journal.pone.0165243

Fitzsimmons, C., Thompson, C. A., & Sidney, P. G. (2019). *Confident or familiar? The role of familiarity and fraction estimation precision on metacognition*. Paper to be presented at the 41th annual meeting North American Chapter of the International Group for the Psychology of Mathematics Education, St. Louis, MO.

Fennema, E., & Sherman, J. A. (1976). Fennema-Sherman mathematics attitudes scales: Instruments designed to measure attitudes toward the learning of mathematics by females and males. *Journal for Research in Mathematics Education, 7*(5), 324–326. doi:10.2307/748467

Fuchs, L. S., Malone, A. S., Schumacher, R. F., Namkung, J., & Wang, A. (2016). Fraction intervention for students with mathematics difficulties: Lessons learned from five randomized controlled trials. *Journal of Learning Disabilities*, 50(6), 631–639. doi:10.1177/0022219416677249

Gunderson, E. A., Ramirez, G., Levine, S. C., & Beilock, S. L. (2012). The role of parents and teachers in the development of gender-related math attitudes. *Sex Roles*, 66(3-4), 153–166. doi:10.1007/s11199-011-9996-2

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., & Gernsbacher, M. A. (2007). The science of sex differences in science and mathematics. *Psychological Science in the Public Interest*, 8(1), 1–51. doi:10.1111/j.1529-1006.2007.00032.x

Hamdan, N., & Gunderson, E. A. (2017). The number line is a critical spatial-numerical representation: Evidence from a fraction intervention. *Developmental Psychology*, 53(3), 587–596. doi:10.1037/dev0000252

Hartnett, P., & Gelman, R. (1998). Early understandings of numbers: Paths or barriers to the construction of new understandings? *Learning and Instruction*, 8(4), 341–374. doi:10.1016/S0959-4752(97)00026-1

Hattikudur, S. D., Sidney, P. G., & Alibali, M. W. (2016). Does comparing informal and formal procedures promote mathematics learning? The benefits of bridging depend on attitudes towards math. *Journal of Problem Solving*, 9(1), 13–27. doi:10.7771/1932-6246.1180

Hyde, J. S., Fennema, E., & Lamon, S. (1990). Gender differences in math performance: A meta-analysis. *Psychological Bulletin*, 107(2), 139–155. doi:10.1037//0033-2909.107.2.139

Judd, C. M., McClelland, G. H., & Ryan, C. S. (2009). *Data analysis: A model comparison approach* (2nd ed.). New York, NY: Routledge.

Landy, D., Charlesworth, A., & Ottmar, E. (2017). Categories of large numbers in line estimation. *Cognitive Science*, 41(2), 326–353. doi:10.1111/cogs.12342

Lauermann, F., Tsai, Y. M., & Eccles, J. S. (2017). Math-related career aspirations and choices within Eccles et al.'s expectancy–value theory of achievement-related behaviors. *Developmental Psychology*, 53(8), 1540–1559. doi:10.1037/dev0000367

Lee, I. A., & Preacher, K. J. (2013). *Calculation for the test of the difference between two dependent correlations with one variable in common [Computer software]*. Retrived from http://quantpsy.org

Lenhard, W., & Lenhard, A. (2016). *Calculation of effect sizes*. Bibergau: Psychometrica. Retrieved from https://www.psychometrica.de/effect_size.html

Lipkus, I. M. (2007). Numeric, verbal, and visual formats of conveying health risks: Suggested best practices and future recommendations. *Medical Decision Making*, 27(5), 696–713. doi:10.1177/0272989X07307271

Lortie-Forgues, H., Tian, J., & Siegler, R. S. (2015). Why is learning fraction and decimal arithmetic so difficult? *Developmental Review*, 38, 201–221. doi:10.1016/j.dr.2015.07.008

Ma, X., & Kishor, N. (1997). Assessing the relationship between attitude towards mathematics and achievement in mathematics: A meta-analysis. *Journal for Research in Mathematics Education*, 28(1), 26–47. doi:10.2307/749662

Moss, J., & Case, R. (1999). Developing children's understanding of the rational numbers: A new model and an experimental curriculum. *Journal for Research in Mathematics Education*, 30(2), 122–147. doi:10.2307/749607

National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). *Common core state standards for mathematics*. Retrieved from http://www.corestandards.org/Math/

Neale, D. C. (1969). The role of attitudes in learning mathematics. *The Arithmetic Teacher*, 16(8), 631–640.

Ni, Y., & Zhou, Y. (2005). Teaching and learning fraction and rational numbers: The origins and implications of whole number bias. *Educational Psychologist*, 40(1), 27–52. doi:10.1207/s15326985ep4001_3

Opfer, J. E., & DeVries, J. M. (2008). Representational change and magnitude estimation: Why young children can make more accurate salary comparisons than adults. *Cognition*, 108(3), 843–849. doi:10.1016/j.cognition.2008.05.003

Opfer, J. E., & Siegler, R. S. (2007). Representational change and children's numerical estimation. *Cognitive Psychology*, 55(3), 169–195. doi:10.1016/j.cogpsych.2006.09.002

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, 66(4), 543–578. doi:10.3102/00346543066004543

Pajares, F., & Graham, L. (1999). Self-efficacy, motivation constructs, and mathematics performance of entering middle school students. *Contemporary Educational Psychology*, 24(2), 124–139. doi:10.1006/ceps.1998.0991

Parker, M., & Leinhardt, G. (1995). Percent: A privileged proportion. *Review of Educational Research*, 65(4), 421–481. doi:10.3102/00346543065004421

Petty, R. E., & Briñol, P. (2014). The elaboration likelihood and meta-cognitive models of attitudes: Implications for prejudice, the self, and beyond. In J. Sherman, B. Gawronski, & Y. Trope (Eds.), *Dual-process theories of the social mind* (pp. 172–187). New York, NY: Guildford Press.

Sidney, P. G., & Alibali, M. W. (2015, October). *Conceptual change in children's number categories: The integration of fraction and whole number knowledge*. Poster presented at the biennial meeting of the Cognitive Development Society in Columbus, OH.

Sidney, P. G., & Alibali, M. W. (2017). Creating a context for learning: Activating children's whole number knowledge prepares them to understand fraction division. *Journal of Numerical Cognition*, *3*(1), 31–57. doi:10.5964/jnc.v3i1.71

Sidney, P. G., Thalluri, R., Buerke, M., & Thompson, C. A. (2018). Who uses more strategies? Linking mathematics anxiety to adults' strategy variability and performance on fraction magnitude tasks. *Thinking & Reasoning*, *25*, 94–131. doi:10.1080/13546783.2018.1475303

Siegler, R. S. (2016). Magnitude knowledge: The common core of numerical development. *Developmental Science*, *19*(3), 341–361. doi:10.1111/desc.12395

Siegler, R. S., Duncan, G. J., Davis-Kean, P. E., Duckworth, K., Claessens, A., Engel, M., … Chen, M. (2012). Early predictors of high school mathematics achievement. *Psychological Science*, *23*(7), 691–697. doi:10.1177/0956797612440101

Siegler, R. S., Fazio, L. K., Bailey, D. H., & Zhou, X. (2013). Fractions: The new frontier for theories of numerical development. *Trends in Cognitive Sciences*, *17*(1), 13–19. doi:10.1016/j.tics.2012.11.004

Siegler, R. S., & Opfer, J. E. (2003). The development of numerical estimation: Evidence for multiple representations of numerical quantity. *Psychological Science*, *14*(3), 237–243. doi:10.1111/1467-9280.02438

Siegler, R. S., & Thompson, C. A. (2014). Numerical landmarks are useful-except when they're not. *Journal of Experimental Child Psychology*, *120*, 39–58. doi:10.1016/j.jecp.2013.11.014

Siegler, R. S., Thompson, C. A., & Schneider, M. (2011). An integrated theory of whole number and fractions development. *Cognitive Psychology*, *62*(4), 273–296. doi:10.1016/j.cogpsych.2011.03.001

Sinayev, A., Peters, E., Tusler, M., & Fraenkel, L. (2015). Presenting numeric information with percentages and descriptive risk labels: A randomized trial. *Medical Decision Making*, *35*(8), 937–947. doi:10.1177/0272989X15584922

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. *The Journal of Educational Research*, *95*(6), 323–332. doi:10.1080/00220670209596607

Sowinski, C., Dunbar, K., & LeFevre, J. (2014). *Calculation fluency test* (Unpublished technical report). Ottawa, Canada: Math Lab, Carleton University.

Steiger, J. H. (1980). Tests for comparing elements of a correlation matrix. *Psychological Bulletin*, *87*(2), 245. doi:10.1037/0033-2909.87.2.245

Thompson, C. A., & Opfer, J. E. (2010). How 15 hundred is like 15 cherries: Effect of progressive alignment on representational changes in numerical cognition. *Child Development*, *81*(6), 1768–1786. doi:10.1111/j.1467-8624.2010.01509.x

Tian, J., & Siegler, R. S. (2018). Which type of rational numbers should students learn first? *Educational Psychology Review*, *30*(2), 351–372. doi:10.1007/s10648-017-9417-3

Torbeyns, J., Schneider, M., Xin, Z., & Siegler, R. S. (2015). Bridging the gap: Fraction understanding is central to mathematics achievement in students from three different continents. *Learning and Instruction*, *37*, 5–13. doi:10.1016/j.learninstruc.2014.03.002

Vamvakoussi, X., Christou, K. P., Mertens, L., & Van Dooren, W. (2011). What fills the gap between discrete and dense? Greek and Flemish students' understanding of density. *Learning and Instruction*, *21*(5), 676–685. doi:10.1016/j.learninstruc.2011.03.005

Vamvakoussi, X., & Vosniadou, S. (2010). How many decimals are there between two fractions? Aspects of secondary school students' understanding of rational numbers and their notation. *Cognition and Instruction*, *28*(2), 181–209. doi:10.1080/07370001003676603

Van Hoof, J., Vandewalle, J., Verschaffel, L., & Van Dooren, W. (2015). In search for the natural number bias in secondary school students' interpretation of the effect of arithmetical operations. *Learning and Instruction*, *37*, 30–38. doi:10.1016/j.learninstruc.2014.03.004

Van Hoof, J., Verschaffel, L., & Van Dooren, W. (2015). Inappropriately applying natural number properties in rational number tasks: Characterizing the development of the natural number bias through primary and secondary education. *Educational Studies in Mathematics*, *90*(1), 39–56. doi:10.1007/s10649-015-9613-3

Wang, M. T., Eccles, J. S., & Kenny, S. (2013). Not lack of ability but more choice: Individual and gender differences in choice of careers in science, technology, engineering, and mathematics. *Psychological Science*, *24*(5), 770–775. doi:10.1177/0956797612458937

Waters, E. A., Fagerlin, A., & Zikmund-Fisher, B. J. (2016). Overcoming the many pitfalls of communicating risk. In *Handbook of health decision science* (pp. 265–277). New York, NY: Springer. doi:10.1007/978-1-4939-3486-7_19

Webb, R. M., Lubinski, D., & Benbow, C. P. (2002). Mathematically facile adolescents with math-science aspirations: New perspectives on their educational and vocational development. *Journal of Educational Psychology*, *94*(4), 785–794. doi:10.1037/0022-0663.94.4.785

Weigel, R. H., Vernon, D. T., & Tognacci, L. N. (1974). Specificity of the attitude as a determinant of attitude-behavior congruence. *Journal of Personality and Social Psychology*, *30*(6), 724–728. doi:10.1037/h0037540

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary Educational Psychology*, *25*(1), 68–81. doi:10.1006/ceps.1999.1015

Wigfield, A., Eccles, J., Maclver, D., Reuman, D., & Midgley, C. (1991). Transitions at early adolescence: Changes in children's domain-specific self-perceptions and general self-esteem across the transition to junior high school. *Developmental Psychology*, *27*, 552–565.

Wigfield, A., Eccles J.S., Yoon, K. S., Harold, R. D., Arbreton, A., Freedman-Doan, C., & Blumenfeld, P. C. (1997). Changes in children's competence beliefs and subjective task values across the elementary school years: a three-year study. *Journal of Educational Psychology*, *89*(3), 451–469.

Appendix A: Math attitude questionnaire

Self-Perceived Ability

Item	Number	Prompt			
G1	General	How good are you at math?			
W1	Whole Number	How good are you at thinking about how big whole numbers (numbers like 34 or 57) are?			
F1	Fraction	How good are you at thinking about how big fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) are?			
*P1	Percentage	How good are you at thinking about how big percentages (numbers like 43% and 75%) are?			
W2	Whole Number	How good are you at solving math problems with whole numbers (numbers like 34 and 57) in them?			
F2	Fraction	How good are you at solving math problems with fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) in them?			
*P2	Percentage	How good are you at solving math problems with percentages (numbers like 43% or 75%) in them?			
Studies 1 & 2 Responses	–	Not Good At All	OK	Good	Very Good
Study 3 Responses	Very Bad	Bad	Slightly Bad	Slightly Good	Good	Very Good

Preference

Item	Number	Prompt			
G2	General	How much do you like math?			
W3	Whole Number	How much do you like thinking [learning] about problems with whole numbers (numbers like 34 and 57) in them?			
F3	Fraction	How much do you like thinking [learning] about problems with fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) in them?			
*P3	Percentage	How much do you like thinking about problems with percentages (numbers like 43% and 75%) in them?			
W4	Whole Number	How much do you like solving problems with whole numbers (numbers like 34 and 57) in them?			
F4	Fraction	How much do you like solving problems with fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) in them?			
*P4	Percentage	How much do you like solving problems with percentages (numbers like 43% and 75%) in them?			
Studies 1 & 2 Responses	–	I don't like it.	It's OK.	I like it.	I love it.
Study 3 Responses	I hate it.	I dislike it.	I dislike it a little.	I like it a little.	I like it.	I love it.

Perceived Frequency of Use

Item	Number	Prompt
G3	General	How often do you use or think about numbers each day [outside of school]?
W5	Whole Number	How often do you use or think about whole numbers (numbers like 34 or 57) in your job [outside of school]?
F5	Fraction	How often do you use or think about fractions (numbers like $\frac{3}{4}$ or $\frac{5}{7}$) in your job [outside of school]?
*P5	Percentage	How often do you use or think about percentages (numbers like 43% or 75%) in your job?
W6	Whole Number	How often do you [think you will] use or think about whole numbers (numbers like 34 or 57) in your daily activities, outside of work [as an adult]?
F6	Fraction	How often do you [think you will] use or think about fractions (numbers like $\frac{3}{4}$ or $\frac{5}{7}$) in your daily activities, outside of work [as an adult]?

(continued)

Appendix A. Continued.

Self-Perceived Ability

Item	Number	Prompt
*P6	Percentage	How often do you think you will use or think about percentages (numbers like 43% or 75%) in your daily activities, outside of work?
Studies 1 & 2 Responses	–	Not at all / A little bit / Sometimes / Frequently / A lot
Study 3 Responses	Very infrequently	Infrequently / Somewhat infrequently / Somewhat frequently / Frequently / Very frequently

Perceived Importance

Item	Number	Prompt
G4	General	How important is it to be accurate when doing math in your daily life?
W7	Whole Number	How important is understanding math with whole numbers (numbers like 34 and 57) for being exactly accurate when doing math in your daily life?
F7	Fraction	How important is understanding math with fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) for being exactly accurate when doing math in your daily life?
*P7	Percentage	How important is understanding math with percentages (numbers like 43% and 75%) for being exactly accurate when doing math in your daily life?
W8	Whole Number	How important is understanding math with whole numbers (numbers like 34 and 57) for estimating when doing math in your daily life?
F8	Fraction	How important is understanding math with fractions (numbers like $\frac{3}{4}$ and $\frac{5}{7}$) for estimating when doing math in your daily life?
*P8	Percentage	How important is understanding math with percentages (numbers like 43% and 75%) for estimating when doing math in your daily life?
Study 2 Responses	–	Not at all important / A little bit important / Fairly important / Very important
Study 3 Responses	Very unimportant	Unimportant / Somewhat unimportant / Somewhat important / Important / Very important

Note. This table includes all the items given to adults. Bracketed text shows the phrases used in the child versions of the survey. Percentage items marked with an asterisk were presented only in Study 3. Studies 1 and 2 used the four-choice response options, and Study 3 used the six-choice response options.

Appendix B: Regression analysis results

Table B1. Study 1 relationships with general attitudes regression analysis results.

Predictor	b	SE	t value	df	p value	ΔR^2
Whole-Number Attitudes	0.45	0.09	5.15	116	<.01	12%
Fraction Attitudes	0.39	0.07	5.54	116	<.01	14%

Table B2. Study 1 individual differences regression analysis results.

Predictor	b	SE	t value	df	p value	ΔR^2
Model 1: Difference Scores						
Math Achievement	−0.05	0.06	−0.78	104	.44	1%
Gender	0.03	0.12	0.28	104	.78	0%
Grade	0.35	0.12	2.83	104	.006	7%
Model 2: Fraction Attitudes						
Math Achievement	0.25	0.06	4.05	104	<.001	13%
Gender	0.02	0.12	0.20	104	.84	0%
Grade	−0.13	0.12	−1.05	104	.30	1%
Model 3: Whole-Number Attitudes						
Math Achievement	0.20	0.05	4.08	104	<.001	14%
Gender	0.06	0.10	0.60	104	.55	0%
Grade	0.22	0.10	2.22	104	.03	4%

Table B3. Study 2 relationships with general attitudes regression analysis results.

Predictor	b	SE	t value	df	p value	ΔR^2
Whole-Number Attitudes	0.63	0.04	16.68	368	<.001	17%
Fraction Attitudes	0.29	0.03	8.29	368	<.001	4%

Note. Unstandardized regression coefficients are reported.

Table B4. Study 2 individual differences regression analysis results.

Predictor	b	SE	t value*	N df	D df	p value	ΔR^2
Model 1: Difference Scores							
Order Condition	0.04	0.05	0.88	1	350	.38	0%
Whole-Number Performance*	–	–	F = 2.25	2	350	.11	1%
Fraction Performance*	–	–	F = 1.25	4	350	.29	1%
Math Anxiety	0.01	0.01	1.13	1	350	.26	0%
Education	−0.05	0.02	−2.15	1	350	.03	1%
Gender	−0.18	0.05	−3.45	1	350	<.001	3%
Model 2: Fraction Attitudes							
Order Condition	0.20	0.06	3.27	1	350	.001	2%
Whole-Number Performance*	–	–	F = 3.77	2	350	.02	1%
Fraction Performance*	–	–	F = 3.78	4	350	.005	3%
Math Anxiety	−0.10	0.01	−8.15	1	350	<.001	11%
Education	0.11	0.03	4.13	1	350	<.001	3%
Gender	0.17	0.06	1.87	1	350	.06	1%
Model 3: Whole-Number Attitudes							
Order Condition	0.24	0.06	4.30	1	350	<.001	3%
Whole-Number Performance*	–	–	F = 5.97	2	350	.003	2%
Fraction Performance*	–	–	F = 3.41	4	350	.009	2%
Math Anxiety	−0.09	0.01	−7.78	1	350	<.001	10%
Education	0.06	0.02	2.53	1	350	.01	1%
Gender	−0.06	0.06	−1.05	1	350	.29	0%

Note. Relationships with whole-number and fraction performance (*) were tested by comparing nested models with and without the associated predictors: whole-number-magnitude estimation and whole-number fluency for whole-number performance and fraction-magnitude estimation (0 to 1, 0 to 5), fraction-magnitude comparison, and fraction arithmetic for fraction performance. Thus, F values associated with each model comparison test, rather than t values associated with individual predictors, are reported here and in the text. Unstandardized regression coefficients are reported.

Table B5. Study 3 relationships with general attitudes regression analysis results.

Predictor	b	SE	t value	df	p value	ΔR^2
Model 1						
Whole-Number Attitudes	0.69	0.05	12.66	73	<.01	32%
Fraction Attitudes	0.36	0.05	7.13	73	<.01	10%
Model 2						
Whole-Number Attitudes	0.62	0.08	8.09	72	<.01	13%
Fraction Attitudes	0.31	0.07	4.99	72	<.01	5%
Percentage Attitudes	0.10	0.09	1.19	72	.24	0%

Note. Unstandardized regression coefficients are reported.