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Math mindsets in elementary school students: testing two conceptualizations of mindsets and their links with achievement and self-concept

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Abstract

Math mindsets are mathematical abilities beliefs that can take two forms: *growth* (i.e., abilities can develop) and *fixed* (i.e., abilities are innate). Math mindsets during elementary school received little attention, especially among younger students. This study examined math mindsets and tested a mediation model in which math achievement predicted math mindsets via math self-concept. Elementary students ($N=220$) from grades 1–6 completed a questionnaire in class. Results showed that growth and fixed math mindsets can be measured and distinguished in younger students, younger students endorsed growth math mindset more strongly than older students, and girls endorsed it more strongly than boys. Structural equation modeling showed that math achievement positively and directly link on both dimensions of math self-concept (affect and competency), and that affect directly link to a stronger adoption of a growth math mindset while competency negatively and directly link on growth and fixed math mindsets. Findings have important implications for mindset theory and interventions.

Keywords Mindset · Self-concept · Math · Achievement · Elementary school

Introduction

Mathematics is an important school subject, allowing students to acquire basic knowledge, which is fundamental to their math progress in subsequent school levels (Träff et al., 2020). While external factors like socioeconomic and sociodemographic variables (e.g., parental income), the school environment (e.g., safe environment), and students' teacher (i.e., teaching method; Crocker, 2012) support math success, their contribution is distal. More proximal predictors of math success include student internal factors (e.g., logical reasoning; Träff et al., 2020), psychological factors (e.g., attitudes toward school; Crocker, 2012), and their beliefs and perceptions about themselves in general and in math (Marsh & Craven, 2006). Since math beliefs and perceived math abilities are more directly linked to learning and achievement in math (Costa & Faria, 2018; Marsh & Craven, 2006), this study focuses on a specific type of belief, namely math mindsets.

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Math mindsets

Students' mindsets refer to their representations of humans' abilities, which are vast, and that can be developed toward their personality or intelligence (Dweck & Yeager, 2019). Intelligence mindset can be general or specific to a domain, like math or literacy, and it manifests as an implicit theory of an ability that can take two forms (Gunderson et al., 2017). *Growth mindset* is the belief that abilities can develop (Dweck & Yeager, 2019). Students with this mindset view persistence in the face of difficulties as essential to developing abilities and failure as a lack of effort (Dweck & Yeager, 2019). In contrast, *fixed mindset* is the belief that abilities are innate and stable (Dweck, 1999). Students with this mindset focus on validating their ability level and looking smart (Dweck, 1999). As a result, they tend to avoid difficult tasks, and view effort as indicative of low ability

(Dweck, 1999). Growth and fixed mindsets thus are important in learning situations by shaping students' perceptions of effort and performance (Dweck & Yeager, 2019).

Conceptualizing mindsets

Although there are two mindsets (Dweck, 1999), their conceptualization can differ from their operationalization (Lüftenegger & Chen, 2017). One perspective conceptualizes the two mindsets as opposite poles on a continuum (i.e., bipolar construct) where students endorsed either a growth or fixed mindset for a same attribute (i.e., strongly endorsing a growth mindset entails weakly endorsing a fixed mindset; Dweck et al., 1995). Consequently, one only needs to assess one type of mindset as the other is represented by low endorsement of the targeted mindset (Dweck et al., 1995). Another strategy, yielding similar results, is to use items measuring both mindsets and creating a score for one mindset (e.g., growth) with their items and reversed items for the other mindset (e.g., fixed; Lüftenegger & Chen, 2017).

The second perspective conceptualizes mindsets as two distinct constructs (Lüftenegger & Chen, 2017). Measuring each mindset separately (i.e., items assessing each are averaged into separate scores), studies found these two constructs to be distinguishable, and that one could endorse both mindsets simultaneously (Lüftenegger & Chen, 2017). From this perspective, some studies with children found growth and fixed intelligence mindsets to be moderately and negatively related (Kinlaw & Kurtz-Costes, 2007). Linking the two mindsets with achievement, research found no association with fixed math mindset and a weak and positive association with growth math mindset among adolescents (Costa & Faria, 2018; Cury et al., 2006). Hence, using a multidimensional perspective on mindsets, which requires measuring fixed and growth mindsets separately, was deemed optimal (Lüftenegger & Chen, 2017).

Mindsets and gender

Dweck (1999) suggested that girls who get high grades perceived their failures as a lack of abilities and endorsed a fixed mindset while high-achieving boys tend to adopt a growth mindset. Empirical support for the gender-specific endorsement of mindsets yielded contradictory results. While a recent meta-analysis showed that gender did not influence the relation between mindsets and achievement (Costa & Faria, 2018), some studies found boys to endorse a growth mindset more strongly toward intelligence than girls at the same elementary school level (Levine & Pantoja, 2021), although no gender differences were found on fixed mindset (Kinlaw & Kurtz-Costes, 2007). Given these divergent results, we might expect girls and boys to endorse mindsets in a similar fashion.

Children's mindsets

Throughout elementary school, children develop their specific mindsets according to school domains (Dweck, 2002). Hence, specific mindsets develop as students receive and use information from their environment (e.g., school evaluation). With school experience, they begin using their mindsets to explain their achievement (Dweck, 2002), and consequently, their mindsets start having consequences for their behaviours (e.g., having a fixed mindset leads to avoid difficult tasks; Dweck, 2002).

Generally, studies on students' mindsets focused on the end of elementary school or later. Few studies considered early elementary school years and even fewer on math (Park et al., 2016b). Results with children suggest variations through schooling years in their endorsement of mindsets about intelligence or math abilities as well as in the predominance of one mindset over the other. Some found no difference on intelligence mindsets across elementary school years (Kinlaw & Kurtz-Costes, 2007). In contrast, others showed that mindsets were differently endorsed across school levels (e.g., Levine & Pantoja, 2021). In math, growth mindset was more strongly endorsed by older students (i.e., grades 5 and 6) than by younger ones (i.e., grades 1 and 2; Gunderson et al., 2017). These contradictory results make predicting the prevalence of each math mindset across elementary school years difficult.

Mindsets and math achievement

A meta-analysis addressing math mindsets found a small positive association between growth math mindset and math achievement (Costa & Faria, 2018). Unfortunately, there were not enough studies evaluating the links between fixed math mindset and math achievement (Costa & Faria, 2018). Using a longitudinal survey design, Park et al. (2016b) found the relation between intelligence mindsets and math achievement to be reciprocal in elementary school: high achievement predicted a stronger growth mindset while low achievement predicted a stronger fixed mindset (and vice versa). Based on these studies, we might expect growth math mindset to be positively related to math achievement.

Linking math mindsets and self-concept

Math mindsets are distinct from students' perceptions about how they succeed in math, referred to as their self-concept (Marsh & Craven, 2006), although both are important for school success (Dweck & Yeager, 2019; Marsh & Craven, 2006). Academic self-concept (ASC) refers to students' perceptions and evaluation of themselves in the academic domain (Marsh & Craven, 2006). Math self-concept (MSC) refers to perceptions and evaluation of one's abilities in math (Marsh & Craven, 2006). MSC is associated with positive behaviours like effort and its relation to math achievement was found to be reciprocal and positive (Marsh & Craven, 2006).

While MSC was initially proposed as a unidimensional construct (Marsh & Craven, 2006), studies supported its bidimensionality (Marsh et al., 1999). Two underlying components of MSC were identified among elementary students (Marsh & Ayotte, 2003): math *competency* (i.e., students perceived math competence) and *affect* (i.e., affective reactions to math; Marsh et al., 1999). These two dimensions are strongly and positively correlated, yet nonredundant (Marsh et al., 1999). Despite their strong relation, competency and affect were differently related to academic variables (Marsh & Ayotte, 2003). Math competency was more strongly correlated with math achievement than was math affect, which was more strongly correlated with students' efforts in math (Pinxten et al., 2014).

Mindsets determine the basis on which students perceive their abilities, which are associated with their ASC (Dweck & Molden, 2017). Moreover, some studies found that mindsets were not only predictors of education outcomes but also that their level of endorsement could vary among students depending on their achievement level or their self-perception such as ASC (Gonida et al., 2006; Park et al., 2016b). However, while mindsets could be influenced by different factors, these relations have been understudied (Limeri et al., 2020). The relationship between math mindsets and MSC has been understudied and yielded divergent results. Some studies found mindsets and MSC to be unrelated to adolescent samples (Cury et al., 2006). Using a bipolar conceptualization, others found a growth mindset and MSC to be positively related to samples of elementary students (Lee et al., 2021).

According to Dweck (1999), mindsets are a predictor of important achievement outcomes and several studies have tested their predicting role. However, other researchers have suggested that the relation between mindsets and these variables is bidirectional (Limeri et al., 2020). Using a longitudinal design, Gonida et al. (2006) assessed the bidirectional relations between intelligence mindsets, ASC, and school achievement among older elementary students. While not specific to math, their results supported a developmental sequence during the last two years of elementary school where achievement predicted ASC (assessed as a unidimensional construct), which in turn predicted mindsets (using a bipolar conceptualization). This *achievement → ASC → mindset* sequence offers a potent basis for predictions in the math domain. They also found ASC to be a mediator, where achievement predicted growth mindset directly and indirectly via ASC. Replicating this mediation model in math, while considering the bidimensionality of MSC and mindsets, will offer valuable information on student functioning in this vital school subject. In addition, considering students throughout the elementary school years will be important to measure these concepts since this period is fundamental for establishing the basis of their math path (Träff et al., 2020). On the other hand, methodological considerations regarding questionnaire measurement with children need to be addressed to ensure the quality of mindsets measures.

Measurement issues with children

Children can provide information about themselves (Borgers et al., 2000) and one method to gather this information is the questionnaire (Borgers et al., 2000). Especially useful with large samples, children's questionnaires must be adapted to their age group and several considerations must be applied to ensure data quality (Borgers et al., 2000). School-aged children's understanding of questions depends on their cognitive development – reading comprehension – leading to use simple words, personalized formulations (i.e., use "I"), and avoid negative and abstract formulations (Borgers et al., 2000). Children's working memory is also more limited than that of adolescents, and interpreting information is harder and takes more time for them (Borgers et al., 2000). It is thus preferable to use short questionnaires and sentences, to supplement these with visual aids (e.g., illustrations), and to offer few response options (e.g., 4-point rather than 7-point scales; Borgers et al., 2000, 2004). It is also crucial to pretest questionnaires to ensure they are adapted to children (Borgers et al., 2000).

Links between math achievement, mindsets and MSC

Overall, past research highlights several key findings regarding the links between math achievement, math growth and fixed mindsets, and MSC (i.e., math competency and affect). First, for affect and competency components of MSC, studies showed that math achievement was positively and directly linked to math affect among elementary students (Lohbeck, 2019; Pinxten et al., 2014). For math competency, studies showed that math achievement was strongly, positively, and directly link to math competency (Lohbeck, 2019; Pinxten et al., 2014). The relationship between math achievement and math competency was stronger than that between math achievement and math affect and this was supported by studies among elementary students (Lohbeck, 2019; Pinxten et al., 2014). In light of these findings, our first hypothesis (H1) was that math achievement would be directly and positively linked to math competency and that this link would be stronger than that between math achievement and math affect.

Second, for mindsets, results of a meta-analysis with older students (i.e., middle school, high school, and college) showed that growth mindset was more strongly associated with math achievement when mindset was about math rather than intelligence (Costa & Faria, 2018). For fixed mindset, there were not enough studies that tested the association between fixed math mindset and math achievement to make clear conclusions (Costa & Faria, 2018). However, intelligence fixed mindset was negatively associated with math achievement among elementary students (Park et al., 2016b). Although, mindsets may be specific to math, few studies specifically evaluated mindsets in math among elementary students, and even fewer linked them with math achievement (Levine & Pantoja, 2021). Thus, based on these past findings, our second hypothesis (H2a) was that math achievement and math growth mindset would be positively and directly linked in a sample of elementary students. For fixed math mindset, based on the negative link previously obtained between fixed mindset for intelligence and math achievement, we hypothesized (H2b) that math achievement and fixed math mindset would be negatively and directly linked among elementary students.

Third, regarding a mediation model, one study examined the mediating role of math affect and math competency separately in the relation between math achievement and self-perception of effort (Lohbeck, 2019). This study showed distinct mediating role for math affect and math competency where math competency had a positively and stronger mediating role than did math affect (Lohbeck, 2019). To our knowledge, no studies tested the mediator role of math affect and math competency in the relation between math achievement and math mindsets. It is therefore difficult to formulate a specific hypothesis. We nevertheless rely on Lohbeck's (2019) study that regarding the mediating role of math competency and math affect in math achievement and self-perception effort relation to propose a third hypothesis (H3). Specifically, we expected that the mediating role of math competency and math affect would be different on the relations between math achievement and math growth mindset relation and between math achievement and math fixed mindset.

The present study

This study aimed to better document math mindsets among school-aged children and their link with MSC and math achievement across elementary school. A first objective was to measure fixed and growth math mindsets and contrast bipolar and bidimensional conceptualizations with students in all elementary school years. Math mindsets were sometimes found to be unidimensional (e.g., in older elementary students; Lee et al., 2021) and, at other times, to be bidimensional (e.g., in adolescents; Cury et al., 2006). Yet, few studies formally tested mindsets' conceptualization to ensure it fitted their data well (Tempelaar et al., 2015). Conceptualizing mindsets without empirically testing whether it is supported leading to inadequately assess relationships with mindsets and other variables (e.g., educational outcomes; Tempelaar et al., 2015). Another issue is that some of the scales used to assess mindsets in younger samples did not follow the guidelines for adapting scales to children's cognitive development when using elementary students samples (e.g., depersonalized formulation by referring to a student in general and not to the child themself). In line with the suggestions of Lüftenegger and Chen (2017) and of Tempelaar et al. (2015) that mindsets' conceptualization needs to be assessed, our first goal was exploratory. Indeed, as we could not formulate specific hypotheses as to which of the conceptualizations would prevail among elementary students from all school years since no study examined the measurement of math mindsets in elementary students. Also, according to the study results, there was no difference in endorsement of a growth mindset of intelligence for students in Grade 2 (i.e., first cycle) and Grade 4 (i.e., second cycle) or of a fixed intelligence mindset (Kinlaw & Kurtz-Costes, 2007). But, in math, students in Grades 5 and 6 (i.e., third cycle) endorsed a growth math mindset more strongly than students in Grades 1 and 2 (i.e., first cycle). To our knowledge, no studies have tested the difference in endorsement of math growth and fixed mindsets between students in each of the three cycles of elementary school.

In the literature, mindsets were measured toward intelligence or toward a specific domain (Costa & Faria, 2018) and both specific (e.g., math) and general (e.g., intelligence) measures of mindsets have been linked to outcomes in specific contexts (e.g., math achievement). Yet, it was shown that the relation between success in math and mindsets was stronger when mindsets were measured specifically toward math than toward intelligence (Costa & Faria, 2018). In addition, studies found that MSC plays a role in the relation between math achievement and math growth mindset among children (Lee et al., 2021). Therefore, the second objective was to replicate Gonida et al.'s (2006) mediation model (1) in the context of math, (2) while considering the bidimensionality of mindsets and MSC, and (3) among students from all elementary school years (see Fig. 1). As mentioned previously, we hypothesized (H1) that students' math achievement would be positively and directly linked with each dimension of their MSC. We also hypothesized (H4) that both dimensions of the MSC would have a direct

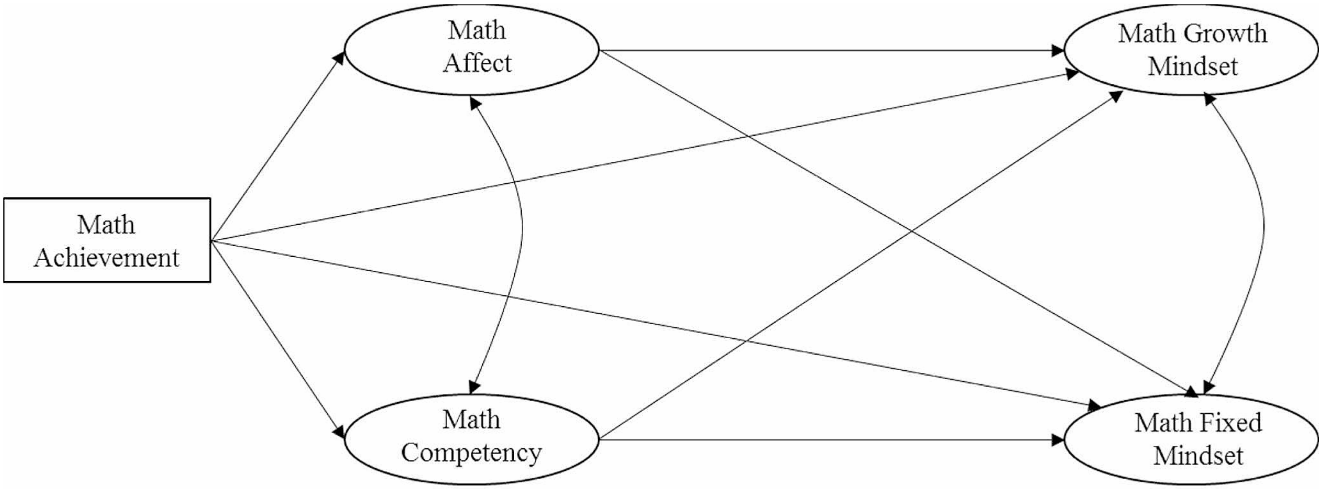

Fig. 1 Proposed model

and strong link on math growth mindset and a weaker direct link on fixed math mindset. Also, since math affect has been strongly correlated with students' effort (Pinxten et al., 2014), we expected affect to be more strongly directly linked with math mindsets than competency, which should positively be directly linked with a growth mindset and negatively be directly linked with a fixed mindset. The contribution of gender and school level was controlled for given their relations with mindsets, achievement, and MSC (Marsh et al., 1999; Park et al., 2016b).

Method

Participants and procedure

Participants ($N=220$; 53% girls) were elementary students (public [$N=3$] or private [$N=1$]) in [masked for review]. In the education system, elementary school levels consist of six grades, grouped into three two-year cycles. Students have two years to develop specific academic competencies before passing on to the next cycle. Here, participants were in first ($N=84$; M_{age} = 6.97 years, $SD=0.74$), second ($N=53$; M_{age} = 9.19 years, $SD=0.71$), or third ($N=83$; M_{age} = 11.27 years, $SD=0.63$) cycles. According to the Socio-Economic Environment Index calculated by the Ministry of Education, students from the three public schools of the sample are considered as coming from a privileged background. Most students in the sample came from intact families (i.e., living with both biological parents; 79%) and spoke [masked for review] at home (98%). The average annual family income was $100,000 [masked for review] and more – which is higher than the average family income in the province ($59,822 [masked for review]) at the time of data collection – and most of the participants' mother obtained at least a high school diploma (72%). Over half of the participants (57%) were the eldest in their family, the majority never repeated a grade (97%), and few received educational support services in school (e.g., psychologists; 18%).

The study was approved by Research Ethics Committee of [masked for review]. Students were grouped into 29 classrooms and followed the general education program. Participants individually completed a paper questionnaire in class during the third school term (the academic year is composed of three terms lasting about three months each). Teachers were present for classroom management purposes but did not participate in the administration of the questionnaire, which was handled by the researcher and assistants, nor did they have access to students' questionnaires. The researcher informed students that their answers were personal, confidential, and that they would have no influence on their school record. For visual support, a copy of the questionnaire was projected on a screen. Also, verbal explanations and examples were given to help children understand how to respond using the scale. Each item was read to students once and again if needed. Parents and students gave their consent prior to participation, where parental consent was obtained electronically through an email sent by schools. This email included a link to an online questionnaire containing questions regarding their child and themselves.

Measures

Math mindsets

Da Fonseca et al.'s (2007) scale was adapted to measure student fixed and growth math mindsets, following recommendations for measuring mindsets (e.g., separately measuring fixed and growth mindsets; Lüftenegger & Chen, 2017) and for using measurement scales with children (Borgers et al., 2000). Hence, wording for six items (3 per mindset) was reformulated at the first person ("I" or "me") and used simpler words (e.g., "To be smart, you have to learn a lot" became "I have to learn a lot to be good at math"; see Supplementary Information for the complete scale). Rather than using a 7-point scale, participants indicated the extent to which each item represented their beliefs using a 4-point Likert scale ranging from 3 (*yes/much*) to 0 (*no/not at all*). To facilitate participants' understanding of the Likert scale, a colour code was used where the higher score 3 was in a green circle, 2 was in a yellow circle, 1 was in an orange circle, and 0 was in a red circle. Prior to conducting the study, this adapted scale was pretested with seven students, who were in first ($N=3$), second ($N=2$), and third ($N=2$) cycles of elementary education. They provided feedback on vocabulary and the use of a 4-point Likert scale with colour codes.

Math self-concept

Students' MSC was assessed with the math subscale of the [*masked for review*] version (Marsh & Ayotte, 2003) of the Self-Description Questionnaire I (SDQ-I; Marsh, 1988). While this 10-item scale is intended to be unidimensional, factor analyses supported a two-factor structure (see Supplementary Information), in line with Marsh et al. (1999) who revealed a first factor reflecting students *affect* toward math ("I am interested by math") and a second representing students' perceived math *competency* ("Work in math is easy for me"). Each dimension was measured by five items, scored using the 4-point Likert scale with colour codes described above. Students indicated the extent to which each item applied to them from 3 (*true*; green circle) to 0 (*false*; red circle).

Math achievement

Students' grade in math in the second school term was provided by the questionnaire that parents completed before student participation. In anticipation of low parental participation, teachers also reported students' grades in math at the end of the school year.

Sociodemographic information

Students answered questions about their age, gender, and school year. Parents provided information about their child's family environment (e.g., number of siblings) and school track (e.g., whether they repeated a grade).

Statistical analyses

Model estimation

Models were tested with structural equation modeling (SEM) using Mplus (version 8.5; Muthén & Muthén, 1998–2019) under robust estimation (MLR), which is robust to the non-normality of data, the Likert nature of items, and the interdependence of observations (i.e., students nested within classes). Fixed effects models (FEMs) was used for students nested within classes, which is an alternative to the cluster option with few clusters (<50) found under MLR to be problematic for several estimates such as convergence and variances (Hox et al., 2014; McNeish & Kelley, 2019). FEMs considers cluster data by integrating them as predictors in the model (McNeish & Kelley, 2019). Adequacy of model fit was evaluated using the Comparative Fit Index (CFI; Bentler, 1990), the Turker-Lewis Index (TLI; Bentler & Bonett, 1980), and the root mean square error of approximation (RMSEA). Values above 0.90 for CFI and TLI and below 0.08 for RMSEA represent acceptable model fit while values above 0.95 for CFI and TLI and below 0.05 for RMSEA indicate excellent model fit (Marsh et al., 2005).

Missing data

The full information maximum likelihood (FIML) estimation method allowed dealing with missing data (Kline, 2016). In the present study, the highest proportion of missing data was for math grades provided by parents (13%). Hence, math grades provided by teachers at the end of the school year were used as an auxiliary variable to improving the estimation of missing data (Asparouhov & Muthén, 2008).

Measurement models

Measurement models tested whether the items adequately measured their respective constructs. Several measurement models were estimated to test measurement adequacy of mindsets and MSC and to identify whether factors were unidimensional or multidimensional. To determine if mindsets was a bipolar or bidimensional construct, measurement models were first estimated for fixed and growth mindsets and tested if (1) mindsets in math represent one factor where growth and fixed are opposite poles on a continuum (reversing items for one of the mindsets and have all items load on a same factor) or (2) if mindsets were multidimensional where two distinct factors, growth and fixed mindsets, can be measured separately. Measurement models were also estimated for MSC. Given that these constructs can both be conceptualized as bidimensional, measurement models were carried with confirmatory factor analysis (CFA) and exploratory structural equation modeling (ESEM; Marsh et al., 2014). A detailed description of CFA and ESEM measurement models can be found in the Supplementary Information.

Factor scores

Factor scores represent an individual's score on a latent factor if this factor was directly measured (Tabachnick & Fidell, 2018). They are obtained from factor estimation in CFA or ESEM measurement models and are standardized ($M = 0$, $SD = 1$; Tabachnick & Fidell, 2018). They allow using the results from measurement models to represent latent constructs in other types of analyses (e.g., path model; Tabachnick & Fidell, 2018). Advantages of using factor scores include (1) increasing the validity of the latent factor, (2) estimating a factor while considering the weight of each item (vs. observed means where each item has the same weight on the mean; Tabachnick & Fidell, 2018), (3) partially controlling the psychometric quality of scales, and (4) increase the statistical power, which is affected by small sample sizes. In Mplus, factor scores are estimated with the maximum of the posterior distribution of the factor, which is like the multiple regression method (Muthén & Muthén, 1998–2019).

Factor scores were used for testing differences on mindsets across school cycles and student gender. Given the size of the sample, conducting multiple-group analysis in SEM would have been problematic (Kline, 2016). Furthermore, multiple-group analyses in SEM need to first test the invariance of the measurement model across groups, which was not possible with such a small sample (Marsh et al., 2014). Factor scores obtained with Mplus using oblique rotation were thus used for comparing student mindsets and self-concept as a function of gender and cycles using multivariate analysis of variance (MANOVA) in SPSS.

Mediation model

The proposed *achievement* → *MSC* → *mindsets* model was tested within Mplus. It contained one exogenous variable (math achievement) and endogenous factors (MSC, math mindsets). The adequacy of model fit was based on the fit indices identified above. With a cross-sectional design, we cannot test causal effects, we can only presume causal effects (Kline, 2023). To test the mediating role of MSC in the achievement → mindset relation, presumed indirect effects were tested where math achievement was presumed to predict mindsets via MSC dimensions (mediators). The bootstrap resampling method was used to estimate presumed indirect effects (Preacher & Hayes, 2008). It calculated confidence intervals (CI) for presumed indirect effects and a presumed indirect effect is considered statistically significant if zero is excluded from its CI (Preacher & Hayes, 2008). Here, 1000 resampling were used. The bootstrap resampling method was robust to the non-normality of data and it did not need a statistically significant presumed direct effect to interpret presumed indirect effects (Preacher & Hayes, 2008).

Interpretation of results

Relying on *new statistics* (Cumming & Calin-Jageman, 2017), the results are interpreted based on effect size estimates (e.g., η^2, β, R^2) and confidence intervals rather than relying on results of null hypothesis significance testing (i.e., *p* values). The results for mean comparisons are interpreted with partial eta squared (η^2), which estimates the proportion of variance in a variable (e.g., fixed mindset) explained by group variables (e.g., gender), and with confidence intervals (CI) for group means (i.e., whether they overlap or not). The 95% CI were also used for interpreting the mediation model. Results of regression models are interpreted with effect sizes of regression coefficients ($\beta \geq 0.10$) and R^2 (i.e., proportion of variance in an endogenous factor explained by its predictors).

Results

Preliminary analyses

Data screening identified two univariate outliers ($z < -3.00$; Kline, 2016). Because no mean difference was obtained with or without these outlying cases (Cohen's $d = 0.04$), they were kept in the sample. Data met the multivariate normality statistical assumption, but not the independence assumption since students were nested into classes, which are nested into schools. The analyses controlled for this interdependence by using FEMs in Mplus while the robust estimator (MLR) adjusted for possible deviations from normality.

Measurement models

Several models were estimated for math mindsets using ESEM and CFA. Tested models were: ESEM with two factors (growth and fixed mindsets; Model 1), CFA with two factors (Model 2), and one-factor CFA in which items for fixed mindset were reversed (Model 3). Results for Models 2 and 3 revealed a poor fit to the data (see Table 1). Model 1 (two-factor ESEM) presented an excellent fit for the data and factor loadings were all satisfying (λs > 0.32; Tabachnick &

Table 1 Goodness-of-fit statistics for all models

Models	χ^2	df	CFI	TLI	RMSEA	90% CI	*N*
Measurement Models for Mindset							
Model 1: ESEM 2 factors	9.11	(8)	0.99	0.97	0.03	[0.00, 0.09]	220
Model 2: CFA 2 factors	35.16*	(13)	0.79	0.67	0.09	[0.05, 0.12]	220
Model 3: CFA 1 factor	43.51*	(14)	0.72	0.59	0.10	[0.07, 0.13]	220
Model 4: ESEM 2 factors (3 items for growth and 2 items for fixed)	7.44	(4)	0.97	0.88	0.06	[0.00, 0.13]	220
Measurement Models for Self-Concept							
Model 5: CFA 2 factors	79.85*	(42)	0.97	0.95	0.06	[0.04, 0.09]	220
Model 6: ESEM 2 factors	66.46*	(34)	0.97	0.95	0.07	[0.04, 0.09]	220
Measurement Models Including All Variables							
Model 7: ESEM for Mindsets and CFA for Self-Concept (with control variables and achievement)	215.25*	(142)	0.95	0.94	0.05	[0.03, 0.06]	245
Proposed Model							
Model 8: without control variables	190.36*	(118)	0.95	0.94	0.05	[0.04, 0.06]	245
Model 9: with control variables	215.25*	(142)	0.95	0.94	0.05	[0.03, 0.06]	245
Mediation Model							
Model 10: with all items	249.84*	(145)	0.94	0.92	0.05	[0.04, 0.07]	245
Model 11: without item problematic	209.30*	(125)	0.95	0.94	0.05	[0.04, 0.07]	245

Control variables were school cycle and gender

χ^2 Robust chi-square test of exact fit, *df* degrees of freedom, *CFI* Comparative Fit Index, *TLI* Tucker-Lewis Index, *RMSEA* root-mean-square error of approximation, *90% CI* 90% confidence interval of the RMSEA

*$p < .05$

Table 2 Factor Loadings from the Measurement Model of Mindsets in Math (ESEM) and Dimensions of Math Self-Concept (CFA), math achievement, gender and school cycle ($N = 245$)

Items	Factor Loadings			
	1	2	3	4
Factor 1: Math Growth Mindset				
Math Growth 1	0.71	0.00		
Math Growth 2	0.68	0.03		
Math Growth 3	0.57	−0.37		
Factor 2: Math Fixed Mindset				
Math Fixed 1	−0.25	0.43		
Math Fixed 2	0.04	−0.08		
Math Fixed 3	0.10	0.62		
Factor 3: Math Self-Concept – Affect				
Math Affect 1			0.71	
Math Affect 2			0.91	
Math Affect 3			0.86	
Math Affect 4			0.90	
Math Affect 5			0.92	
Factor 4: Math Self-Concept – Competency				
Math Competency 1				0.71
Math Competency 2				0.76
Math Competency 3				0.75
Math Competency 4				0.84
Math Competency 5				0.64
ω	0.69	0.28	0.93	0.86

ω McDonald's omega

Fidell, 2018) except for one item (see Table 2). The results supported a multidimensional conceptualization of mindset, assessed by two distinct factors – growth and fixed mindsets. Since one item for fixed mindset had a small factor loading and correlated weakly with other items (rs = −0.01 and 0.04), a fourth model was estimated without this item (Model 4). This brought the TLI value under an acceptable threshold and penalized the RMSEA 95% confidence intervals, extending its upper value (see Table 1). This suggests that Model 1 offers a better fit to the data than Model 4 (Kline, 2016). McDonald's omega coefficient was used to estimate the scale reliability (McDonald, 1970; see Table 2). Results for growth mindset was lower yet close to 0.70, but it was unsatisfying for fixed mindset.

Measurement models for MSC yielded results that were consistent with those of Marsh et al. (1999), where MSC was found to be a multidimensional construct that includes two factors: affect and competency (see Supplementary Information). Bidimensional CFA (Model 5) and ESEM (Model 6) models for MSC offered excellent equally fit for the data, with strong factor loading (λs > 0.50; Tabachnick & Fidell, 2018). The more parsimonious CFA model (Model 5) was therefore retained for subsequent analyses (Marsh et al., 2014). Omega coefficients (ω) for affect and competency were satisfying (see Table 2).

A global measurement model integrating mindsets (ESEM), MSC (CFA), achievement, gender, and cycles was estimated (Model 7) and yielded an excellent fit to the data (see Table 1 and Supplementary Information). It was used as the basis for subsequent analyses and for examining correlations among all constructs (see Table 3). Growth and fixed mindsets were positively and moderately related to each other. Growth mindset was negatively and weakly correlated to math achievement and fixed mindset was negatively and moderately correlated with math achievement. Affect and competency were positively and strongly correlated, and both were positively associated with math achievement. Also, growth mindset was negatively and weakly related to competency but uncorrelated with affect while fixed mindset was negatively and strongly correlated with both affect and competency. Because growth mindset was negatively and moderately correlated with gender and school cycle, these two variables were used as control variables in subsequent analyses.

Group differences on mindsets

A $2\,(\text{gender}) \times 3\,(\text{school cycle})$ MANOVA was conducted on student growth and fixed mindsets using factor scores derived from the measurement model – data screening identified one multivariate outlier which was deleted because this produced mean difference (Cohen's $d > 1$; Tabachnick & Fidell, 2018). Results indicated that mindsets differed across cycles Wilk's $\lambda = 0.81$; partial $\eta^2 = 0.10$; F (4, 424) = 11.99, $p < .01$ and gender Wilk's $\lambda = 0.83$; partial $\eta^2 = 0.17$; F (2, 212) = 21.34, $p < .01$ but not as a function of their interaction Wilk's $\lambda = 0.98$; partial $\eta^2 = 0.01$; F (4, 424) = 1.34, $p > .05$. Results of these group differences are presented in Fig. 2 and Supplementary Information.

Main effects of school cycle revealed that growth mindset substantially decreased as students progressed through elementary school cycles, where 95% CI did not overlap (see Fig. 3). No differences were, however, found on fixed mindset. Students in the 1st cycle endorsed both mindsets at a similar level but as we move up elementary school cycles, students' growth mindset declined and fixed mindset remained stable and stronger than growth mindset. School cycle explained proportions of variance (see Supplementary Information) that were large for growth mindset, and small for fixed mindset. For the main effect of gender, results revealed that growth mindset was more strongly endorsed by girls than boys, as revealed by the non-overlapping 95% CI (see Fig. 3). For girls and boys, fixed mindset was more strongly endorsed than growth mindset, where 95% CI did not overlap. Student gender explained a large amount of variance in growth mindset but not in fixed mindset (see Supplementary Information).

Testing the proposed model

The proposed model was tested and yielded an excellent fit to the data (see Table 1 and Supplementary Information). A second model added cycle and gender as control variables and yielded a similarly excellent fit. A chi-square difference test comparing these two models revealed no substantial difference, $\Delta\chi^2$ (24) = 24.87, $p > .05$. Hence, the model with control variables was retained (see Fig. 3). Results associated with our first hypothesis (H1) indicated that math achievement was strongly, positively, and directly linked to competency and moderately to affect. With respect to H2a, results indicated that math achievement was negatively, weakly, and directly linked to growth mindset, while for H2b, no statistically significant link was obtained with fixed mindset. Math achievement explained a small proportion of variance in affect and a moderate proportion in competency. Contrary to our fourth hypothesis (H4), students' positive affect for math weakly and positively directly linked to growth mindset while competency negatively directly linked on growth (weakly) and fixed (strongly) mindsets. Math achievement and MSC dimensions explained a moderate proportion of variance in growth mindset and a large proportion in fixed mindset. These findings suggest that the higher students' math achievement was, the more they liked math and perceived themselves as competent. While their liking of math slightly increased their adoption of growth mindset, their competency directly linked to a strong rejection of a fixed mindset and weak rejection of growth mindset.

Control variables (not illustrated in Fig. 3 for the sake of parsimony) indicated that boys perceived themselves as more competent than girls in math ($\beta = 0.18$), and girls endorsed more strongly growth mindset than boys ($\beta = -0.32$). Cycles negatively and moderately linked directly

Table 3 Correlations among factors and variables of interest

Variable	1	2	3	4	5	6
1. Math Growth Mindset	-					
2. Math Fixed Mindset	0.30	-				
3. Math Affect	0.07	−0.44*	-			
4. Math Competency	−0.11	−0.83**	0.57**	-		
5. Gender	−0.41**	−0.24	0.02	0.13	-	
6. Math Achievement	−0.07	−0.28*	0.26**	0.45**	−0.05	-
7. School Cycle	−0.39**	−0.11	−0.14*	−0.10	0.26**	−0.15*

Gender is coded 0 for girls and 1 for boys. Correlations are derived from the measurement model with all variables (Model 7)

$N = 245$. *$p < .05$. **$p < .01$

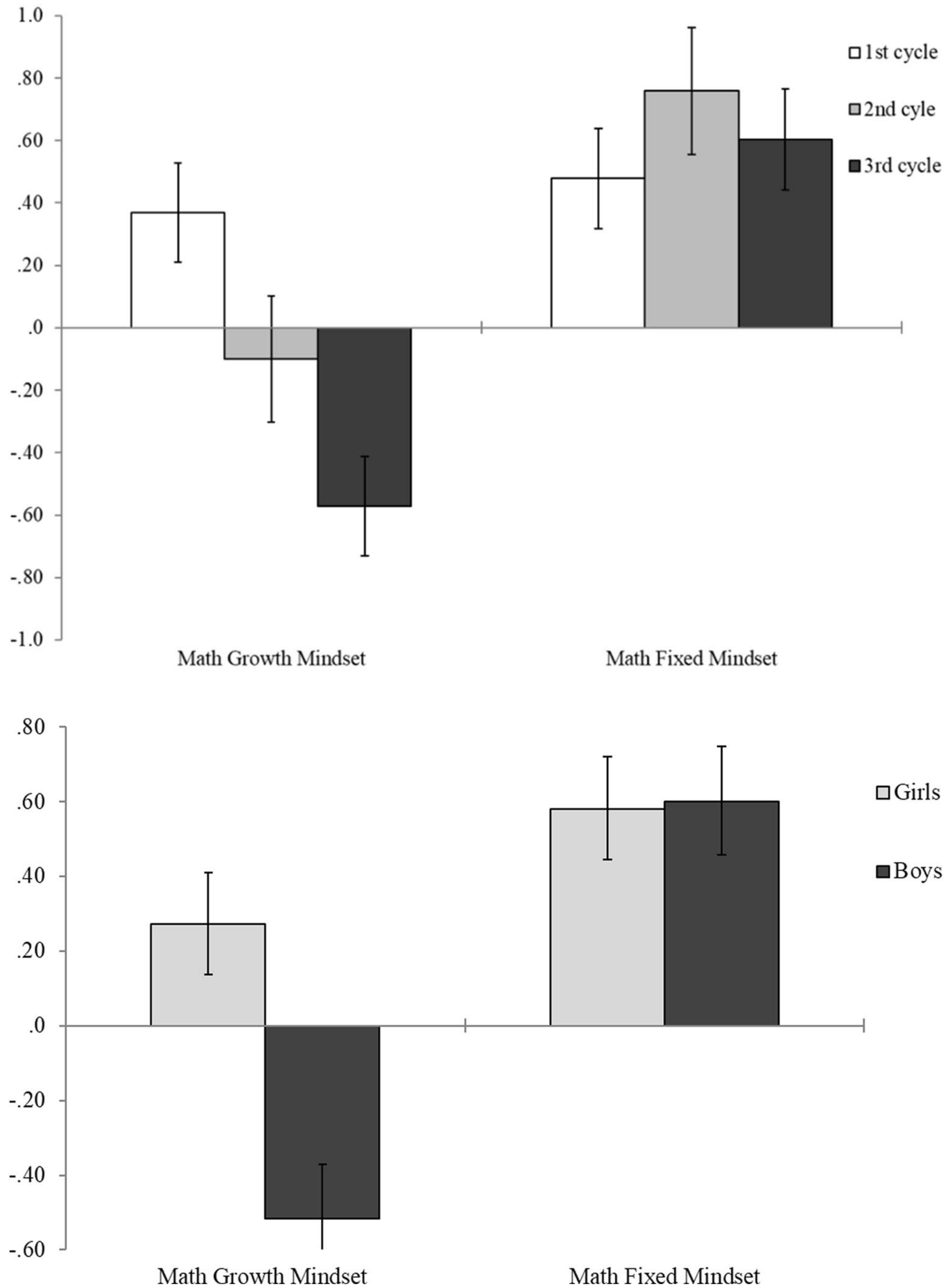

Fig. 2 Average factor scores and 95% confidence intervals for math mindsets by school cycles (top panel) and gender (bottom panel). *Note.* $N = 219$. Factor scores are standardized ($M = 0$, $SD = 1$). Errors bars represent 95% confidence intervals

on growth mindset ($\beta = -0.32$) and weakly and directly linked to fixed mindset ($\beta = -0.16$). Affect and competency components of MSC were positively and strongly correlated, suggesting that the more students liked math, the more they perceived themselves as competent (and vice versa). Growth and fixed mindsets were positively and moderately correlated, which suggests that students could endorse both growth and fixed mindsets, to some extent. Gender and cycles were positively and moderately correlated ($r = .26$), while cycle and math achievement were negatively and weakly associated ($r = -.16$), such that younger students had higher math achievement than students in upper cycles.

Mediation effects

Presumed indirect effects were tested with (Model 10) and without (Model 11) the inclusion of a problematic item for fixed mindset (see Table 1), which revealed substantial differences $\Delta\chi^2$ $(20) = 40.54$, $p < .05$. Hence, Model 11 was retained. The results of the bootstrap resampling method revealed that there was a presumed indirect effect of math

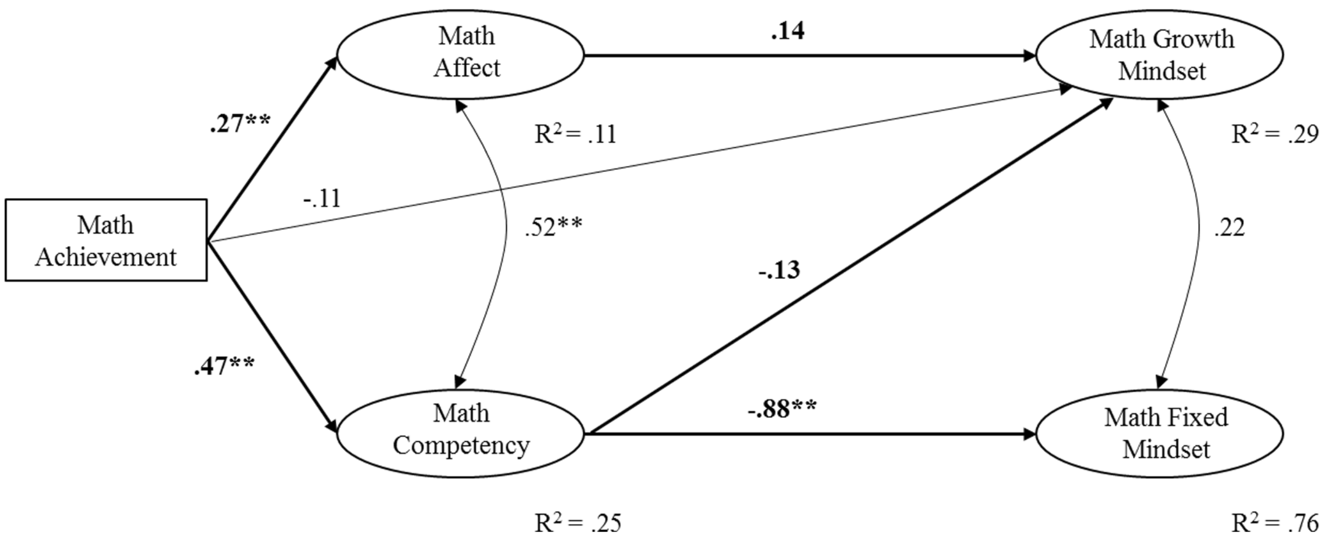

Fig. 3 Obtained model. *Note.* $N = 245$. $*p < .05$. $**p < .01$. Regression coefficients with at least a small effect size or more ($\beta \geq 0.10$) are shown, regardless their p value

achievement on fixed mindset via competency (standardized estimate = −0.40, $p = .00$; 95% CI [-0.65, −0.18]). Results partially supported H3. Indeed, only math competency had a mediating role in the relation between math achievement and fixed mindset. This result suggests that the contribution of math achievement on fixed mindset was possibly mediated by math competency. Hence, high-achieving students would endorse a fixed mindset to a lesser extent in part because they perceived themselves as more competent in math.

Discussion

The first objective of the present study was to assess math mindsets – measuring fixed and growth mindsets – in a sample of students from all elementary school years. The results supported a bidimensional conceptualization of math mindsets in which two distinct dimensions, growth and fixed, could be identified (although one item for fixed mindset was suboptimal). The endorsement of a growth mindset differed across gender and school cycle. The second objective was to test a presumed mediation model where the contribution of students' math achievement on their math mindsets was mediated by MSC – while considering the bidimensionality of mindsets and MSC. H1 was empirically supported as math achievement was positively and directly linked to both MSC dimensions. Contrarily to H2, students with higher math achievement endorsed less a growth mindset and did not significantly endorse a fixed mindset. Results showed that affect positively and directly linked to growth mindset and competency negatively and directly linked on both mindsets. Hence, the stronger students' math achievement was, the more competent they perceived themselves, which lead them to endorse a growth mindset less and to reject a fixed mindset; and the more they enjoyed math, the more they endorsed a growth mindset. These findings have important scientific and applied contributions, which are discussed next.

Scientific implications

A first implication is for mindset theory (Lüftenegger & Chen, 2017). Our findings support a bidimensional conceptualization of math mindsets across elementary school cycles and suggest math mindsets co-exist within the self. Here, students could distinguish both mindsets for math as well as endorse them simultaneously to some degree, in line with previous studies (e.g., Fonseca et al., 2007). Furthermore, our results concur with previous ones showing that each mindset is differently associated with student outcomes, something a bipolar operationalization does not allow (Tempelaar et al., 2015).

Second, our findings demonstrate that measurement scales can be used to assess fixed and growth math mindsets among elementary students from all cycles with adapted scale for children (Borgers et al., 2000). As found in other studies with children (e.g., Gunderson et al., 2017), the reliability of the growth mindset subscale was close to be satisfactory. It was not for the fixed mindset subscale, which might be explained by fixed items being difficult to understand for children. The process of answering items require cognitive function that is still in development among children (Borgers et al., 2004). Then, having problematic items for child versions on a scale can substantially decline its reliability (Borgers et al., 2004). It will thus be important that future studies on math mindsets continue working on improving the psychometric qualities of this questionnaire in samples of young students, particularly for fixed mindset.

A third implication is for literature on mindsets and its link with achievement and MSC. Our results replicated those of other studies showing that math achievement had a stronger direct link with math competency than with math affect (Lohbeck, 2019; Pinxten et al., 2014). Partially supporting Gonida et al. (2006)'s model – which used school achievement, unidimensional constructs for ASC and mindsets was not contextualized to math – we found that higher math achievement students had, the higher they' math interest was and the more they endorsed a growth math mindset (achievement → interest → growth). The directly link with grades, interest, and growth mindset in math was found in high school students with a different sequential order than ours (e.g., grade → growth → interest; Jones et al., 2012). This study found in math that the higher students' grades were, the more they endorsed a growth mindset and increased their interest. Jones et al. (2012) suggested that growth mindset and interest were connected to a more general construct like general intelligence. With our finding and those of Jones et al. (2012), we can assume that growth mindset and interest were linked, a finding that would need further investigation. Surprisingly, math achievement was weakly, negatively, and directly linked to growth math mindset while no statistically significant link was obtained with fixed math mindset. Tempelaar et al. (2015) also reported a negative relation between growth mindset for intelligence and math achievement in a sample of undergraduate students, suggesting that the relationship between achievement and mindsets was complex and involves a mediator such has effort belief. Another unexpected of our results was that student math competence directly linked with lower endorsement of growth and fixed mindsets, but also suggest that children cannot distinguish incompetence form a fixed mindset. Precisely, students perceived themselves incompetent strongly endorsed fixed math mindset. Similar findings were obtained using a unidimensional conceptualization of MSC, but only for adolescent girls (Heyder et al., 2021). With few studies using a bidimensional conceptualization of mindsets had tested the links from mindsets to competency, the opposite link (i.e., competency → mindsets) needs future investigation to determine if they obtained negative relationship replicates. Finding that math competency weakly undermined students' adoption of a growth math mindset contradicts what Gonida et al. (2006) obtained with ASC and intelligence mindset and needs further investigation. Highlighting the need to distinguish dimensions of MSC, our findings suggest that growth and fixed math mindsets are directly linked differently by affect and competency, in line past studies that linked mindsets with achievement and effort (Tempelaar et al., 2015).

Finally, our findings suggest that students' school level and gender shape their endorsement of math mindsets, in line with past studies that suggested that student mindsets show differences (Park et al., 2016b). Moreover, our results replicated findings that a growth math mindset was more strongly endorsed by younger students than by older ones (Park et al., 2016a). As children develop, they come to understand that a trait is stable and begin developing the notion that their abilities can be stable (Dweck, 2002). Consequently, their interpretation to a situation comes to be linked with their mindsets (e.g., having a growth mindset leads to put effort after a failure; Dweck, 2002). This can explain why they gradually diminish their adoption of a growth math mindset. Our results also showed that girls endorsed a growth mindset more strongly than boys, which contrasts with earlier studies that revealed no gender differences (Gunderson et al., 2017), although this might be explained by the fact that we used a bidimensional conceptualization of math mindsets whereas others used a bipolar conceptualization. Further research should thus try to replicate school level and gender difference on math mindsets using a bidimensional operationalization.

Practical implications

These findings contribute to interventions in important ways. First, they illustrate the importance of examining students' math mindsets across elementary school levels and by gender. Math growth mindset declines throughout elementary school, as math becomes more complex. Assessing mindsets can therefore help identify students for whom interventions are most needed. Among students who should be prioritized are those perceiving themselves as incompetent in math reported since it directly linked to their adoption of a fixed math mindset. Since children mindsets development through interaction with their environment (Dweck, 1999), parents and teachers can play roles in shaping the development of children's mindsets through their interactions (Haimovitz & Dweck, 2017). This involves paying attention to their comments to young students' success and failure in math (e.g., "It's not your fault you're not good at math"; Haimovitz & Dweck, 2017).

Second, parents and teachers should pay attention to how their interaction can be different across gender since girls endorse a growth mindset more strongly than boys. The feedback children receive was found to differ according to their gender (Levine & Pantoja, 2021). Also, as children gain experience, they built their representation of abilities and assesses them to use information from environment and this plays a role in developing their mindsets (Dweck, 2002). It is therefore important to implement interventions early on, by highlighting children's individual progress, and explaining that difficulties are part of the learning process (i.e., promoting a growth mindset; Haimovitz & Dweck, 2017). Another strategy for improving growth mindset is to cultivate students' math interest, which can be done via feedback from parents and teachers about how they're perceived student performance (Marsh et al., 1999; Dweck & Molden, 2017). Rejection of a fixed math mindset also requires students perceiving themselves as competent, which can be done by working on developing their math skills (Marsh et al., 1999).

Strengths, limits, and future directions

Strengths of this study include the focus on math mindsets across elementary school years, the importance given to their directly links, the size of the sample, and sophisticated analytical strategies. However, some limits must be considered when interpreting the findings. First, the design was cross-sectional, which does not allow drawing causal inferences nor allow estimation of time effects. Future studies should use a longitudinal design to evaluate the stability of elementary students' math growth and fixed mindsets and to test reciprocal effects with achievement and MSC over time. Studies have shown that longitudinal changes were different for growth and fixed mindsets among older students (Limeri et al., 2020). This could be tested more specifically toward math. Second, only math mindsets were considered. It will be important for future studies to assess mindsets in several school subjects to allow comparing mindsets across school subjects among elementary students. Doing so will provide valuable information regarding the subject-specific nature of students' mindsets and their directly link among elementary students. Few studies assed mindsets across different school subjects and these revealed no difference on mindsets in math, language and school in general among elementary students when using both conceptualizations of mindsets (bipolar and bidimensional; Gunderson et al., 2017; McCutchen et al., 2016). Their results lead to the conclusion that specific mindsets for school subjects develop towards adolescence. However, these studies used both depersonalized and personalized formulations for measuring mindsets in a same questionnaire, which can be samples (e.g., using only personalized formulation, avoid abstract formulations; Borgers et al., 2000). McCutchen et al. (2016) assessed mindsets in math and reading among elementary students and showed that the relation between mindsets and achievement differed by subject mindsets. A third limit pertains to the representativeness of the sample, which is composed of students coming from a privileged background. Hence, our results might not generalize to students from more diverse socioeconomic backgrounds. Since parents' socioeconomic status was found to relate positively with students' achievement (Crocker, 2012), parents' socioeconomic status could relate to students' mindsets. Finally, as reported earlier, the fixed mindset subscale was less reliable, which prompts us to be careful when interpreting the results. Future research is needed to replicate the psychometric qualities, and therefore, whether item revisions are needed to improve this subscale. This, in turn, can allow testing if our results with fixed math mindset can be replicated.

Other suggestions for future directions include assessing elementary students' mindsets and their relations with school outcomes (e.g., struggles, easiness) and test the direction of these links. With undergraduate students, a positive feedback loop was observed with students' perception of their academic performance and their mindsets, and their experience with the struggle played a role in mindsets changes (e.g., students who continually struggle at school reported a decline in their growth mindset and increased endorsement of a fixed mindset, compared to students who overcame struggle; Limeri et al., 2020). With elementary school being a decisive period in math progress (Träff et al., 2020), it is essential to understand and document the processes involved in improving interventions and to promote positive math progress for everyone. It would be necessary for future studies to empirically test mindsets' conceptualization, improve the measure's reliability by using more items, and with a larger sample, examine mindsets' predictors (i.e., achievement, ASC, grade) in math and in other school subjects, as well as to test the role of school experiences (e.g., overcame struggles), parents and teachers in the development of students' math mindsets.

Conclusion

This study showed that it was possible to assess growth and fixed math mindsets among students from all elementary school years, thereby supporting the bidimensional conceptualization of math mindsets. Results also indicate that younger students adopted a growth math mindset more strongly than older students, while a fixed math mindset was more endorsed than a growth math mindset and remained stable throughout elementary school. Our findings also showed that the higher students' math achievement was, the more they perceived themselves to like math—which predicted endorsing a growth mindset—and the more they perceived themselves as competent in math, which negatively albeit weakly predicted endorsing a growth math mindset. Perceiving themselves as competent in math also predicted a strong rejection of a fixed math mindset. Hence, knowing that a math growth mindset is beneficial to students' development, important stakeholders such as teachers and parents can support them in adopting such a mindset during elementary school by nurturing their liking of math. They can also help reduce students' endorsement of a fixed math mindset by encouraging their perceived competence in math.

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Declarations

Consent to participate Informed consent was obtained from all children' participant and one of their parents.

Employment No employment that may gain or lose financially though publication of this manuscript has been involved in this study or this manuscript.

Financial interest All authors declare they have no financial interest though publication of this study or this manuscript.

Conflict of interest All authors have no competing interests and no conflict of interest to declare.

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