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Perceptions of ease and difficulty, but not growth mindset, relate to specific math attitudes

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Background. People report negative attitudes towards fractions and percentages relative to whole numbers (WNs, Sidney, Thompson, Fitzsimmons, & Taber, 2021), and these attitudes may relate to an individual's interpretation of what experiences with these number types signify. Because fractions are challenging, individual differences related to beliefs about challenge, such as endorsement of a growth versus fixed mindset (Dweck, 2006) and interpretations of easy or difficult experiences (Fisher & Oyserman, 2017), could relate to attitudes towards fractions relative to other number types.

Aims. Two studies tested whether gender, math skills, mindset beliefs, and perceptions of difficulty relate to negative math attitudes towards specific number types.

Samples. Two samples of college students (Study 1: N = 491; Study 2: N = 415), approximately 19 years of age (17% male, 51% first year students) participated.

Methods. Participants rated attitudes pertaining to WNs, fractions, and percentages, endorsement of a growth mindset, and perceptions of ease and difficulty.

Results. Replicating prior work (Sidney, Thompson, Fitzsimmons, & Taber, 2021), college students endorsed more negative attitudes about fractions than WNs and percentages. Self-reported ACT scores related to all number-type attitudes, endorsement of the belief that 'difficult tasks/goals are important' related to fraction attitudes, and endorsement of the belief that 'easy tasks/goals are possible' related to whole number attitudes. Endorsement of a growth mindset did not relate to specific math attitudes.

Conclusions. People struggle to integrate their whole number and rational number representations, and one reason people hold negative attitudes about fractions may be that they view them as difficult and even impossible.

People of various ages dislike fractions relative to whole numbers (WNs; Sidney, Thompson, Fitzsimmons, & Taber, 2021). Are there particular individual differences – such as a person's gender, overall math skills, beliefs that intelligence can or cannot change with effort, or appraisals of difficult tasks as important challenges or not – that relate to negative math attitudes? A better understanding of the correlates of negative attitudes about fractions relative to WNs and percentages may illuminate *why* students in the United States continue to struggle to understand fractions despite years of targeted

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interventions to help them improve their rational number understanding (Lortie-Forgues, Tian, & Siegler, 2015; Siegler, Thompson, & Schneider, 2011).

Negative attitudes towards different number types

Learning mathematics poses unique challenges relative to other subjects, in part because of affective and motivational factors such as math anxiety (Ashcraft, 2002; Dowker, Sarkar, & Looi, 2016), stereotype threat (Spencer, Steele, & Quinn, 1999), and negative attitudes towards math (Eccles & Wigfield, 1995; Eccles, Wigfield, Harold, & Blumenfeld, 1993; Sidney et al., 2021). These factors not only impact math performance (Beilock, Rydell, & McConnell, 2007; Ma & Kishor, 1997; Sidney, Thalluri, Buerke, & Thompson, 2018; Singh, Granville, & Dika, 2002; Sorvo et al., 2017), but also can discourage people from pursuing math courses and STEM careers (Halpern et al., 2007; Hembree, 1990). Negative affective experiences vary based on the specific mathematical content being learned (Baloglu, 2004; Sidney et al., 2021), and are pronounced for difficult topics, such as fractions (Sidney et al., 2021).

Both children and adults struggle with difficult fraction content (Alibali & Sidney, 2015; Siegler et al., 2011; Stafylidou & Vosniadou, 2004). This struggle may contribute to negative affective experiences, as evidenced by lower precision on fraction number line estimation and magnitude comparison tasks being correlated with higher math anxiety (Sidney et al., 2018). Children perform worse on rational number tasks than analogous WN tasks (Fazio, Bailey, Thompson, & Siegler, 2014). For example, Braithwaite, Tian, and Siegler (2018) compared children's performance estimating individual WN and fraction magnitudes with their performance estimating WN and fraction sums. In both cases, estimation of sums was worse than estimation of individual magnitudes, but estimating fraction sums was so poor that children would have been more accurate had they simply placed all estimates in the middle of the number line.

Other forms of rational numbers, such as decimals and percentages, are not immune to demonstrations of poor understanding (e.g., Rittle-Johnson, Siegler, & Alibali, 2001). For example, more than half of middle school students were unsuccessful at indicating that 87% of 10 is less than 10 (Gay & Aichele, 1997). This lack of understanding percentages is somewhat surprising, given their connection to WNs (Moss & Case, 1999), and because percentages are quite ubiquitous in daily life (e.g., denoting battery charge on all devices, coupon discounts, and interest rates.). Moreover, colloquially percentages are often referred to in terms of WNs (e.g., 'I got a 100 on my test', rather than 'I got 100% of the problems correct on my test'.). Thus, individuals should be able to bootstrap WN knowledge to percentages easier than fractions (although, see Sidney et al., 2021 and Yu et al., 2020). Indeed, Siegler et al. (2011) noted that a common strategy for estimating fractions on number lines is by applying percentage knowledge (e.g., $^4/_5$ is 80% of the way across a number line from left-to-right).

Children's and adults' sensitivity to the difficulty of rational numbers (fractions and percentages) is reflected in negative attitudes towards fractions and percentages relative to WNs (Sidney et al., 2021). Additionally, adults', but not children's, attitudes towards fractions related more strongly to general math attitudes than WN attitudes. This finding suggests adults do not possess an integrated understanding of WNs and fractions. This integrated understanding (Siegler, 2016; Siegler, Fazio, Bailey, & Zhou, 2013; Siegler et al., 2011) is important because people can harness correct WN understanding to accurately solve fraction problems (Sidney & Thompson, 2019; Sidney, Thompson, & Rivera, 2019; Yu et al., 2020).

What factors relate to attitudes towards different number types?

The primary aim of the current studies is to replicate and extend research by Sidney et al. (2021) to better understand factors contributing to negative attitudes towards fractions and preventing an integrated understanding of numbers (Siegler et al., 2011). Ramirez, Shaw, and Maloney (2018) have proposed an interpretation account for how math anxiety, a construct related to math attitudes, develops. The interpretation account is rooted in the literature on appraisal (see Moors, Ellsworth, Scherer, & Frijda, 2013 for a review), and attributes the development of math anxiety not to the mere presence of challenging experiences or failures related to mathematics, but rather to an individual's interpretation of what those experiences of difficulty and failure signify. Thus, one of the main goals of this study was to test the relation between attitudes towards different number types and a measure of people's interpretations of experienced ease and difficulty developed by Fisher and Oyserman (2017). Because fractions are challenging, we anticipated that interpretations of difficulty, as either indicating impossibility or importance, could relate to learners' attitudes towards fractions, relative to other number types. One novel contribution of the current studies is testing relations among attitudes towards different number types as well as two measures of individual differences related to beliefs about challenge: (1) endorsement of a growth versus fixed mindset and (2) interpretations of easy or difficult experiences.

Individuals' attitudes towards challenging tasks may reflect their interpretation of difficulty. For example, people can interpret difficulty as signalling importance or impossibility (Fisher & Oyserman, 2017). Those who associate difficulty with impossibility perceive challenging tasks as insurmountable (hereafter, referred to as 'difficulty-as-impossibility' belief). Other individuals tend to associate difficulty with importance (i.e., 'difficulty-as-importance' belief) such that harder tasks are perceived as critical (e.g., 'no pain no gain'). Conversely, individuals' attitudes towards simple tasks may reflect their interpretation of ease. The experience of ease can be interpreted as connoting possibility (e.g., 'I can be good at this') or triviality (e.g., 'This is not worthwhile'.).

Priming the difficulty-as-importance rather than difficulty-as-impossibility belief has benefits. For example, priming the difficulty-as-importance belief can increase the extent to which students report academics as central to their identity (Smith & Oyserman, 2015). However, no research has tested the relation between individual differences in interpretations of ease and difficulty and attitudes about difficult math content. Depending on how learners interpret the experience of learning fraction content, they may be more or less likely to report negative fraction attitudes.

Attitudes about difficult topics, like rational numbers, may also be related to mindset (Dweck, 2006; Dweck & Yeager, 2019): the belief that ability is either a stable trait (fixed mindset), or that it can be developed through effort (growth mindset). Prior work has shown that students with a growth mindset (1) have more positive beliefs about effort (i.e., effort leads to favourable outcomes), (2) report being more likely to respond to academic failure with increased effort, and (3) attain higher math achievement (Blackwell, Trzesniewski, & Dweck, 2007). If believing that ability can be developed through effort makes the challenge of learning fraction content a more positive experience, then endorsing a growth mindset might relate to less negative fraction attitudes.

Other individual differences – such as math achievement, educational attainment, and gender – may leave people vulnerable to adverse effects of negative math attitudes. Children who had higher standardized math test scores endorsed more positive WN and fraction attitudes (Sidney et al., 2021). Adults' higher performance on fraction and WN tasks and higher educational attainment were each related to more positive fraction and

WN attitudes. In the current studies, Math ACT was used as a measure of math achievement, and we tested whether these scores were associated with more positive attitudes towards different number types across two college samples with more homogeneous educational attainment than adults in Sidney et al. (2021).

A final factor that relates to attitudes about math is gender. The evidence for gender differences in math performance and achievement is mixed, with some work showing differences in math and related spatial abilities (Geary, Scofield, Hoard, & Nugent, 2021; Hutchinson, Lyons, & Ansari, 2019; Rivers, Fitzsimmons, Fisk, Dunlosky, & Thompson, 2021; Thompson & Opfer, 2008) and other work failing to show such differences (Lindberg, Hyde, Petersen, & Linn, 2010; Stoet & Geary, 2018) or showing gender-related achievement gaps under certain conditions (Halpern et al., 2007; Reardon, Fahle, Kalogrides, Podolsky, & Zárate, 2019). However, regardless of actual levels of math achievement, women continue to be under-represented in STEM careers (Lauermann, Tsai, & Eccles, 2017). Further, girls and women may be more vulnerable to negative affective experiences in math learning than boys and men (Ramirez, Gunderson, Levin, & Beilock, 2013). For instance, the relation between math anxiety and math performance may be stronger for females than males (Devine, Fawcett, Szűcs, & Dowker, 2012). Females report more negative attitudes (Else-Quest, Hyde, & Linn, 2010; Sidney et al., 2021) and have less confidence in their math performance than males, even when accounting for actual performance (Rivers et al., 2021). Given the possibility that lower confidence and more negative attitudes towards math may contribute to gender differences in pursuing STEM careers, it is important to understand gender differences in affective and motivational factors related to math. Therefore, we included gender in our analyses, allowing for the possibility that males would report more positive attitudes towards various number types relative to non-males.

Current studies

In a set of two studies, we replicate and extend Sidney et al. (2021) with two samples of college students. Sidney et al. (2021, Study 4) used a between-subjects design wherein college students reported attitudes for one number type and found that students reported more negative attitudes towards fractions and percentages than WNs. Also, Sidney and colleagues found that adult MTurk workers' general math attitudes were less strongly related to attitudes towards fractions than towards WNs. Our first goal was to test whether these patterns would replicate in a within-subjects design in a sample of college students. Given that affective and motivational factors relating to mathematics change with age (Chouinard & Roy, 2008; Ma & Kishor, 1997; Mata, Monterio, & Peixoto, 2012; Sidney et al., 2021), our study illuminated how college students' specific math attitudes compared with those of children and older adults. College students' specific math attitudes could be unique given that they may still be immersed in formal fraction instruction as compared with older adults tested by Sidney et al. (2021). Fractions are foundational for college students' success in higher-level mathematics courses but are less prevalent for older adults who are many years removed from formal fraction instruction.

Our second goal was to assess which individual differences were related to attitudes towards specific number types. We investigated several novel hypotheses related to this goal:

1. If endorsing a growth mindset is associated with more positive beliefs about effort in academic contexts (e.g., Blackwell et al., 2007), then mindset should positively relate to specific math attitudes. Because fractions are more difficult than WNs, the relation between mindset and attitudes might be stronger for fractions than WNs. We also tested whether math achievement, operationalized as standardized test performance, would relate positively to attitudes towards different number types, and whether males would report more positive attitudes than non-males.
2. Fraction attitudes should relate to interpretations of difficulty. Fraction attitudes should be positively related to the difficulty-as-importance belief – higher endorsement of the difficulty-as-importance belief, the more positive attitudes towards fractions. Fraction attitudes should also be negatively related to the difficulty-as-impossibility belief – higher endorsement of the difficulty-as-impossibility belief should be related to lower fraction attitudes.
3. Finally, although fractions are generally regarded as difficult, it is unclear whether WNs are considered easy, especially since people commonly say they are not a 'math person' (Miller-Cotto & Lewis, 2020). Therefore, we explored whether interpretations of easy experiences related to WN attitudes. Moreover, we hypothesized that percentages would be perceived as more difficult than WNs but easier than fractions, despite percentages being mathematically equivalent to fractions (e.g., $\frac{4}{5}$ = 80%). Moss and Case's (1999) experimental curriculum used percentages as an intermediary between WN and fraction concepts because WNs build on students' mental number line representations between 0 and 100. However, the assertion that percentages are perceived as easier than fractions remains untested. There might be a negative relation between the ease-as-triviality belief and WN attitudes, and a positive relation between the ease-as-possibility belief and WN attitudes. Interestingly, when children compare two rational number magnitudes with differing notations (i.e., fractions, decimals, percentages), they are more accurate when the percentage is larger than the other notation (Schiller, 2020). This *Percentages-are-larger bias* suggests that individuals might perceive percentages as more similar to WNs, which may influence adults to rate percentages more positively than fractions and as relatively easy.

Method

Participants

Undergraduates in a Psychology Department subject pool at a Midwestern university participated in both Study 1 (N = 491) and Study 2 (N = 433, n = 18 excluded for having participated in Study 1) as part of mass testing during two semesters. The mass testing session occurs at the beginning of each semester and is the first opportunity for students to earn research credits during the semester. As many participants as were in the subject pool could volunteer to complete the studies, and our goal was to recruit as many students as possible. Only participants with complete data[1] for a given measure were included in reliability calculations of that measure. Demographic information is reported in Table 1.

[1] *In an effort to retain as many participants as possible for each analysis, we opted to use different subsamples depending on missing data. As shown in Table 1, the demographics were similar across the subsamples used for the analyses reported below.*

Table 1. Demographic information for Study 1 and Study 2

	Study 1				Study 2			
Sample	*N*	Male (%)	First year students (%)	Age *M* (*SD*)	*N*	Male (%)	First year students (%)	Age *M* (*SD*)
Full	491	18.53	56.42	19.08 (1.85)	415	15.12	46.34	19.74 (2.99)
Complete MAQ	466	18.45	56.65	19.10 (1.88)	410	15.12	46.34	19.74 (2.99)
Complete Lay Theories	436	19.95	56.65	19.10 (1.90)	386	15.54	47.15	19.75 (3.06)
Complete Mindset	481	18.09	56.55	19.09 (1.86)	403	15.14	45.91	19.74 (3.00)
Complete MAQ, Lay Theories, and Mindset	418	19.38	56.70	19.10 (1.92)	383	15.67	47.00	19.75 (3.06)
Complete MAQ, Lay Theories, Mindset, and Math ACT	361	18.83	58.17	18.87 (1.19)	322	15.53	48.76	19.54 (2.80)

Materials

Math Attitudes Questionnaire

The Math Attitudes Questionnaire (MAQ; see Sidney et al., 2021 for item wording) measures general math attitudes and specific attitudes about WNs, fractions, and percentages. The MAQ includes four scales: (1) ability (e.g., 'How good are you…'), (2) preference (e.g., 'How much do you like learning about…'), (3) use (e.g., 'How often do you use…in your daily activities, outside of work?'), and (4) perceived importance (e.g., 'How important…when doing math in your daily life?'). Participants responded to each item using a 6-point scale (Study 1) or 4-point scale (Study 2) with higher mean scores indicating higher perceived ability, preference, use, and importance. Participants rated their general attitudes, then attitudes about WNs, fractions, and then percentages as in Sidney et al. (2021).

In Study 1, participants rated only their attitudes on the ability and preference scales.[2] In Study 2, participants completed all four MAQ scales.[3] Reliability for each number type across both studies ($N = 466$ for Study 1, $N = 410$ for Study 2) was acceptable and similar to that reported by Sidney et al. (2021; Study 1: general $\alpha = .88$, WN $\alpha = .88$, fractions $\alpha = .90$, percentages $\alpha = .91$; Study 2: general $\alpha = .73$, WN $\alpha = .85$, fractions $\alpha = .87$).

Intelligence Mindset Questionnaire

Participants completed an intelligence mindset questionnaire (Dweck, 2000), which assessed beliefs about whether intelligence is fixed (i.e., fixed mindset) or malleable (i.e., growth mindset). All participants completed the same seven items (e.g., 'You have a certain amount of intelligence, and you can't really do much to change it'.) in the same order. Items were scored on a 6-point scale (1 = 'strongly disagree' to 6 = 'strongly agree'). Four items were recoded such that an overall mean score closer to 6 indicated

[2] *This design choice decreased the time needed to complete our survey given that it was part of a larger mass testing survey.*
[3] *This design choice was made because we validated the full MAQ scale.*

stronger endorsement of a growth mindset. Cronbach's alpha (Study 1: $N = 481$, Study 2: $N = 403$), a measure of reliability, was high for both studies ($\alpha = .91$).

Lay theories of ease and difficulty

This four-scale measure, with six items per scale, assessed participants' beliefs about what the experience of ease and difficulty signify (Fisher & Oyserman, 2017): (1) ease-as-triviality (e.g., 'When a goal feels easy to attain, then it is probably not worth my effort'.), (2) difficulty-as-importance (e.g., 'If a task feels difficult, my gut says that it really matters for me'.), (3) ease-as-possibility (e.g., 'When a goal feels easy to attain, then it is probably within my reach'.), and (4) difficulty-as-impossibility (e.g., 'I know a goal is impossible for me when it feels difficult to work on'.). Each participant completed the 24 items in random order. All items were scored on a 6-point scale (1 = 'strongly disagree' to 6 = 'strongly agree'), and mean scores closer to 6 on any scale indicated higher endorsement of that belief. Cronbach's alpha (Study 1: $N = 436$, Study 2: $N = 386$) was comparable to Fisher and Oyserman (2017; Study 1: ease-as-triviality $\alpha = .83$, ease-as-possibility $\alpha = .86$, difficulty-as-importance $\alpha = .84$, difficulty-as-impossibility $\alpha = .86$; Study 2: ease-as-triviality $\alpha = .84$, ease-as-possibility $\alpha = .87$, difficulty-as-importance $\alpha = .81$, difficulty-as-impossibility $\alpha = .89$).

Procedure

The procedures were the same for both studies. At the start of the mass testing session, students provided demographic information (i.e., age, gender, year in school). The lay theories of ease and difficulty, mindset, and MAQ were completed together, in that order, in one block. Finally, students self-reported their SAT or ACT scores, proxies for general math ability. SAT scores were converted into ACT scores (see ACT/SAT Concordance Tables, ACT, 2018).

Results

Analytic plan

In order to replicate Sidney et al. (2021), we first analysed participants' performance on the MAQ using paired-samples *t*-tests to assess whether college students, similar to children and older MTurk workers, held more negative attitudes towards fractions than WNs or percentages. Then, we regressed attitudes towards specific numbers on general math attitudes to test how attitudes towards each number type related to general math attitudes (see Supplemental Materials).

To test which individual differences related to attitudes about different number types, we regressed ease and difficulty ratings, mindset, and ACT scores on fraction and whole number attitudes. We ran separate models regressing attitudes towards WNs, fractions, and percentages (Study 1 only) on gender, Math ACT scores, four subscales of the lay theories of ease and difficulty, and mindset (see Supplemental Materials). However, since the MAQ scales that were administered did vary across studies, each MAQ scale was modelled separately to assess whether particular MAQ scales were driving the relations between the individual difference measures and attitudes towards different number types. This approach allowed for comparison of the MAQ scales, perceived ability and preference, which were administered across both studies. Gender was coded with non-males (females and two participants who identified as nonbinary) as the reference group. Math ACT score was standardized ($M = 0, SD = 1$). The multicollinearity of variables was acceptable for all models (all VIF values < 2) for both studies.

Replicating more negative attitudes towards rational numbers than WNs

Descriptive statistics and correlations for all measures can be found in Table 2 (Study 1) and Table 3 (Study 2). Mean values for overall MAQ attitudes for each number type and each scale for participants with complete MAQ data (Study 1: $N = 466$, Study 2: $N = 410$) are reported in Table 4 (MAQ descriptives by gender and year in school can be found in the Supplemental Materials). Replicating Sidney et al. (2021), college students in both studies reported more negative attitudes towards fractions compared with WNs (see Table 5). These patterns held across the perceived ability, preference, use, and importance scales.

Also consistent with Sidney et al. (2021, Study 3), Study 1 participants reported more negative attitudes towards percentages than WNs, $t(465) = 18.85$, $p < .001$, $d = 0.63$, and more negative attitudes towards fractions than percentages, $t(465) = 10.58$, $p < .001$, $d = 0.35$. This pattern held across both ability and preference scales with participants reporting lower ability with percentages relative to WNs, $t(465) = 15.01$, $p < .001$, $d = 0.58$, lower preference for percentages than for WNs, $t(465) = 17.34$, $p < .001$, $d = 0.58$, lower ability with fractions compared with percentages, $t(465) = 11.33$, $p < .001$, $d = 0.37$, and less preference for working with fractions than percentages, $t(465) = 7.82$, $p < .001$, $d = 0.28$. In summary, fractions were viewed more negatively than WNs and even percentages, another type of rational number.

Table 2. Descriptive statistics and correlations for measures for study 1

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. MAQ General	3.66	1.43									
2. MAQ Whole Numbers	4.57	1.03	.70**								
3. MAQ Fractions	3.37	1.19	.71**	.63**							
4. MAQ Percentages	3.78	1.21	.73**	.71**	.74**						
5. Math ACT	22.51	5.02	.58**	.39**	.47**	.54**					
6. Difficulty as impossibility	2.66	0.92	−.18**	−.12*	−.20**	−.21**	−.11*				
7. Difficulty as importance	4.21	0.81	.07	.13*	.14**	.13**	−.10	−.40**			
8. Ease as possibility	4.87	0.77	.04	.17**	.03	.12*	.10	−.20**	.35**		
9. Ease as triviality	2.54	0.79	.03	−.04	.07	.00	.02	.03	−.14**	−.06	
10. Growth mindset	4.63	0.90	.03	.08	.08	.03	−.10	−.26**	.19**	.08	−.07

Note. All MAQ items were on a 1–6 scale, with higher values indicating more positive attitudes. Ease/Difficulty and Mindset scale responses were on a 1–6 scale with higher values indicating greater endorsement. ACT math is scored out of 36 possible points.
* indicates $p < .05$; ** indicates $p < .01$.

Table 3. Descriptive statistics and correlations for measures for Study 2

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. MAQ General	2.78	0.64								
2. MAQ Whole Numbers	2.87	0.58	.81**							
3. MAQ Fractions	2.13	0.62	.71**	.71**						
4 Math ACT	23.15	4.69	.47**	.42**	.46**					
5. Difficulty as impossibility	2.54	0.94	−.24**	−.25**	−.19**	−.04				
6. Difficulty as importance	4.23	0.76	.25**	.29**	.22**	.04	−.34**			
7. Ease as possibility	4.87	0.73	.18**	.28**	.14**	.11	−.18**	.31**		
8. Ease as triviality	2.51	0.75	−.03	−.05	.05	.00	.44**	−.02	−.32**	
9. Growth mindset	4.67	0.89	.14**	.16**	.03	.03	−.39**	.22**	.29**	−.39**

Note. All MAQ items were on a 1–4 scale with higher values indicating more positive attitudes. Ease/Difficulty and Mindset scale responses were on a 1–6 scale with higher values indicating greater endorsement. ACT math is scored out of 36 possible points.
*indicates $p < .05$; ** indicates $p < .01$.

Table 4. Descriptive statistics for MAQ Data in Study 1 and Study 2 compared to Sidney et al. (2021) Study 3

MAQ measure	General *M* (*SD*)	Whole numbers *M* (*SD*)	Fractions *M* (*SD*)	Percentages *M* (*SD*)
Sidney et al. (2021) Study 3				
Overall attitudes	3.84 (1.07)	4.14 (1.04)	2.86 (1.14)	3.37 (1.14)
Study 1				
Overall attitudes	3.62 (1.44)	4.50 (1.09)	3.34 (1.20)	3.76 (1.23)
Ability		4.89 (1.03)	3.72 (1.29)	4.19 (1.28)
Preference		4.12 (1.39)	2.95 (1.31)	3.32 (1.37)
Study 2				
Overall attitudes	2.76 (0.65)	2.84 (0.59)	2.11 (0.62)	–
Ability		3.14 (0.75)	2.28 (0.86)	–
Preference		2.33 (0.88)	1.63 (0.73)	–
Use		2.80 (0.81)	1.87 (0.80)	–
Perceived importance		3.11 (0.72)	2.66 (0.86)	–

Note. MAQ items in Study 1 were on a 6-point scale, whereas items in Study 2 were on a 4-point scale. In Sidney et al. (2021, Study 3) items were on a 6-point scale.

Relations between attitudes towards different number types and general math

In Sidney et al. (2021, Studies 2 and 3), the relation between fraction attitudes and general math attitudes was not as strong as the relation between general math attitudes and WNs or percentage attitudes. This pattern was replicated in Study 2 when all scales of the MAQ were administered. More details about these analyses can be found in the Supplemental Materials.

Table 5. Difference in attitudes about whole numbers and fractions for Study 1 and Study 2

MAQ measure	*t*-test	Cohen's *d*
Study 1		
Overall attitudes	26.23***	1.01
Perceived ability	23.68***	0.98
Preference	22.05***	0.86
Study 2		
Overall attitudes	32.01***	1.20
Perceived ability	25.41***	1.06
Preference	20.29***	0.85
Frequency of use	26.34***	1.14
Perceived importance	14.46***	0.56

Note. For Study 1 $df = 465$ and for Study 2 $df = 409$.
*** indicates $p < .001$.

Factors relating to attitudes towards specific number types

The analyses collapsing across MAQ scales can be found in the Supplemental Materials. Below, we report analyses by individual MAQ scale (perceived ability and preference in Study 1, perceived ability, preference, use, and perceived importance for Study 2) to facilitate comparison across studies. Predictors for WN attitudes can be found in Table 6, predictors for fractions can be found in Table 7, and predictors for percentages (Study 1 only) can be found in Table 8.

Do gender, mindset, or math achievement relate to attitudes towards different number types?

The effect of gender was only found in the perceived ability and frequency of use scales for fractions in Study 2, with males reporting higher perceived ability and higher frequency of use relative to non-males. Mindset was not significantly related to any individual scale for any number type. Math ACT was significantly related to all individual MAQ scales for all number types in each study, explaining between 4% and 17% of the variance in each model.

Do interpretations of difficulty relate to attitudes towards fractions?

Endorsement of difficulty-as-importance related to higher perceived ability and greater preference for fractions across both studies (explaining 1–4% of variance), whereas endorsement of difficulty-as-impossibility was associated with lower preference for fractions in both studies (explaining 1% of variance). None of the difficulty scales were significantly related to frequency of use or perceived importance of fractions in Study 2.

Do interpretations of ease relate to attitudes towards WNs or percentages?

Only ease-as-possibility was consistently related to WN attitudes – higher endorsement of the ease-as-possibility belief related to higher ratings of perceived ability across both studies (explaining 3–4% of variance) and higher perceived importance in Study 2 (explaining 3% of variance).

Table 6. Regression results for MAQ Whole Number Scale Predictors in Study 1 and 2

	Study 1						Study 2					
	b	β	SE	t	p	ΔR^2	b	β	SE	t	p	ΔR^2
Perceived ability												
Gender	0.10	0.04	0.12	0.82	.41	0%	0.10	0.05	0.10	0.96	.34	0%
Math ACT	**0.31**	**0.33**	**0.05**	**6.55**	**<.001**	**10%**	**0.24**	**0.33**	**0.04**	**6.56**	**<.001**	**10%**
Difficulty as impossibility	−0.01	−0.01	0.06	0.15	.88	0%	−0.12	−0.16	0.05	2.60	<.01	2%
Difficulty as importance	0.07	0.06	0.06	1.04	.30	0%	0.06	0.06	0.06	1.14	.26	0%
Ease as possibility	**0.29**	**0.23**	**0.07**	**4.42**	**<.001**	**4%**	**0.20**	**0.20**	**0.06**	**3.58**	**<.001**	**3%**
Ease as triviality	<−0.01	<−0.01	0.06	0.05	.96	0%	0.01	0.01	0.06	0.11	.92	0%
Mindset	0.10	0.09	0.05	1.83	.07	1%	0.05	0.07	0.05	1.15	.25	0%
Preference												
Gender	−0.02	−0.01	0.18	0.14	.89	0%	−0.12	−0.05	0.12	0.94	.35	0%
Math ACT	**0.50**	**0.37**	**0.07**	**7.00**	**<.001**	**12%**	**0.32**	**0.36**	**0.04**	**7.09**	**<.001**	**13%**
Difficulty as impossibility	0.02	0.01	0.08	0.19	.85	0%	−0.15	−0.16	0.06	2.52	.01	2%
Difficulty as importance	0.15	0.09	0.10	1.54	.13	1%	0.14	0.12	0.07	2.10	.04	1%
Ease as possibility	0.00	< 0.01	0.10	0.02	.99	0%	0.14	0.12	0.07	2.06	.04	1%
Ease as triviality	−0.12	−0.07	0.09	1.36	.17	0%	0.03	0.03	0.08	0.44	.66	0%
Mindset	0.02	0.01	0.08	0.24	.82	0%	−0.06	−0.06	0.06	1.03	.31	0%
Frequency of use												
Gender	–		–	–	–	–	0.00	<0.01	0.12	0.03	.98	0%
Math ACT	–		–	–	–	–	**0.20**	**0.24**	**0.04**	**4.41**	**<.001**	**6%**
Difficulty as impossibility	–		–	–	–	–	−0.06	−0.07	0.04	0.97	.33	0%
Difficulty as importance	–		–	–	–	–	0.13	0.12	0.07	1.91	.06	1%
Ease as possibility	–		–	–	–	–	0.07	0.06	0.07	1.04	.30	0%
Ease as triviality	–		–	–	–	–	0.06	0.05	0.08	0.78	.44	0%
Mindset	–		–	–	–	–	0.01	0.01	0.06	0.18	.86	0%

Continued

Table 6. (*Continued*)

	Study 1						Study 2					
	b	β	*SE*	*t*	*p*	ΔR^2	*b*	β	*SE*	*t*	*p*	ΔR^2
Perceived importance												
Gender	–		–	–	–	–	−0.02	−0.01	0.10	0.20	.84	0%
Math ACT	–		–	–	–	–	**0.14**	**0.21**	**0.04**	**3.81**	**<.001**	**4%**
Difficulty as impossibility	–		–	–	–	–	−0.07	−0.09	0.05	1.36	.17	0%
Difficulty as importance	–		–	–	–	–	0.05	0.05	0.06	0.83	.41	0%
Ease as possibility	–		–	–	–	–	**0.20**	**0.21**	**0.06**	**3.41**	**<.001**	**3%**
Ease as triviality	–		–	–	–	–	0.10	0.10	0.07	1.52	.13	0%
Mindset	–		–	–	–	–	0.02	0.03	0.05	0.45	.65	0%

Note. Unstandardized coefficients are reported. For Study 1 *df* = 351 and for Study 2 *df* = 314.
Predictors that emerged as significant in both Study 1 and Study 2 are bolded, except for Frequency of Use and Perceived Importance scales, which were only administered in Study 2.

Table 7. Regression results for MAQ Fraction Scale Predictors in Study 1 and 2

	Study 1						Study 2					
	b	β	SE	t	p	ΔR^2	b	β	SE	t	p	ΔR^2
Perceived ability												
Gender	0.09	0.03	0.15	0.56	.57	0%	0.32	0.14	0.11	2.84	<.01	2%
Math ACT	**0.63**	**0.50**	**0.06**	**10.37**	**<.001**	**10%**	**0.36**	**0.42**	**0.04**	**8.84**	**<.001**	**17%**
Difficulty as impossibility	−0.06	−0.04	0.07	0.85	.40	0%	−0.16	−0.17	0.05	2.96	<.01	2%
Difficulty as importance	**0.24**	**0.15**	**0.08**	**2.93**	**<.01**	**4%**	**0.14**	**0.12**	**0.06**	**2.28**	**.02**	**1%**
Ease as possibility	−0.01	−0.01	0.08	0.15	.88	0%	0.13	0.11	0.06	2.08	.04	1%
Ease as triviality	0.13	0.08	0.08	1.71	.09	0%	0.06	0.05	0.07	0.89	.37	0%
Mindset	0.13	0.09	0.07	1.94	.05	1%	0.03	0.03	0.05	0.61	.54	0%
Preference												
Gender	0.10	0.03	0.17	0.61	.54	0%	0.12	0.06	0.11	1.13	.26	0%
Math ACT	**0.51**	**0.39**	**0.07**	**7.64**	**<.001**	**13%**	**0.27**	**0.37**	**0.04**	**7.07**	**<.001**	**13%**
Difficulty as impossibility	**−0.17**	**−0.12**	**0.08**	**2.19**	**<.01**	**1%**	**−0.12**	**−0.15**	**0.05**	**2.40**	**.02**	**1%**
Difficulty as importance	**0.26**	**0.16**	**0.09**	**2.86**	**<.01**	**2%**	**0.14**	**0.13**	**0.06**	**2.33**	**.02**	**1%**
Ease as possibility	−0.15	−0.09	0.09	1.68	.09	0%	0.03	0.03	0.06	0.49	.62	0%
Ease as triviality	0.06	0.03	0.08	0.68	.50	0%	0.04	0.04	0.07	0.66	.51	0%
Mindset	0.06	0.04	0.07	0.89	.38	0%	−0.09	−0.10	0.05	1.77	.08	1%
Frequency of use												
Gender	–		–	–	–	–	**0.28**	**0.13**	**0.12**	**2.34**	**.02**	**1%**
Math ACT	–		–	–	–	–	**0.23**	**0.28**	**0.04**	**5.20**	**<.001**	**7%**
Difficulty as impossibility	–		–	–	–	–	−0.02	−0.02	0.06	0.33	.75	0%
Difficulty as importance	–		–	–	–	–	0.13	0.11	0.07	1.91	.06	1%
Ease as possibility	–		–	–	–	–	−0.01	−0.01	0.07	0.18	.85	0%
Ease as triviality	–		–	–	–	–	0.09	0.08	0.08	1.15	.25	0%
Mindset	–		–	–	–	–	−0.01	−0.01	0.06	0.23	.82	0%

Continued

Table 7. (*Continued*)

	Study 1						Study 2					
	b	*β*	*SE*	*t*	*p*	ΔR^2	*b*	*β*	*SE*	*t*	*p*	ΔR^2
Perceived importance												
Gender	–		–	–	–	–	0.01	< 0.01	0.13	0.05	.96	0%
Math ACT	–		–	–	–	–	**0.19**	**0.23**	**0.05**	**4.18**	**<.001**	**5%**
Difficulty as impossibility	–		–	–	–	–	−0.09	−0.10	0.06	1.49	.14	0%
Difficulty as importance	–		–	–	–	–	0.11	0.09	0.07	1.56	.12	1%
Ease as possibility	–		–	–	–	–	0.12	0.10	0.07	1.63	.10	1%
Ease as triviality	–		–	–	–	–	0.11	0.10	0.08	1.41	.16	1%
Mindset	–		–	–	–	–	−0.03	−0.04	0.06	0.56	.57	0%

Note. For Study 1 $df = 351$ and for Study 2 $df = 314$. Predictors that emerged as significant in both Study 1 and Study 2 are bolded, except for Frequency of Use and Perceived Importance scales, which were only administered in Study 2.

Table 8. Regression results for MAQ Percentage Scale Predictors in Study 1

	b	*β*	*SE*	*t*	*p*	ΔR^2
Perceived ability						
Gender	−0.15	−0.05	0.15	−1.05	.30	0%
Math ACT	**0.69**	**0.55**	**0.06**	**11.76**	**<.001**	**27%**
Difficulty as impossibility	−0.13	−0.09	0.07	−1.84	.07	1%
Difficulty as importance	0.12	0.08	0.08	1.52	.13	0%
Ease as possibility	0.07	0.04	0.08	0.91	.36	0%
Ease as triviality	0.10	0.06	0.07	1.38	.17	0%
Mindset	0.05	0.33	0.06	0.72	.47	0%
Preference						
Gender	−0.03	−0.01	0.17	−0.19	.85	0%
Difficulty as impossibility	**−0.17**	**−0.12**	**0.08**	**2.17**	**.03**	**1%**
Difficulty as importance	0.17	0.10	0.09	1.91	.06	1%
Ease as possibility	−0.05	−0.03	0.09	−0.54	.59	0%
Ease as triviality	0.02	0.01	0.09	0.26	.79	0%
Mindset	−0.05	−0.03	0.07	−0.64	.52	0%

Note. Unstandardized coefficients are reported, *df* = 351. Significant predictors are bolded.

For percentage attitudes in Study 1, difficulty-as-impossibility was significantly negatively related to preference ratings (explaining 1% of variance), but not perceived ability ratings.

Discussion

Across two large samples of college students, we replicated findings from Sidney et al. (2021) seminal study on specific math attitudes about WNs, fractions, and percentages. Students in these samples endorsed more negative attitudes towards rational numbers than WNs. Additionally, in Study 1, students' mean ratings of attitudes about percentages fell in between their attitudes about WNs and fractions, and specific math attitudes accounted for significant unique variance in general math attitudes. Taken together, these findings suggest that elementary school children in fifth and sixth grade, college students, and older MTurk workers hold less positive attitudes about rational numbers relative to WNs. These negative attitudes are present early in formal fraction instruction and persist across the lifespan as college students and older adults amass additional experiences with rational numbers in daily life (e.g., math courses, cooking, interest rates, health risks).

Unique to the current studies, we investigated which individual differences were significantly related to specific math attitudes. First, we tested whether math achievement, gender, and mindset related to attitudes about specific number types. Across both samples, math ability, operationalized as ACT scores, strongly related to WN, fraction, and percentage attitudes in the full MAQ scale and each subscale. Thus, not only does objective performance on rational number tasks correlate with general and specific math attitudes (Sidney et al., 2021), but *self-reported* performance on a standardized measure of math ability also related to math attitudes. The ACT contains items involving fractions and decimals (see ACT College & Career Readiness Standards), therefore, even though the tests are considered to assess overall math ability, they may actually tap students' ability with rational numbers, specifically.

Contrary to our predictions, endorsement of a growth mindset (Dweck, 2006) did *not* relate to math attitudes for specific number types. This may be because the mindset items did not specifically mention math, but whether intelligence generally is fixed or malleable. However, an intervention in which adolescents were told that intelligence is malleable *did* result in improved standardized math performance (Good, Aronson, & Inzlicht, 2003). Findings from the current studies are aligned with recent meta-analyses suggesting that the relation between mindset and academic achievement is weak (Sisk, Burgoyne, Sun, Butler, & Macnamara, 2018).

The evidence for a relation between gender and math attitudes was mixed, with males reporting more positive attitudes towards fractions relative to non-males for two MAQ scales, perceived ability and frequency of use, only in Study 2. Sidney et al. (2021, Study 2) did find some evidence for gender differences in math attitudes – specifically that males had a smaller difference between their attitudes towards WNs and fractions compared with non-males. Sidney et al. (2021) interpreted this finding to suggest that males might possess a more integrated understanding of number concepts. Although gender was not consistently related to math attitudes across the current studies, it is important for future work to continue to explore how attitudes towards difficult mathematical concepts, such as fractions, may vary by gender given that women are at risk for disengaging from mathematics regardless of actual mathematical performance and achievement (Lauermann et al., 2017; Wang, Eccles, & Kenny, 2013).

Second, we tested whether beliefs about ease and difficulty (Fisher & Oyserman, 2017), which have not previously been applied to mathematical contexts, were significantly related to specific math attitudes. We predicted that interpretations of difficulty would relate to fraction attitudes, though we did not have specific predictions about whether difficulty-as-impossibility or difficulty-as-importance would relate more strongly to fraction attitudes. Our hypothesis that interpretations of difficulty would uniquely relate to fraction attitudes was supported. College students who endorsed the difficulty-as-importance belief reported higher perceived ability and greater preference for fractions, and students who endorsed the belief of difficulty-as-impossibility reported lower preference for fractions across both studies. We also explored whether beliefs about ease might relate to WN and percentage attitudes. Indeed, interpretations of ease were consistently related to attitudes about WNs, whereas interpretations of difficulty were not. Specifically, the ease-as-possibility scale positively related to perceived ability with WNs across both studies, and perceived importance of WNs in Study 2. These findings align with empirical work indicating WN tasks are easier than fraction tasks (Fazio et al., 2014; Yu et al., 2020). Finally, the difficulty-as-impossibility scale negatively related to ratings of preference for percentages.

Limitations and future directions

Limitations of the current studies offer opportunities for informative follow-up experiments. First, the data are correlational, so they are a first step towards understanding interrelations between specific math attitudes and perceptions of ease and difficulty. An experimental design manipulating ease and difficulty of various WN and fraction/percentage tasks could test whether negative attitudes about rational numbers lead to perceptions of difficulty, or vice versa. Evidence from Study 2 in Sidney et al. (2021) provides initial evidence for the causal direction. The authors counterbalanced the order in which participants answered MAQ items and completed challenging rational number estimation and comparison tasks. All participants rated fractions as more difficult than

WNs, but those participants who rated their math attitudes *after* the difficult math tasks rated *all* number types more negatively. Said another way, completing challenging rational number tasks prior to reporting attitudes about different number types is an effective way to *lower* adults' math attitudes, but a way to *improve* specific math attitudes has yet to be discovered.

In the current studies, both the ease and difficulty measures and the mindset measure were domain-general, that is, neither measure assessed these constructs as they pertain to mathematics specifically. It is unclear whether people who hold difficulty-as-impossibility beliefs might also report more negative attitudes towards *any* type of difficult task, illustrating a domain-general belief. That is, anything perceived as difficult induces negative attitudes (e.g., writing a sentence vs. writing a paragraph). This possibility raises important implications for interventions aimed at improving negative math attitudes. If researchers and teachers want to help people learn rational number concepts more effectively, interventions may first need to target the difficulty-as-impossibility belief as it relates to math specifically. A related line of work has shown that manipulations designed to help people reappraise the arousal experienced during stress as positive (Jamieson, Mendes, & Nock, 2013) can improve responses to stressful situations (Jamieson, Nock, & Mendes, 2012) and even improve performance in high-stakes contexts (Jamieson, Mendes, Blackstock, & Schmader, 2010). Attitudes can be resistant to change (Blankenship, Wegener, & Murray, 2012; Murrar & Brauer, 2019); therefore, changing negative math attitudes may require more time-intensive interventions. Indeed, teachers and parents, who themselves may harbour negative math attitudes (Mielicki, Fitzsimmons, & Thompson, 2021) and math anxiety (Beilock, Gunderson, Ramirez, & Levine, 2010), may need to foster a school and home environment in which difficult tasks are valued (Stevenson, Chen, & Lee, 1993).

Future work could also explore the extent to which different scales of the MAQ and interpretations of ease and difficulty relate to similar measures such as those derived from the expectancy-value framework (Eccles et al., 1983). Specifically, the cost component – or perceptions of the negative effects of engaging in a task – of the expectancy-value framework may relate to perceptions of difficulty. An individual's assessment of the cost of engaging in an activity could relate to the extent to which they possess the belief that difficult tasks/goals are worth completing (i.e., endorsing a difficulty-as-importance belief). Assessments of cost could also relate to the belief that difficulty signifies that a task or goal is impossible, which could contribute to cost assessments in terms of potential negative emotional states (e.g., fear of failure). Because fractions are challenging, measures of cost may be particularly relevant for attitudes towards fractions. The construct of cost is understudied relative to other constructs associated with expectancy-value theory (Jiang, Rosenzweig, & Gaspard, 2018), but some preliminary work has begun looking at how perceptions of cost may interact with other motivational constructs to predict math achievement and affect in math learning (Conley, 2012).

Educational implications

Future work should also investigate whether children's perceptions of ease and difficulty are also related to their math attitudes. Children perform worse on fraction, relative to WN, tasks (Fazio et al., 2014), but it is unclear whether beliefs that relate to adults' specific math attitudes also relate to children's specific math attitudes.

There are important educational implications regarding the current findings. Math educators (Common Core Standards Writing Team, 2018) have established fraction progressions, or the order fractions' standards should be taught. Currently in the United States, formal, symbolic fraction instruction begins in third grade; however, students do not formally learn about percentages until sixth grade. Some researchers (Moss & Case, 1999) have switched the order of instruction, by introducing percentages before fractions, to use percentages as an intuitive and familiar bridge between WNs and fractions. For example, a file that has loaded halfway illustrates 50%, and that is equivalent to ½. Researchers have also investigated whether it might be advantageous to teach children about WNs and rational number concepts in tandem to emphasize equivalent notations (Hurst & Cordes, 2018; Moss & Case, 1999). Even WNs can be expressed as fractions (Sidney, Thompson, Matthews, & Hubbard, 2017). Teaching numerical notations in tandem may help students overcome common misconceptions, such as whole number bias (Alibali & Sidney, 2015; Ni & Zhou, 2005; Thompson et al., in press), and result in an integrated representation of WNs and rational numbers (Siegler et al., 2011, 2013).

To the extent that people avoid difficult math tasks, it could be because they induce math anxiety (cf. Choe, Jenifer, Rozek, Berman, & Beilock, 2019; Sidney et al., 2018). Alternatively, people may fail to see value in persevering on challenging tasks, despite that doing so benefits their learning progress (cf. desirable difficulties; Bjork & Bjork, 2011; Bjork, 1994; Clark & Bjork, 2014). For example, fifth and sixth graders judged fraction division problems illustrated with number lines as more difficult than problems illustrated with circle or rectangle area visual models, despite being more accurate on number line problems (Sidney et al., 2019). Students are not always aware of what benefits their learning. Improving students' metacognitive awareness, or their ability to differentiate more and less difficult problems, could impact their future study decisions or willingness to seek help (Fitzsimmons, Thompson, & Sidney, 2020; Nelson & Fyfe, 2019; Rivers et al., 2021; Wall, Thompson, Dunlosky, & Merriman, 2016).

Conclusions

In summary, we have replicated Sidney et al. (2021) findings that people rate fraction and percentage attitudes more negatively than WN attitudes. Further, college students' ease-as-possibility beliefs related to WN attitudes, whereas difficulty-as-impossibility beliefs related to fractions and percentage attitudes. Given rational numbers are critical to success in higher-level mathematics (Booth, Barbieri, Eyer, & Pare-Blagoev, 2014; Booth & Newton, 2012; Siegler et al., 2012), positive adult life outcomes (NMAP, 2008), and everyday life (Handel, 2016), future research should develop interventions to address people's negative math attitudes and perceptions of difficulty.

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Conflicts of interest

All authors declare no conflict of interest.

Author contribution

Marta Mielicki: Conceptualization (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – original draft (equal); Writing – review & editing (equal). **Lauren Schiller:** Writing – review & editing (equal). **Charles Fitzsimmons:** Formal analysis (equal); Writing – review & editing (equal). **Daniel Scheibe:** Writing – review & editing (equal). **Clarissa Thompson:** Conceptualization (equal); Project administration (equal); Resources (equal); Supervision (equal); Writing – original draft (equal); Writing – review & editing (equal).

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Supporting Information

The following supporting information may be found in the online edition of the article:

Table S1 MAQ Attitudes by Gender and Year in School for Studies 1 and 2
Table S2 Regression Results for General Math Attitudes in Study 1 and Study 2
Table S3 Regression Results for Overall MAQ Predictors in Study 1 and 2