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When Anxiety Grows With Knowledge: The Role of the Natural Number Bias

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Abstract

An important source for the difficulties students face with fractions is the natural number bias (NNB), which refers to the phenomenon of applying natural number properties in fraction tasks, even when this is inappropriate (e.g., 1/4+1/3 = 2/7). The present longitudinal study investigates whether this misconception is related to the development of mathematics state anxiety in the domain of fractions. The results indicated that, when a group of students with a clear NNB profile (n = 38) improved their fraction arithmetic understanding they showed an increase in state anxiety measured after the fraction arithmetic task. These results complement previous research by showing that a clear misconception, namely the natural number bias, might influence the development of students' fraction state anxiety. Importantly, the increase in fraction state anxiety in the low-performing NNB group is not a characteristic of low performing students in general, as a significant decrease in fraction state anxiety was found in low-performing students without signs of the NNB (n = 37). The study highlights the importance of looking at different subgroups of students, as different developmental patterns can be found within qualitatively different groups of students.

Keywords

fractions, misconception, natural number bias, state anxiety, mathematics anxiety, conceptual change

Instruction on fractions forms a crucial part of the mathematics curriculum in elementary school and in the first years of secondary school. Moreover, fraction understanding is an important stepping stone in understanding more advanced mathematics such as algebra in later years (e.g., Siegler et al., 2012; McMullen & Van Hoof, 2020). Unfortunately, despite their significance, fractions pose a significant challenge in education, since they are hard to understand, not only for elementary school students, but also for secondary school students, and even adults and teachers (Gabriel et al., 2023; Van Hoof et al., 2018).

While the literature elaborates on several reasons why fractions are difficult for students (e.g., Moss, 2005), one important source for the difficulties students face with comprehending the rational number domain is the natural number bias (for an overview, see e.g., Gabriel et al., 2023; Van Hoof et al., 2017). The natural number bias (further abbreviated as NNB) can be described as the tendency to apply natural number properties in rational number tasks, even when this is inappropriate (e.g., Ni & Zhou, 2005). Recently, it has been shown that a strong misconception, such as the NNB, may influence the relation between students' fraction performance and their fraction state anxiety (Halme et al., 2024). However, it is unknown how the process of overcoming this natural number bias might influence students' fraction-related mathematics anxiety development.

The Natural Number Bias

The NNB is a highly investigated phenomenon and has been found in large groups of students worldwide (e.g., Li et al., 2023; Vamvakoussi et al., 2013; Van Hoof et al., 2017). While the term 'whole/natural number bias' was only introduced in the beginning of the 2000's, research showing the interference of natural number knowledge in rational number tasks dates further back. As stated by Streefland (1991, p. 70), in the beginning of fraction instruction, learners have the "temptation to deal with fractions in the same manner as with natural numbers".

The literature on the NNB showed that there are at least three aspects in which natural numbers differ from rational numbers: their structure, the way their numerical size can be determined, and performing operations with them (for an overview, see e.g., Van Hoof et al., 2017). In the present study, we focus on the last aspect and more specifically on fraction addition and subtraction tasks. The literature reported several examples in which students make natural number based mistakes while solving fraction arithmetic tasks. For example, many students do not see a fraction as a unified numerical representation of a single magnitude but consider the numerator and denominator of a fraction as two independent natural numbers. This can lead students to think that adding/subtracting fractions can be done by adding/subtracting the numerators/denominators separately in fraction tasks (e.g., 1/4 +1/3 = 2/7; 5/8 − 1/3 = 4/5; e.g., González-Forte et al., 2022; Post, 1981). For example, in a sample of U.S. 8th graders, only 24% could correctly estimate that the sum of 12/13 + 7/8 is closer to 2 than to 1, 19, or 21 (Carpenter et al., 1980). Another example is that, when initially learning arithmetic with natural numbers, many students assume that multiplication and addition will always produce a larger result, while division and subtraction will always produce a smaller one. Once rational numbers are then introduced in the classroom, this can lead to mistakes such as thinking that multiplying a number with a number between 0 and 1 will result in a larger outcome or that to come to a smaller outcome, you always have to divide (e.g., Fischbein et al., 1985; González-Forte et al., 2022; Van Hoof et al., 2017).

One of the theories that attempts to explain students' naive application of natural number properties in rational number tasks, is the framework theory of conceptual change (e.g., Vosniadou, 2013). This theory claims that students interpret their everyday experiences and organize them in a more or less coherent framework theory. These frameworks are "a relatively coherent and principle-based system, which is generative in that it allows children to make predictions and explanations and deal with unfamiliar problems" (Vamvakoussi & Vosniadou, 2010, p. 185). As children grow up, they encounter new information, for instance in the classroom setting. Students comprehend the new information more easily, when it is consistent with and enhances their existing framework theory, as opposed to when it contradicts their original framework theory (Vosniadou, 2013). In the latter situation, there is a need to revise the original framework theory; as is the case with some aspects of fraction knowledge.

Concerning fractions, the gist of the explanation is as follows: In daily life and in the first school years, children encounter natural numbers more often than they encounter fractions. This leads to an initial concept of number which is only based on the properties of natural numbers. This initial number concept, in its turn, influences students' beliefs and interpretations about the rules and characteristics of other types of numbers, for example rational numbers (e.g., Christou & Prokopou, 2020; Gelman, 2000). However, once fractions are introduced, the properties of natural numbers are no longer sufficient to solve all fraction tasks. Nonetheless, due to children's initial number concept, many students overgeneralize the properties of natural numbers and apply them to fractions, even in situations where this is inappropriate, previously referred to as the natural number bias.

Overcoming the NNB is a gradual and time-consuming process (for an overview, see e.g., Van Hoof et al., 2017). Several longitudinal studies have investigated the various intermediate stages students go through in the conceptual process from an initial natural number based concept of fractions towards a more mathematically correct one. For instance, while some students already display some understanding or even a mathematically correct conceptual understanding of fractions at the end of elementary school, others still have a very naïve and strong natural number based concept of fractions shown by answering all fraction tasks in line with natural number reasoning (e.g., González-Forte et al., 2022). In this last group of students, the misconception is very strong as students are found to be certain that their incorrect answers are correct (González-Forte et al., 2023; Reinhold et al., 2020) suggesting they are unaware that they are doing something wrong when solving fraction tasks in a natural number based way.

Unawareness of Misconceptions

Misconceptions in general – including in the domain of fractions – are as Behera (2019, p. 412) stated "more than misunderstandings about a concept. Misconception is defined as knowledge which obstructs to learn scientific knowledge due to personal experience. So, these are wrong concepts that a student accepts as true". This acceptance of a misconception as being true leads students to be unaware of the incorrectness of their knowledge and how their knowledge contradicts scientific knowledge (e.g., Merenluoto & Lehtinen, 2004). The unawareness of the incorrectness has been investigated by looking at the combination between the correctness of a learner's answer and the level of confidence the learner has about their answer (e.g., Engelbrecht et al., 2005). Engelbrecht et al. (2005) state that "Irrespective of whether the answer is correct or not, a low confidence indicates a guess which, in turn, implies a lack of knowledge. However, if the confidence is high and the answer wrong it points to a misplaced confidence in his knowledge on the subject matter, either misjudging his own ability or a sign of the existence of misconceptions." (p. 704).

Students with a natural number bias have been found to have high confidence in their misconception. González-Forte et al. (2023) recently found that seventh-grade students with a clear NNB profile showed high confidence in their incorrect answers on a fraction task. Similarly, Reinhold et al. (2020) found that students who had higher performance on fraction items congruent to natural number-based reasoning (2/5 vs 7/8) compared to their performance on fraction items incongruent to natural number-based reasoning (3/7 vs 2/3) had lower performance on fraction tasks/items and answered them much faster compared to their peers without a NNB. The authors interpreted the combination of lower performance and faster responses as an indication that these students, labeled as having a clear NNB profile, were unaware that the fraction tasks are more difficult than they think.

This is supported by previous evidence that the NNB is a fast intuitive answering pattern rather than a deliberate thought-out reasoning (see discussion by Alibali & Sidney, 2015). When overcoming a misconception, such as the NNB, students become (at least partly) aware that their (original) understanding was not correct. This awareness, if accompanied by a realization that fractions are more difficult than previously thought may lead to increased anxiety when solving tasks including fractions.

Mathematics Anxiety

There is a growing body of research investigating the role of mathematics anxiety and its negative relation with students' mathematics development (see for example the meta-analysis by Namkung et al., 2019). Recent studies showed that it is important to distinguish between two measures of mathematics anxiety: trait mathematics anxiety and state mathematics anxiety. While trait mathematics anxiety refers to an individual's relatively stable level of anxiety towards mathematics and mathematical tasks in general, state mathematics anxiety refers to a more temporary and situational state of anxiety experienced during a specific mathematical situation (Conlon et al., 2021; Demedts et al., 2022).

Notably, these two aspects of mathematics anxiety can have different relations with mathematics performance within and across mathematical tasks. For example, Demedts et al. (2022) showed that while secondary school students' state mathematics anxiety explained more variance in fraction performance on an easy mathematics task, it was trait mathematics anxiety that explained more variance in fraction performance on a more difficult mathematics task. In addition, Halme et al. (2022) found that both trait and state mathematics anxiety predict performance with whole number arithmetic, but that only trait mathematics anxiety predicts students' fraction arithmetic performance. Thus, recent research highlights that task and context characteristics can influence the relation between mathematics anxiety and performance within and across tasks.

There are only a few studies that have investigated the relation between mathematics anxiety and fraction performance, especially in primary school children (e.g., Halme et al., 2022; Starling-Alves et al., 2022). Furthermore, little is known about the influence of student characteristics, such as having an NNB or not, on the relation between students' fraction performance and their mathematics anxiety. To address this, Halme et al. (2024) expanded on previous findings by comparing two groups of low fraction performers: a group with a clear NNB profile (NNB group) and a group with low fraction performance, but no natural number based answers (No-NNB group). Results showed that the NNB group had significantly lower fraction state anxiety compared to the No-NNB group. However, the two groups did not differ in their whole number state anxiety or trait mathematics anxiety, showing that the difference in anxiety between the two groups is not in general, but specific for fraction state anxiety. The proposed explanation was that, given their misconception, NNB students are unaware of their mistakes and poor performance (in line with previous NNB research) leading to lower perceived difficulty of the fraction task and lower fraction state anxiety compared to other low performers without an NNB. Furthermore, their findings suggest that specifically fraction state anxiety reflects the real-time anxiety related to fraction performance, as there was no group difference in trait mathematics anxiety. However, given that the findings are based on cross-sectional data, no developmental statements could be made on the effect of overcoming a misconception on (the development of) students' state anxiety.

Longitudinal research is needed to address how overcoming a misconception may influence the development of state anxiety. In general, longitudinal studies have inconsistent findings on the specific direction of the relation between students' mathematics performance and their mathematics anxiety. While some studies suggest that low mathematics performance leads to higher mathematics anxiety, others claim the opposite where high mathematics anxiety leads to lower performance (e.g., for an overview, see Carey et al., 2016). In the last decade, several studies have proposed that the relation between mathematics performance and mathematics anxiety is bidirectional with mathematics anxiety being the potential cause and outcome of poor performance (e.g., Carey et al., 2016; Gunderson et al., 2018). Moreover, several intervention studies showed that topic-specific instruction not only led to an increase in participants' performance on a mathematics task, but also to a decrease in their mathematics anxiety (for an overview, see literature review by Balt et al., 2022).

Importantly, the aforementioned longitudinal studies were conducted using trait mathematics anxiety measures and, as far as we know, little is known about the longitudinal development of state anxiety. In the present study we investigate how learning about fractions influences the development of fraction state anxiety in primary school students with specific attention to how (partly) overcoming the NNB might affect the development of students' state anxiety.

The Present Study

The present study extends the cross-sectional study of Halme et al. (2024) with longitudinal data from the same group of students to investigate the role of overcoming a clear misconception, namely the NNB, in the development of students' fraction state anxiety in the crucial years of fraction instruction.

To our knowledge, no previous studies have examined the longitudinal development of fraction state anxiety. Therefore, in a first step, we look at the whole sample of students (so all 334 participants, including those with and without NNB) to answer the question: how does fraction state anxiety develop in primary school students? (Research Question 1). This will allow us to contextualize our findings concerning the role of the NNB, in a larger general sample of students. As stated above, several intervention studies showed that topic-specific instruction not only led to an increase in participants' performance on a mathematics task, but also to a decrease in their mathematics anxiety (e.g., Balt et al., 2022). Furthermore, an increased exposure to a mathematics topic is suggested to reduce mathematics anxiety (e.g., Supekar et al., 2015). Thus, even though there is no research yet on the longitudinal development of students' fraction state anxiety, one could argue that fraction instruction should decrease students' fraction state anxiety. However, no specific hypothesis on students' fraction state anxiety development was made in the present study, since we acknowledge that there can be several different homogenous subgroups of students with diverse developmental trajectories of anxiety (e.g., Klee & Miller, 2019).

In the second step, we investigate the possible effect of the NNB on the development of students' state anxiety. More specifically, we aim to examine how changing from a naïve natural number based misconception of fractions to a less naive understanding affects fraction state anxiety levels. Therefore, in the second part of the study, we focus on the specific subgroup of students in our sample that show a pure NNB profile at the first measurement point. Examining the longitudinal data of this specific group of students allows us to answer whether (partly) overcoming a misconception leads to an increase in students' state anxiety? (Research Question 2). We claim that students with a clear NNB at Time Point 1 are unaware of their misunderstanding of fractions and the mistakes they make. Previous research shows that students with a clear NNB have a high level of confidence in their wrong answers (e.g., González-Forte et al., 2023) and they have lower fraction state anxiety compared to other low performers without a clear NNB (see Halme et al., 2024). We hypothesize that when they (partly) overcome their misconception by Time Point 2, they become aware that their understanding of fractions was wrong and that solving the fraction task is more complex than they had previously thought and that this realization can lead to higher fraction state anxiety. This would also align with previous research that lower levels of NNB correlate with higher state anxiety (Halme et al., 2024).

It is important to note that the longitudinal development of state anxiety among low-performing students with a clear NNB may not (solely) be attributed to overcoming a misconception. It might also be a characteristic of low-performing students in general. To address this, we compare the development of state anxiety in students with a clear NNB profile to another group of low-performing students who showed no signs of NNB. This led to our third research question: Does the need to overcome a misconception lead to different developmental patterns of fraction state anxiety in low performers (Research Question 3)? More specifically, we tested two alternative hypotheses: 1) there are differences in the development of state anxiety between the two low-performing groups, suggesting that the change in fraction state anxiety in students with a clear NNB is a product of overcoming a misconception (Hypothesis 3a: misconception), or 2) the development of state anxiety does not differ between the two groups, suggesting that state anxiety develops similarly in low performers (Hypothesis 3b: low performance). Importantly, a difference in performance development might also explain a possible difference in anxiety development between the two low-performing groups. Therefore, we also checked whether both groups show similar fraction performance development over time.

Method

The current study is part of a larger research project investigating the role of trait and state mathematics anxiety in different domains of the mathematics curriculum (for more information about the project, see Halme et al., 2022). Shortly described, state anxiety was measured across various mathematical tasks from symbolic to non-symbolic and whole numbers to rational numbers. State anxiety measured after a mathematical task was shown to correlate with trait mathematics anxiety. Furthermore, while state anxiety correlated with performance in multiple mathematical tasks, such as whole number knowledge and adaptive rational number knowledge, no correlation was found between performance and state anxiety in the domain of fraction arithmetic (Halme et al., 2022). This subdomain of the mathematics curriculum (fraction arithmetic) forms the focus of the present study.

Participants

The same participants of the study by Halme et al. (2022) were followed up in the present longitudinal study, with a first time point in November and the second in May of the 2020-2021 school year. The first time point consisted of 412 fifth and sixth grade students, from 27 classrooms (12 5th grade) within 10 schools, located in two urban municipalities in the south of Finland. Given the longitudinal nature of the study, some drop out was due to COVID-19 (e.g., sick students, students in quarantine, etc.) or other reasons for not being present (n = 40). Some participants had missing data because they started but did not finish the final measurement (n = 36) or for other reasons (n = 2). Consequently, the longitudinal data consisted of 334 students with no missing values on the fraction measures at either of the two time points. The longitudinal sample included 50% fifth graders, 51% females and the mean (*SD*) age was 11.91 (0.59).

In Finland, fraction instruction generally starts in the third grade and continues throughout primary school (end of Grade 6). In the fourth grade, subtracting and adding fractions with the same denominator is covered, while in the fifth grade fractions with different denominators is covered. This means that all students included in the study had instruction on fractions and fraction arithmetic prior to the first time point. Furthermore, all students were in the crucial years of fraction instruction.

Apart from looking at the whole sample, we also examined the development of fraction state anxiety in two specific subgroups of students: low performers with a clear NNB profile (NNB group) and low performers without any signs of a NNB (No-NNB group). The same groups were used as in the study of Halme et al. (2022). Students in the NNB-group were defined by having a clear NNB profile if they gave a natural number biased answer on all 8 items of the fraction arithmetic task (e.g., $1/4 + 1/2 = 2/6$ or $4/6 - 1/2 = 3/4$) at Time Point 1. We were able to collect longitudinal data for 48 out of the 60 students who showed this profile at Time Point 1. The strict choice of students being part of the NNB group only when they answered all items in a natural number based way was not an arbitrary one. As stated above, the conceptual change from a naive NNB profile to a good fraction understanding is a long process with several intermediate states (e.g., González-Forte et al., 2022). Thus, to be able to investigate the role of overcoming a misconception on state anxiety development we had to specifically focus on that homogeneous group of students, who still had a completely naïve natural number based misconception of fractions at the beginning of the study and had not yet started the process of conceptual change.

This group of students is compared to other low performing students without a clear NNB misconception. More specifically, the second group of students, the No-NNB group was defined as: “Students who had all answers incorrect on the fraction arithmetic task items due to some other reasoning than the NNB (e.g., 1/2 + 1/4 = 2/4) were categorized as the No-NNB group. Notably, there were very few students who had all answers incorrect due to some other reasoning than the NNB (n = 13); therefore, the criteria for the No-NNB group was expanded to include students with the two same denominator items as correct (i.e., 1/3 + 1/3 & 3/4 - 1/4). This means that students in the No-NNB group had a maximum of two out of eight correct and all incorrect answers had a different source than the NNB.” (Halme et al., 2024, p. 141). We were able to collect longitudinal data for 45 out of the 59 students who showed this profile at Time Point 1. Given that diverse developmental trajectories of anxiety have been found in different homogeneous subgroups of students (e.g., Klee & Miller, 2019), we see the dichotomous distinction between learners with and without an NNB to be a strength of the study.

The municipalities, school principals, and teachers provided permission for the study. Guardians of the students gave written consent, and each participant was informed that their participation was voluntary, and they could withdraw from the study at any point. The study followed the ethical guidelines of the Finnish National Board on Research Integrity (TENK).

Procedure and Measures

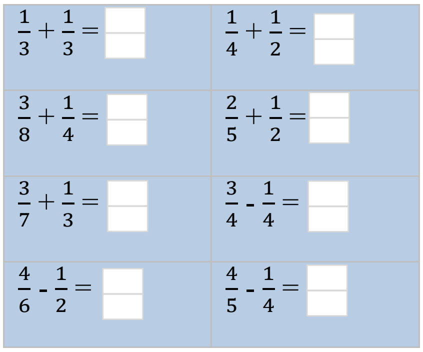
The participants completed a test battery on a digital platform individually on a laptop while being in the classroom under the supervision of their classroom teacher. The teacher informed the students about the general instructions of the test and that participation was voluntary. Within the digital platform, before each task, the participants saw written instructions (for example, before the fraction arithmetic task the participants were instructed to mentally calculate the following exercises) and the time limitation for the task. The reason for a time limitation was to make sure that each participant spent a relatively equal amount of time on each task throughout the battery. The test battery consisted of multiple tasks (for more details, see Halme et al., 2022). For the present study, we only analyzed participants’ performance on a fraction arithmetic task and their self-reported state anxiety measured after the task. These were measured at two time points (November and May) of the 2020-2021 school year. Students received the same fraction arithmetic task and the same fraction state anxiety question at both time points.

Fraction Arithmetic Task

The fraction arithmetic task consisted of five fraction addition and three fraction subtraction items (Figure 1). All eight fraction items were shown simultaneously on the computer screen. The participants had 2.5 minutes to solve the eight items by filling in the correct fraction outcome with their keyboard. At the first time point, the participants had to wait until the time ended to finish the task. At the second time point the participants had a minimum of 1 minute and a maximum of 2.5 minutes, meaning they could continue to the next task before the 2.5 minutes were up. The reliability of the task was high (Cronbach’s alpha = 0.84 for time point one and 0.87 for Time Point 2).

Figure 1

Fraction Arithmetic Task



Fraction State Anxiety Measure

The fraction state anxiety was measured immediately after solving the fraction arithmetic task. After continuing from the fraction arithmetic task, the next screen prompted students to rate "How anxious did you feel during the previous task?" using a continuous Likert scale, going from 'not at all' (score of 1) to 'very much' (score of 5), which is in line with previous studies using this specific question to measure state anxiety (Demedts et al., 2022; Trezise & Reeve, 2018). The scale was adapted from Punaro and Reeve (2012), who had also used it to measure state emotions of mathematics related worry in primary school children. Given that this study was part of a larger research project with multiple mathematical tasks in the study design, it was more feasible and reasonable to only use a single item to measure state anxiety after each mathematical task. While a one-item math anxiety scale has not been used before with children, the reliability of single-item measures for capturing mathematics anxiety has been shown by Núñez-Peña and colleagues (2014) in college students.

Results

Descriptive Statistics

Data was analyzed using IBM SPSS Statistics 28. Descriptive statistics on the two measures at the two time points are displayed in Table 1. Correlations between the measures for the whole group of participants (n = 334) at both time points can be found in Table 2.

Table 1

Descriptive Statistics for Fraction Performance and Fraction State Anxiety

	NNB group n = 38	No-NNB group n = 37	Whole group n = 334		
Variable	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**	**Skewness (*SE*)**	**Kurtosis (*SE*)**
Fraction performance					
Time 1	0.00 (0.00)	1.41 (0.76)	2.28 (2.19)	0.80 (0.13)	-0.31 (0.27)
Time 2	1.97 (1.92)	3.08 (2.38)	3.42 (2.55)	0.40 (0.13)	-1.05 (0.27)
Fraction anxiety					
Time 1	1.74 (1.10)	2.63 (1.60)	2.10 (1.26)	1.13 (0.13)	0.09 (0.27)
Time 2	2.41 (1.57)	2.03 (1.39)	1.95 (1.24)	1.33 (0.13)	0.55 (0.27)

Table 2

Correlations Between the Measures at Time Point 1 and Time Point 2 in the Whole Sample (n = 334)

Variable	1	2	3	4
1. Fraction performance – Time 1	–			
2. Fraction performance – Time 2	.57**	–		
3. Fraction anxiety – Time 1	-.06	-.07	–	
4. Fraction anxiety – Time 2	-.09	-.21**	.29**	–

$^{**}p < .01$.

Development of Students' Fraction State Anxiety and Performance in the Whole Sample

To address Research Question 1 (How does fraction state anxiety develop in primary school students?), paired sample *t*-tests were conducted to examine the change in state anxiety in the whole sample of students (n = 334). The results showed that fraction state anxiety did not differ between Time Point 1 (M = 2.10, SD = 1.26) and Time Point 2 (M = 1.95, SD = 1.24), $t(333) = 1.77$, $p = .08$, Cohen's $d = .10$. In addition, we examined the development of performance and found that students' fraction performance significantly increased from Time Point 1 (M = 2.28, SD = 2.19) to Time Point 2 (M = 3.42, SD = 2.55) with a medium effect size, $t(333) = 9.42$, $p < .001$, Cohen's $d = .52$.

Results of the Two Groups of Low Performers

Apart from looking at the whole sample, we also examined two specific subgroups, the NNB group and the No-NNB group, to answer Research Question 2 (Does (partly) overcoming a misconception lead to an increase in students' state anxiety?) and Research Question 3 (Does the need to overcome a misconception lead to different developmental patterns of fraction state anxiety in low performers?). Students in the NNB group were defined by giving a natural number biased answer on all 8 items of the fraction arithmetic task at Time Point 1. Since we wanted to examine how overcoming a misconception (as shown by a decrease in NNB answers) influences fraction state anxiety in low performing students with a NNB, we only included those students that show a decrease in NNB answers at Time Point 2. Of the 48 students in the NNB group at Time 1, 38 showed a decrease in their NNB answers at Time Point 2 (mean number of NNB answers at Time Point 2 = 3.32, range: 0 – 7). In other words, these 38 students showed signs of at least partially overcoming their NNB misconception. It should be noted that it is possible that a single non-NNB answer at Time Point 2 can also represent a calculation error instead of a sign of overcoming of the natural number bias. However, only a minority of the students (n = 6) showed only one non-NNB answer at Time Point 2. Ten students from the NNB group still showed the same strong NNB misconception at Time Point 2 by giving a natural number based answer on all 8 items of the fraction arithmetic task again. In other words, these ten students showed no signs of overcoming their misconception at all. Therefore, they were not included in the data analysis.

The No-NNB group included students who had a maximum of two out of eight answers correct and all their incorrect answers had a different source than the NNB. Importantly, given that we want to make sure that the NNB does not play any role in this group of students, we only included students that also still do not show any signs of the NNB at Time 2. Of the 45 students that showed a no-NNB profile at Time Point 1, 37 still showed no signs of a NNB at Time Point 2. Thus, the sample we continued with was 75 participants, 38 students who had a NNB profile at Time Point 1 and showed signs of overcoming the NNB at Time Point 2, and 37 students who had a No-NNB profile at Time Point 1 and still had no signs of the NNB at Time Point 2. Power analyses were conducted to determine the required sample size for a two-way repeated measures ANOVA with one between-subjects factor (NNB group vs No-NNB group) and one within-subjects factor (Time Point 1 vs Time Point 2). To detect a medium effect size (f = 0.25) for the interaction between group and time, with an alpha level of .05 and a power of .80, the power analysis showed that a total sample size of 34 participants would be required. Both the NNB and no-NNB group have more than 34 students, showing a high enough power in the current study.

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Development of Fraction Anxiety

We examined differences in the development of fraction state anxiety between the NNB and No-NNB groups. A two-way repeated measures ANOVA was conducted including fraction anxiety as the dependent variable, time (Time Point 1 vs Time Point 2) as a within-subject factor and group (NNB vs. no-NNB) as the between-subject factor.

No significant within-subjects main effect of time on fraction anxiety levels was found, $F(1, 73) = 0.03$, $p = 0.87$, $\eta_p^2 < 0.01$. However, results did indicate a significant interaction effect between group and time, $F(1, 73) = 9.69$, $p = .003$, $\eta_p^2 = 0.12$, answering Research Question 3 (see also Figure 2). Simple effects showed that there was a significant difference in fraction anxiety at Time Point 1 between the groups, with the NNB group exhibiting significantly lower fraction anxiety compared to the No-NNB group, Mean Difference = 0.89, $SD = 0.32$, $p = .006$ (this result is consistent with the findings of Halme et al. (2024) in the original and larger dataset), but not at Time Point 2, $p = .28$. Moreover, to check hypothesis 3a and 3b, simple effects show that the fraction anxiety of the NNB group significantly increased over time, $p = .02$ (answering Research Question 2), whereas the fraction anxiety of the No-NNB group significantly decreased over time, $p = .04$.

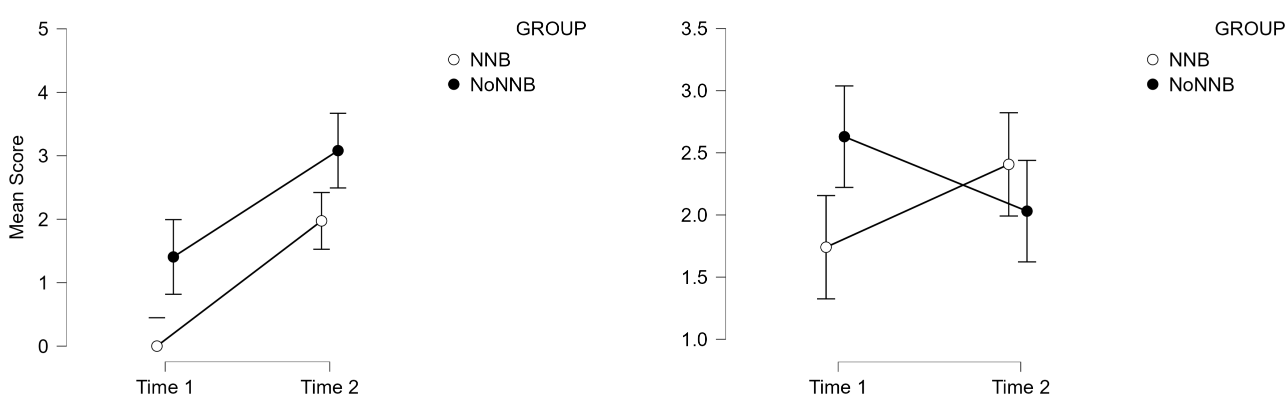
Development of Fraction Performance

We investigated whether the NNB and No-NNB group show differences in their fraction performance development, to see if this may explain the difference in fraction anxiety development. A two-way repeated measures ANOVA was conducted including fraction performance as the dependent variable, time (Time Point 1 vs Time Point 2) as a within-subject factor and group (NNB vs. No-NNB) as the between-subject factor.

A significant within-subjects main effect of time on fraction performance levels was found, $F(1, 73) = 50.48$, $p < .01$, $\eta_p^2 = .41$, but no significant interaction effect between group and time, $F(1, 73) = .34$, $p = .56$, $\eta_p^2 < 0.01$. This indicates that fraction performance developed similarly in the two groups. Simple effects showed that both groups significantly increased in their fraction performance (p-values < .001 for both groups, see also Figure 2). These results confirm that the difference in fraction state anxiety development between the two groups of low performers is not explained by different fraction performance development, consistent with the misconception hypothesis (Hypothesis 3a).

Figure 2

Fraction Performance and Fractions State Anxiety Development in the Two Low Performing Groups



Note. The error bars are 95% confidence intervals. The performance maximum is 8 and the state anxiety range is from 1 to 5.

The Influence of the NNB Group on the Whole Group Results

As shown above, looking at the whole group of students (including the NNB group), a significant increase was found in fraction performance, while there was a non-significant decrease in fraction state anxiety over time. As the NNB group had a significant increase in fraction state anxiety, this shows that there are subgroups within the whole sample that may affect the interpretation of the whole group results. To see whether the presence of the NNB group influenced the whole group results, we reanalyzed the general development of fraction state anxiety in the whole group ($n = 334$)

excluding the NNB group (n = 38). Results of the remaining 296 students show a significant decrease in fraction state anxiety with a small effect size, $t(295) = 3.01$, $p = .003$, Cohen's $d = .18$.

Discussion

Main Findings

The present study concludes that gaining a better understanding of a mathematical topic does not necessarily lead to a decrease in mathematics anxiety related to that topic. Results even showed that in a specific subgroup of students a better understanding of fractions was associated with a significant increase in fraction anxiety.

The main purpose of the present study was to investigate the role of a misconception in the longitudinal development of mathematics state anxiety in the domain of fractions. Results complement previous research by showing that a clear misconception, namely the natural number bias (e.g., Gabriel et al., 2023; Van Hoof et al., 2017), can influence the development of students' fraction state anxiety. More specifically, our results indicated that in the group of students with a naïve NNB profile, improvement in fraction arithmetic understanding does not necessarily lead to reduced state anxiety. Instead, the opposite relation appeared, i.e. for students with a very clear NNB misconception, a decrease in NNB answers (i.e., a sign of overcoming the misconception) co-occurred with increased fraction state anxiety. Importantly, the results showed that the increase in fraction anxiety among the low-performing NNB group is not a characteristic of low performing students in general, as we found a significant decrease in fraction state anxiety in low-performing students without signs of the NNB. Notably, both groups improved in performance over time. Thus, the presence of a NNB appears to influence the development of anxiety and the developmental relation between anxiety and performance.

We claim that the result that (partly) overcoming a misconception is associated with an increase in fraction state anxiety can be explained as follows: (a) students with a clear natural number bias (at the first measurement point) are unaware of their misconception and have no clue that they are doing anything wrong (e.g.; González-Forte et al., 2023; Reinhold et al., 2020), (b) after (at least partly) overcoming this misconception – indicated by a decrease in NNB answers at the second measurement point – they are more aware that a natural number based answer is insufficient to solve fraction tasks and that solving fraction tasks, especially fraction arithmetic, is more difficult than they thought, and (c) this realization leads to higher fraction state anxiety. The latter is in line with the cross-sectional study results (Halme et al., 2024), which showed not only that low performing students without a NNB had higher fraction state anxiety, but also that the number of NNB answers negatively correlated with the level of fraction state anxiety. The cross-sectional study (Halme et al., 2024) also showed that the NNB group did not have a general pattern of lower state anxiety, as their whole number state anxiety was equivalent to the No-NNB group. This supports the proposition made by Halme et al. (2024) that students' subjective perceptions of their own performance influence their state anxiety responses.

Lastly, in the present study, results from the whole sample showed that a significant increase in fraction performance over time co-occurred with a non-significant change in fraction state anxiety. However, after excluding the students with a NNB profile, the decrease in fraction state anxiety became significant. This indicates that examining subgroups of students, especially in a task with a potential for misconceptions, yields important nuanced information on the relation between task performance and state anxiety. It moreover shows that the presence of a misconception in a subgroup of students, such as the NNB, can largely affect the results obtained from the whole group of students. Thus, not taking into account subgroups can lead to incorrect interpretations of developmental relations.

Implications and Avenues for Future Research

Our findings have several theoretical, methodological, and educational implications. They highlight the importance of looking at different subgroups of students, as different developmental patterns can be found within qualitatively different groups of students. Ignoring the influence of these different subgroups on overall effects may influence the interpretation of the results, both in the domain of mathematics anxiety and the domain of mathematics understanding. In the domain of mathematics anxiety, specific subgroups should be taken into account, when examining developmental relations between performance and state anxiety. As fraction performance increases, it is likely that state anxiety levels would decrease in students without a NNB. However, this reduction in anxiety would be hidden behind the increase in state anxiety in students with a NNB. Thus, special attention should be given to the qualitative differences within performance (e.g., different error patterns), as increases in mathematics anxiety may occur in the process of conceptual change, such as overcoming a misconception. This is relevant information for mathematics education. More specifically, it is relevant for teachers or researchers who examine the effects of mathematics instruction and interventions on state anxiety, especially in topics with misconceptions, as only looking at the general development of state anxiety in a sample could suggest that no significant change occurred. The present study also shows that similar quantitative low performance of students can be due to completely different qualitative sources, such as having a clear misconception or not.

Next, the present study adds to the discussion whether the NNB is a deliberate strategy students choose to use or a misconception of which students are not aware (e.g., see the discussion by Alibali & Sidney, 2015). We argue that the results of the present study are in line with the latter. More specifically, we interpret the present results in light of the Dunning-Kruger effect, which refers to a cognitive bias where people with low expertise or knowledge are found to overestimate their ability or knowledge. In other words, they are not only unknowing, but also unaware of their lack of knowledge, which can lead to overconfidence (Kruger & Dunning, 1999). Likewise, students providing NNB answers to fraction tasks have been found to be unaware of their misconception (e.g., González-Forte et al., 2023) and to show significant lower fraction state anxiety compared to other low performers (Halme et al., 2024). The present study shows that when students with a NNB (partly) overcame their misconception, they showed a significant increase in their fraction state anxiety. Thus, once they became aware that they were doing something wrong (for example by negative learning experiences (low grades) due to the misconception, their anxiety towards the task increased. This finding has the important recommendation for education that teachers should be aware of the possible increase of anxiety when students are in the process of conceptual change, given that mathematics anxiety can be detrimental for students further mathematical development (e.g., Dowker et al., 2016; Namkung et al., 2019). The literature provides several approaches to cope with mathematics anxiety in the classroom, such as increasing students' mathematical skills, mindfulness, self-regulation skills, etc. (for an overview, see Balt et al., 2022). However, importantly, it should be noted that an increase of state anxiety in the process of conceptual change can also be seen as a positive sign that students are learning and are becoming aware of their misconception and actual level of knowledge (Merenluoto & Lehtinen, 2004).

Indeed, an incorrect answer combined with *low* state anxiety can point towards a misconception of which students are not aware. Whereas the combination of an incorrect answer with *high* state anxiety can point towards students' being aware that they do not know how to solve this task. Consequently, the present study suggests that state anxiety could be a useful measure for examining the process of conceptual change and students' (un)awareness of their misconception. Given that trait mathematics anxiety is more general and stable over time, it may not capture the task specific changes in situational anxiety as well as state mathematics anxiety does (Halme et al., 2024; Trezise & Reeve, 2018).

This study further shows that even after six months of instruction in the crucial years of fraction arithmetic instruction, more than one-fifth of the students with a clear NNB profile showed no development in their measured fraction arithmetic understanding at all, and still answered using the same natural number based responses at the second measurement point. This confirms previous research in the domain of conceptual change that overcoming a misconception is a long process and students' misconceptions can be stubborn. One effective way to address misconceptions is refutational texts (see for example Christou & Prokopou, 2020). It should be noted that the natural number bias is only one of the possible sources for students' struggle doing arithmetic with fractions. There might also be other, curricular reasons, next to introducing natural numbers before fractions. In our sample, the students were first taught about doing subtraction and addition of fractions with same denominators and only in the next school year they were taught about fractions with different denominators. When instruction first focuses on the procedure of adding numerators and only afterwards introducing fraction problems that require finding a common denominator, this might strengthen the misconception that natural number reasoning can also be used with fractions. This can also be seen in other curricula, for instance in a German context, where students are found to overgeneralize fraction multiplication procedures to fraction addition tasks (Eichelmann et al., 2012).

Next, the present study corroborates the findings of the study by Halme and colleagues (2022), who showed that performance and state anxiety relations with fraction arithmetic tasks appear to be an anomaly. Also in the present study no significant correlation was found between fraction performance and fraction state anxiety at Time Point 1. However, a significant negative correlation emerged at Time Point 2, which is in line with findings from previous research in other areas of the mathematics curriculum (e.g., Namkung et al., 2019). One possible explanation is that the reduced presence of NNB at Time Point 2 may have decreased its confounding effect on the relationship between fraction performance and fraction state anxiety. As a result, the expected negative correlation — consistent with earlier studies — could be found.

Furthermore, the results of the present study seem to be in line with the results of the cross-sectional study (Halme et al., 2024) that state anxiety appears to be affected by students' perceptions of their own performance and task difficulty. The fraction task is likely to be perceived as more difficult, once students understand that fraction arithmetic does not follow the same rules as natural number arithmetic. Furthermore, students' fraction state anxiety levels appear to become more similar across low performers, as the NNB reduces. Thus, it is possible, as suggested above, that the relationship between fraction arithmetic performance and state anxiety is no longer an anomaly after students have overcome their NNB and have a more correct understanding of their performance level. Future studies with larger sample sizes should investigate how state anxiety develops in these students who completely overcome their misconception. Other promising avenues for further research include investigating the development of students' fraction state anxiety in those groups of learners who either (1) started with a NNB profile and showed no signs of conceptual change at all over time and (2) started without any sign of a NNB, but over time showed signs of this natural number based misconception of fraction. In the current study, the second group was underrepresented, while 10 students belonged to the first group—starting with a NNB profile and showing no conceptual change throughout the study period. Descriptive data indicated a further decline in fraction state anxiety among these students, with mean scores dropping from 1.69 to 1.37. This trend aligns with the overall findings of the study and suggests that having a strong naïve misconception over a longer time period can lead to even lower levels of state anxiety. To confirm these findings, future studies should involve larger participant groups.

The current research further shows that it is important to not only measure trait mathematics anxiety when researching anxiety-performance relations, as trait anxiety may not differ between low performers who have qualitative differences in conceptual understanding (Halme et al., 2024). Furthermore, state anxiety is proposed to be a more accurate predictor of mathematics anxiety (Bieg et al., 2015) and shown to capture task-specific characteristics (Trezise & Reeve, 2018). The situational nature of state anxiety makes it also a potential tool for distinguishing the conceptual change, i.e., the process of overcoming a misconception that occurs over time. It should be noted though that similar to the cross-sectional study where not all students with the NNB had high state anxiety, not all students who (partly) overcame their NNB increased in state anxiety. This might be explained by individual differences in other metacognitive processes, such as how one deals with challenges or values learning math (e.g., Di Leo et al., 2019).

Limitations

There were several limitations in the study. First, it was not our aim to make claims about the general developmental relation between fraction performance and fraction state anxiety, but to investigate this relation in a specific subgroup of learners, namely students with a strong NNB. We consider it a strength of the study that it focuses on certain profiles of students; however, this led to a relatively small sample of low performing students, both with and without a clear NNB. Future studies are needed that would replicate our findings to further strengthen our results, conclusions, and recommendations. Second, we only used fraction arithmetic tasks to look at the influential role of overcoming a misconception on the longitudinal development of fraction state anxiety. Ample research showed that fraction arithmetic is only one domain of fractions known to elicit natural number based answers. Therefore, future studies should also include other fraction tasks that may elicit the natural number bias. Moreover, future research should investigate if the result that overcoming a misconception can lead to an increase in state anxiety can be generalized towards other domains of the school curriculum known to elicit misconceptions, such as statistics, physics, history, etc. (e.g., Vosniadou, 2013).

Conclusion

In conclusion, the present study complements previous research by showing that a clear misconception, such as the natural number bias, might influence the development of students' fraction state anxiety. While previous research concludes that an improved topic-specific understanding is typically related to lower anxiety, the results of the present study show that in a specific group of students, namely students with a misconception, the opposite can occur. In fact, in students with a clear misconception, coming to a better understanding went hand in hand with an increase in state anxiety. The study highlights the importance of looking at various subgroups of students, as different developmental patterns were found within qualitatively different groups of students.

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Data Availability: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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