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Review

A systematic review of mindset interventions in mathematics classrooms: What works and what does not?☆

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ABSTRACT

A growing body of research has suggested that mindset is one powerful predictor of students' academic achievement and that students are likely to hold self-beliefs about the malleability or stability of their academic abilities. In the domain of mathematics education, a belief in 'math brain' – as something you do or do not possess – is widely prevalent. Studies have shown that teachers and students are more likely to consider achievement in mathematics than achievement in other academic domains to be due to inborn ability. Most growth mindset-related research in schools is domain-general; however, given the prevalence of strong beliefs about the innateness of mathematical ability, possible idiosyncratic effects of mindset interventions in the mathematics domain may have been overlooked by research reviews and meta-analyses that do not examine domain-specific effects. The purpose of this paper is to compile and synthesise quantitative and qualitative research on interventions in mathematics classrooms that aim to change or foster teachers' and/or students' beliefs/mindset in primary and secondary schools and the reported impacts of these interventions (16 studies). The interventions in these studies were identified and sorted based on their targets (teacher-focused or student-focused), content (implicit theories of intelligence (ITI) intervention for general domains or in mathematics domain), and delivery mode (technology-based or in-contact). The results suggested most of the considered studies were quantitative and used student-focused interventions. Moreover, when ITI interventions were conducted specifically in the mathematics domain, positive results were reported, regardless of the intervention target or content or mode of delivery, whereas general ITI interventions yielded mixed results. Future studies should therefore consider the impacts of domain-specific effects and intervention targets when designing mindset interventions.

In recent decades, a growing body of research has suggested that students' beliefs are a powerful predictor of academic achievement (Bandura, 1997; Dweck & Leggett, 1988; Pajares & Kranzler, 1995) and that students are likely to hold self-beliefs about the malleability or stability of their academic abilities (Chen & Pajares, 2010; Dweck, 2000; Dweck & Leggett, 1988; Yeager & Dweck,

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2012). According to Dweck (2000, 2006), these self-beliefs, mindsets, or implicit theories of intelligence (ITI) concern whether intelligence is malleable (growth mindset, incremental theory) or fixed (fixed mindset, entity theory). As reported by Dweck and colleague (Blackwell et al., 2007; Dweck, 2006) students with a fixed mindset believe that intelligence or ability is fixed and cannot be improved; moreover, they tend to view mistakes as consequences of their unchangeable ability or that they were made because they (i. e., the students) are not smart enough. In contrast, when students endorse a growth mindset, they believe that intelligence or ability is malleable and can be developed through learning and effort. They also demonstrate a few traits, such as embracing challenges and considering them opportunities to learn, practise, and improve; persisting when faced with setbacks; and considering effort as the key to mastery (Blackwell et al., 2007), whereas fixed-mindset individuals tend to shy away from challenges and consider mistakes as failures (Dweck, 2006).

Research pioneered by Dweck has shown growing evidence that growth-mindset interventions can shift students' mindsets and consequently improve their academic performance and motivation (Blackwell et al., 2007); significantly help at-risk students to improve their average learning outcomes in core academic courses on a larger scale (Paunesku et al., 2015); and successfully aid students academically in their transition to high school (Yeager et al., 2016). Growth-mindset interventions demonstrate that "struggle" or "failure" is an opportunity for intelligence to grow, especially when learners take on difficult and challenging tasks; therefore, struggles or mistakes should not be conceived of as evidence of a continually incapable student. Thus, an extensive focus on growth-mindset interventions in academic settings attempts to encourage individuals to see failures or mistakes as chances to improve their ability.

Additionally, fostering a growth mindset is considered to reduce social, gender, and economic gaps. The results of research using a sample recruited across all socioeconomic levels in Chile showed that a growth mindset might play a mediating role among economically disadvantaged participants to combat the effect of poverty on academic achievement (Claro et al., 2016). When it comes to damaging stereotypes, endorsing a growth mindset helped African American students resist stereotype threats (Steele & Aronson,

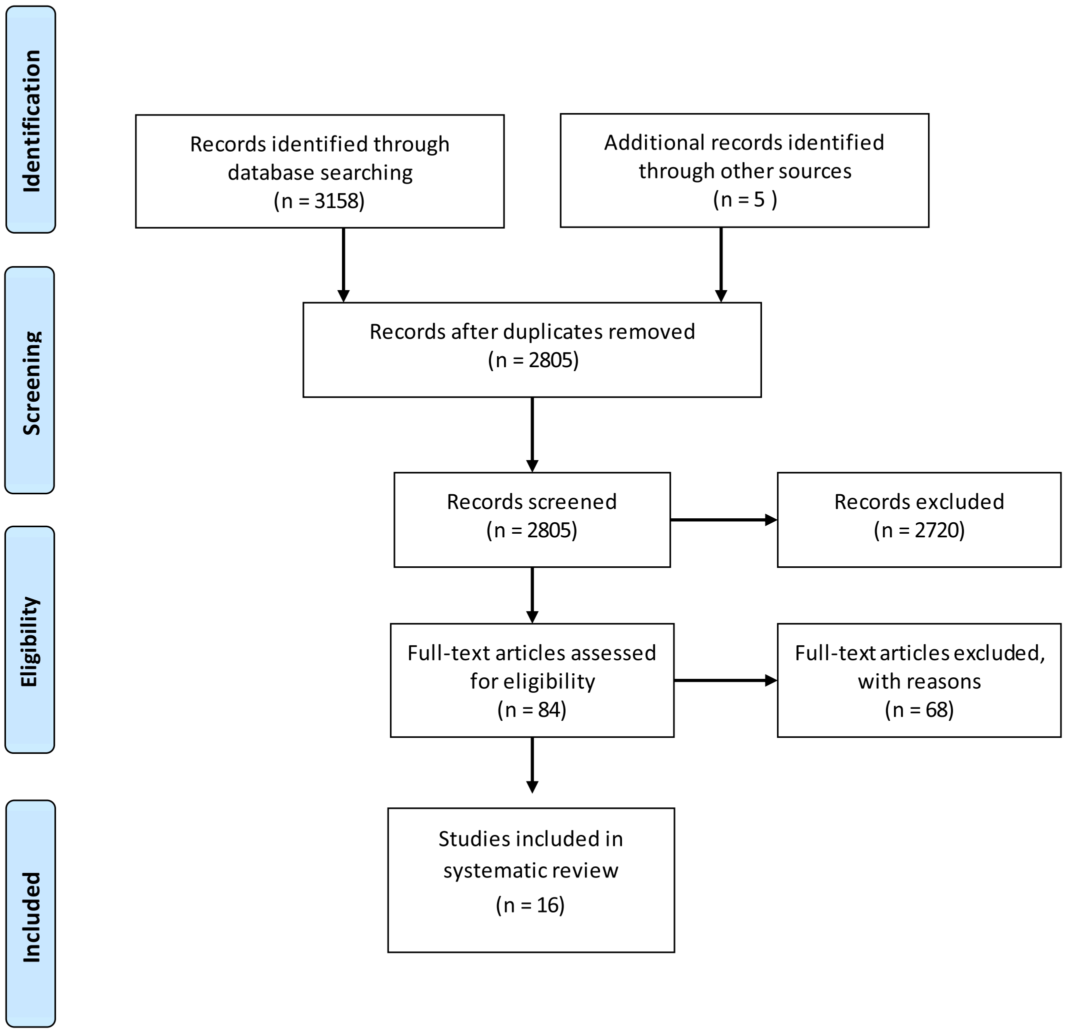

Fig. 1. Search procedure based on the PRISMA flow diagram.

2004), increased grade point average (GPA) for Latinos/as, and reduced the GPA gap by 72% between this group and White students (Broda et al., 2018).

Although notable claims have been made, the extent to which efforts to shift students' mindsets from fixed to growth have transferable effects on their learning performances remains a subject of ongoing debate. One major source of criticism comes from a study containing two meta-analyses by Sisk et al. (2018) which examined the strength of the relationship between mindset and academic achievement and the effectiveness of mindset interventions on academic achievement. In the first meta-analysis, the researchers analysed 129 studies and concluded that the correlation between a growth mindset and academic achievement was very weak, with an average meta-analytic correlation of $r = 0.10$. The second meta-analysis evaluated 29 studies, and the results did not support claims suggesting that mindset interventions had a significant impact on the academic achievement of adolescents, typical students, or students facing situational challenges. The only groups which seemed to benefit from mindset interventions were academically high-risk and economically disadvantaged students (see also, e.g., Claro et al., 2016; Paunesku et al., 2015).

Another criticism concerns the issue of the replication and practical implementation of the original growth-mindset findings. Li et al.'s (2019) efforts to independently replicate the original growth mindset (Mueller & Dweck, 1998) with over four studies considering 600 Chinese students aged between nine and 13 showed repeatedly null effects, suggesting no link between mindset and resilience or attainment. This result also suggests there might be unaccounted cultural effects when it comes to the replication of mindset interventions (Dong & Kang, 2022). Furthermore, there is little evidence of the effectiveness of teacher-focused mindset interventions on students' academic outcomes or teachers' changes in instructional practices (Foliano et al., 2019; Rienzo et al., 2015). Some of these criticisms have been addressed by Dweck (2017) and others (Yeager et al., 2019). Examples include their efforts to conduct a pre-registered national randomised control trial (RCT) with a growth-mindset online intervention to 9000 students making the transition to high school and a further 9000 in an active control group (Yeager et al., 2019). The study was carried out by neutral research organisations, and the data collected were analysed independently by a network of sociologists and economists. The results indicated that teaching students about a growth mindset improved lower-achieving students' grades and increased students' enrolment to advanced mathematics courses. Researchers have also raised the issue of how the growth mindset was poorly interpreted, misunderstood, or oversimplified during the process of translating the concept into classroom practice by cautioning that mindset does not offer a 'magic bullet' (Yeager & Dweck, 2020; Yeager & Walton, 2011) and that mindset research depends critically on context and implementation.

Another source of criticism is presented by the newest and largest-scale systematic review and meta-analyses carried out by Macnamara and Burgoyne (2022). In their work, they employed multiple meta-analytic models to examine the effects of the included studies, considered quality control, bias analyses, and different combinations of best practice criteria, and concluded that the idea that fostering a growth mindset will lead to academic achievement or meaningful changes in motivation is not well supported. Furthermore, Macnamara and Burgoyne (2022) argued that the positive effects of growth-mindset interventions might be due to potential bias, study design, and lack of transparency in reporting.

1. Growth mindset and mathematics education

In the context of mathematics education, the belief in 'math brain' – something you do or do not possess – is widely prevalent (Frank, 1990). 'I am not a math person' is a claim frequently made by students referring to this idea. In fact, it is claimed that mindset differs according to domain, as students can endorse a fixed mindset for some academic disciplines and have a growth mindset for others (Dweck, 2006). Studies showed that teachers and students in the discipline of mathematics more often considered mathematics achievement as representing an inborn ability than achievement in other academic domains (Beach & Dovemark, 2007; Jonsson et al., 2012). Mathematics teachers commonly carry fixed ideas about their own and their students' abilities in mathematics learning (Stipek et al., 2001), and such beliefs can transfer into classroom practices that have negative effects on students' beliefs or mathematical academic achievement (Rattan et al., 2012). Since most growth-related research in schools is domain-general, mindset work and interventions within the realm of mathematics seem particularly important and relevant.

One issue is, however, that even when these studies were conducted within the domain of mathematics, they evaluated the impact of a general mindset intervention rather than focusing on the specific content of teaching and learning mathematics (Boyd & Ash, 2018). Several studies have developed interventions to induce a growth mindset in students either by teaching them about neuroplasticity, which is the capacity of the brain to transform its neural connections through learning (Dommett et al., 2013), or teaching about the growth mindset directly, such as how the brain works and how intellectual abilities can be improved through effort, practice, or personal mentoring about growth mindset (Good et al., 2003). Another concern is that these studies' designs mainly targeted students (Blackwell et al., 2007; Good et al., 2003); if mathematics teachers were involved, they received somewhat similar insights about how the brain learns, not about the specific domain of mathematics education (Dommett et al., 2013). In a double-blind clinical trial (Yeager et al., 2022), teaching a short, general domain growth mindset intervention improved math grades overall, but the benefits varied based on the classroom environment. Yeager et al. (2022) demonstrated that students in classrooms with growth-mindset teachers showed significant gains, while students with fixed-mindset teachers did not. However, the existing literature lacks sufficient focus on teachers' mindsets (Zhang et al., 2017).

2. Review studies and meta-analyses concerning growth-mindset interventions

Previous reviews and meta-analyses have highlighted the associations of implicit theories with self-regulation theory (Burnette et al., 2013) and focused on the effects of teaching neuroplasticity to induce a growth mindset on motivation and achievement

(Sarrasin et al., 2018). Studies have examined the strength of the relationship between mindset and academic achievement and the effectiveness of mindset interventions on academic achievement (Sisk et al., 2018). They have modelled the link between ITI and students' academic achievement in different domain-specific subjects (verbal and quantitative) with consideration of relevant factors such as socio-demographic and cultural moderators (Costa & Faria, 2018) or surveyed how mindsets have been studied among teachers and students (Zhang et al., 2017). Scherer and Campos (2022) conducted a meta-analysis on the most used Implicit Theories of Intelligence Scale (ITIS) developed by Dweck (2000) to assess mindsets. Their study analysed the relationships between fixed- and growth-mindset items, investigated variations in these items, explored the factor structure of the ITIS, and identified potential factors that may influence the results. Probably the largest-scale review to date was conducted by Macnamara and Burgoyne (2022), who carried out a systematic review and multiple meta-analyses of growth-mindset interventions to answer two questions: (1) whether growth-mindset interventions generally improve students' academic achievements; and (2) whether growth-mindset intervention effects are due to instilling growth mindsets in students, or the positive impacts are due to shortcomings in study designs, analyses, and reporting. While these studies has profoundly enriched the literature of implicit theories and provided critical theoretical frameworks and reviews that are needed for future researchers to develop and hone mindset-based interventions, they largely considered studies that first, evaluate the impact of a generic mindset intervention and second, do so across domains, with the exceptions of Sarrasin et al. (2018) and Costa and Faria (2018). These two reviews, however, are synthesised purely from quantitative studies, as are the majority of meta-analyses about implicit theories. As most currently available reviews concerning mindset interventions are meta-analyses, therefore potentially informative qualitative studies and mixed-method approaches focusing on mathematics teachers' in-class practices, choice of mathematics tasks, grouping activities, etc. have been ignored.

3. Goals and research questions of the present review study

The objective of this study is to conduct a systematic review of mindset interventions in mathematics classrooms in primary and secondary schools. The study aims to achieve two main goals: (1) to identify and summarise existing research on mindset interventions in mathematics teaching and learning, and (2) to compile a comprehensive body of scientific research on mindset interventions in mathematics education that encompasses diverse perspectives and methodologies, including both quantitative and qualitative studies. Additionally, the study intends to propose practical implications for research and instructional practices based on the findings.

The research questions guiding this study are as follows.

1) What kinds of interventions aiming at changing, shifting, or fostering teachers' and students' beliefs or mindset have been carried out in mathematics classrooms?
2) What are the reported impacts of these interventions on students' beliefs, motivation, and engagement in mathematics learning?
3) What are the reported impacts of these interventions on mathematics teachers' beliefs and practices related to mathematics learning and instructional practices?

4. Methods

The study is designed, and the results are reported, in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (see Fig. 1) (Moher et al., 2009).

4.1. Inclusion criteria, exclusion criteria, literature search, and coding

The inclusion criteria for studies in this review are as follows.

- An intervention that aims at changing, shifting, or fostering teachers' and/or students' beliefs or mindset (ITI, implicit beliefs, incremental view of intelligence, or beliefs about human attributes), which was administered explicitly/implicitly, directly/ indirectly to students and/or teachers of mathematics.
- Interventions with either or both mathematics teachers and students in primary and secondary schools; studies should include a measure of students' mathematical achievement and/or beliefs, mindset, motivation, and engagement in mathematics, and/or mathematics teachers' beliefs, attitudes, and mindset.
- Descriptive data about the procedure with sufficient information about intervention characteristics to understand how the interventions were implemented.
- Peer-reviewed and published in English.

The exclusion criteria for studies in this review are as follows.

- Publications that are not peer-reviewed or published in other languages rather than English.
- Studies that did not have a suitable participant target (e.g., high school students, college students, etc.)
- The present review focuses on *mindset interventions in the mathematics domain*, therefore we excluded studies that did not provide enough information to decide whether the intervention content is related to ITI (e.g., Eskreis-Winkler et al., 2016; Gaspard et al., 2015), even if they reported results about changes in students' attitudes, mindset, beliefs, interests, or mathematics achievements (e.g., White & McCoy, 2019).

- Studies in which mathematics achievement only used as one among many academic achievements (e.g., general GPA, other academic subjects such as science, languages, reading skills, etc.) to be measured after a general domain student-focused intervention without any mathematical content (e.g., Outes-León et al., 2020; Rienzo et al., 2015; Yeager et al., 2019; Yeager et al., 2022).
- Preprints of studies that are currently going through preparation or peer-reviewed processes. (e.g.,Combette et al., 2022).

4.2. Information source and search strategy

A comprehensive literature search of the Educational Resource Information Center (ERIC), SCOPUS, ProQuest, and Google Scholar databases were initially conducted. These databases were chosen due to the high quantity of educational research journals that they host. Only articles which were published in English between 1998 and May 2023 were included. Since research into growth mindset interventions in math education is relatively scarce, peer-reviewed conference papers, reports, and book chapters were also included in the search.

First, several key phrases were used to guide the preliminary search: "growth mindset", "implicit theories of intelligence", and "mindset intervention". However, these main key phrases returned too many irrelevant results in some databases thus different combinations of these main terms were used with "math" OR "mathematics" OR "math intervention" to narrow down the results: "growth mindset" AND "math", OR "growth mindset" AND "mathematics", OR "growth mindset" AND "math intervention"; "implicit theories of intelligence" AND "math", OR "implicit theories of intelligence" AND "mathematics", OR "implicit theories of intelligence" AND "math intervention"; "mindset intervention" AND "math", OR "mindset intervention" AND "mathematics". Related key phrases were also identified for "malleable intelligence", "instructional practices" and "pedagogy" based on the literature in the field, so additional search included: "malleable intelligence" AND "mathematics" OR "growth mindset" AND "pedagogy" OR "mindset" AND "instructional practices". Then, the authors reviewed the references of all eligible studies, previously published systematic reviews and meta-analyses articles of growth mindset and implicit theories by backtracking to find potentially relevant articles that might have been lost during the initial research.

4.3. Quality appraisal

The purpose of the quality appraisal was to assess the quality of each selected study. Based on the quality appraisal, a weight was assigned to each study (0–1: 0 indicates a low-quality study, and 1 indicates a high-quality study). This process allowed us to examine possible differences in studies concerning rigour and validity.

Two appraisal instruments were selected to perform the evaluation of the selected studies. For quantitative studies, the evidence-based librarianship critical appraisal checklist (EBLCAC) (Glynn, 2006) was chosen; for qualitative studies, the qualitative research checklist (QRC) was used (CASP, 2006). These instruments were chosen because they were appropriate to the research domain (education) and have been used by other systematic reviews in the field (Van Leeuwen & Janssen, 2019). Moreover, they included clear guidelines on how to make use of the checklists with clear instructions on each section and examples of critical examination of the quality and validity of a selected paper. Both checklists consist of *Yes/No/Can't tell* (or *Unclear*) questions that address the quality of the study. Answers to each question were scored from −1 (when the answer was *No*), to 0 (when the answer was *Can't tell* or *Unclear*). And 1 (when the answer was *Yes*).

The QRC includes 10 items with questions such as whether the selection of participants was appropriate or not. The EBLCAC checklist consists of 26 questions. Because the QRC includes questions about the aim and value of the study, but the EBLCAC does not, we added these two items to the EBLCAC, yielding 28 questions. In addition, some items in the EBLCAC can be answered with *Not Applicable* (N/A), for example 'If a face-to-face survey, was inter-observer and intra-observer bias reduced?' Items marked N/A were not assigned a score and not included in the total number of scores. Thus, possible scores for the QRC checklist ranged from −10 to 10, and the EBLCAC had a possible range score from −28 to 28.

All 16 selected publications were read and coded carefully by two researchers. To establish a common understanding of the quality appraisal instruments, a sample set of one quantitative article (using the EBLCAC instrument) and one mixed-method article (using the QRC instrument) was chosen and coded individually by two researchers at the same time. Then, each item and decision were reviewed one by one. After establishing the coding methodology, the rest of the selected publications were individually coded by two researchers. During the coding phases, weekly meetings were held to discuss any questions or doubts about any of the publications. For the EBLCAC (14 studies), an interrater validity of Cohen's kappa = 0.68. This measure of interrater agreement can be considered substantial (Landis & Koch, 1977). Regarding the qualitative studies, only two studies were evaluated using the QRC instrument, with scores ranging from 7 to 8 and 9 to 10 within the possible range of −10 to 10. These scores indicated a high interrater agreement (see Appendix B for more information). One researcher coded and summarised the description, procedures of the interventions, and results of the included studies, while the other checked and reviewed the results of the coding process. Summaries and preliminary coding schemes were reviewed and discussed during weekly meetings during the coding phase.

4.4. Coding of variables

There are different ways to synthesise and combine both qualitative and quantitative evidence. In a review paper, Dixon-Woods et al. (2005) outlined a selection of common strategies used to summarise diverse forms of evidence, ranging from techniques that are interpretative and mainly qualitative to techniques that are more integrative and quantitative. The approach chosen for the present review study is integrated design (Heyvaert et al., 2016), which means converting all findings into qualitative form by reading the

Table 1
Studies included in the review process.

No	Authors (Year)	Focus targets	Type of publication	Location	Type of intervention for students	Type of intervention for teachers	General ITI/ domain-specific measure	Outcomes/measures
01	Blackwell et al. (2007) Study 2	Students	Peer-reviewed journal	New York USA	General ITI taught through structured workshops by mentors	N/A	General	- Mathematics achievement - Motivational variables: general ITI, goal orientation, beliefs about effort, and attributions and strategies in response to failure - Teachers' assessment of students' mathematics classroom motivation and behaviours
02	Dommett et al. (2013)	Teachers & students	Peer-reviewed journal	England	General ITI through neuroscience workshops by Advanced Skills Teacher (AST-Neuro) or via an interactive computer software (Comp-Neuro)	Workshops for mathematics teachers were delivered via Articulate software. Additional readings from the Society of Neuroscience publication	General	- Mathematics test - Motivational measures (including intelligence beliefs): general ITI, beliefs about effort and academic performance - Workshop quiz - Students' feedback on workshop's engagement, content, & delivery
03	Star et al. (2014)	Students	Peer-reviewed journal	Virginia U.S.A.	An abridged (designed for this study) version of the Mindset Works-Brainology web-based activity. General ITI		Self-efficacy, ITI (general), mathematics value & mathematics learning (specific)	Motivational measures
04	(O'Rourke et al., 2014)	Students	Peer-reviewed conference proceeding	USA	Game-based learning Embedded specific ITI within game narrative & incentive structure in mathematics domain.	N/A	N/A	Game analytics: time-play, number of unique levels
05	O'Rourke et al. (2016)	Students	Peer-reviewed conference proceeding	USA	Game-based learning Embedded specific ITI through game narrative & incentive structure in the mathematics domain.	N/A	N/A	Game analytics: time-play, number of unique levels, number of attempts, challenge level, win rate, time working on challenge and average number of growth mindset behaviours exhibited per minute during challenge level.
06	Bagès et al. (2016)	Students	Peer-reviewed journal	France	Within-class randomised experimental conditions Reading exercises of successful role-model in mathematics (*Hardworking, gifted, or not explained*) Not direct ITI but through the role model's explanation of success. Specific to	N/A	N/A	- Identification & perceived self-efficacy questionnaire - Standardised mathematics test

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Table 1 (*continued*)

No	Authors (Year)	Focus targets	Type of publication	Location	Type of intervention for students	Type of intervention for teachers	General ITI/ domain-specific measure	Outcomes/measures
					the mathematics domain			
07	Bonne and Johnston (2016)	Teachers	Peer-reviewed journal	New Zealand		Professional learning and development workshop Indirect ITI through self-efficacy micro-intervention	Specific	Mathematics achievement, task-specific mathematics self-efficacy, domain general theory of intelligence (pre-, mid-, & post-tests – 1 year)
08	Boyd and Ash (2018)	Teachers	Peer-reviewed journal	England	N/A	PD Singapore Mathematics curriculum development project Specific ITI in mathematics domain	N/A	In-class teaching practices, strategies, and teachers' beliefs.
09	Boaler et al. (2018)	Students	Peer-reviewed journal	California USA	RCT MOOC learning Specific ITI in mathematics domain	N/A	Specific ITI in mathematics domain	- Smarter Balanced Assessment Consortium (SBAC) Summative Assessment (mathematics achievement) - MOOC survey exploring students' engagement and mindset in mathematics
10	Anderson et al. (2018)	Teachers	Peer-reviewed journal	California USA	N/A	Blended Mathematical Mindset PD Approach: Online course, face-to-face meetings, school coaching, admin training. Specific ITI in mathematics domain	Specific ITI in mathematics domain	- Mathematical mindset observations - Online course survey responses - Survey on teachers 'practices, strategies, and beliefs - Teacher interviews - Students' mindset survey - Students' mathematics achievement
11	Wang et al. (2019)	Students	Peer-reviewed journal	USA	Embedded self-regulation focusing on fostering growth mindset & goal setting, self-monitoring, and strategies in fraction intervention. Specific ITI in mathematics domain	N/A	N/A	Fraction measure outcomes (task-specific)
12	Fuchs et al. (2021)	Students	Peer-reviewed journal	USA	Self-regulation & growth mindset component focusing on fostering growth mindset with self-assessment and goal setting in fraction intervention. Specific ITI in mathematics domain.	N/A	N/A	Fraction measure outcomes (task-specific)

(*continued on next page*)

Table 1 (*continued*)

No	Authors (Year)	Focus targets	Type of publication	Location	Type of intervention for students	Type of intervention for teachers	General ITI/ domain-specific measure	Outcomes/measures
13	Lee et al. (2021)	Students	Peer-reviewed journal	South-Korea	Joint intervention on growth mindset and gender stereotypes. Specific ITI in mathematics domain.	N/A	Specific ITI in mathematics domain	- Motivation measures: Perceived competence, test anxiety, persistence. - Mathematics achievement measurements.
14	Gaspard et al. (2021)	Students	Peer-reviewed journal	Germany	MoMa - a classroom-based relevance intervention that targets students 'utility value in mathematics, which includes: the importance of effort & self-concept for math achievement, growth mindset, and utility of mathematics for future education (specific ITI in mathematics domain)	N/A	N/A	- Self-reported math motivation at 3 time points (pre, post & follow up). - Teacher-reported effort: Teachers rated individual students 'math effort on two items - Math grades from previous year; specific math tests at pre-test & follow-up test.
15	Balan and Sjöwall (2022)	Students	Peer-reviewed journal	Sweden	Joint intervention on growth mindset and deliberate practice. General ITI	N/A	General ITI	- Pre & post-test of self-report in growth mindset, deliberate practice, and grit. - Mathematical achievement tests & deliberate practice behaviour.
16	Lee, Lee, Song, Kim, & Bong (2022)	Students	Peer-reviewed journal	South Korea	Intervention for parents and students about gender stereotypes & expectations for mathematics Specific ITI in mathematics domain.	N/A	Specific ITI in mathematics domain	Measures of students' mindsets, gender stereotypes, self-efficacy, and test anxiety in math as well as students' perceived importance of math were measured pre (T1) and after (T2) Intervention-P and post Intervention-S (T3). - Mathematical achievement tests were assessed only at T1and T3.

studies, formulating summary phrases that capture their characteristics and findings, and subsequently performing a thematic analysis (Dixon-Woods et al., 2005) using NVivo 12. This approach was chosen because the methodological differences in quantitative and mixed-method studies are minimised, given that both produce findings that can be synthesised qualitatively as they address the same research purpose and questions (Heyvaert et al., 2016). Secondly, this approach allowed data related to the population and context of individual studies to be integrated and synthesised as well as findings that might be helpful in answering the question of whether the success of the implementation of the intervention was context-dependent (Noyes et al., 2019), which is impossible to find in meta-regression studies (Yeager & Dweck, 2020a). In short, this process allowed us to process all types of data, including mixed-method studies that included both quantitative and qualitative findings.

Eligible studies were coded to summarise the information from each study in two broad categories: (1) features of study (research design, participant characteristics, setting) and intervention characteristics (intervention methods, group size, duration, delivery methods, intervention content); and (2) results and discussion of the findings. Then, the features of the study were organized into groups and clusters based on the type of intervention (generic or mathematics domain-specific), target population (teacher-focused or student-focused), and intervention content (ITI-related concepts, mathematics content, or professional development content). Next, data were tabulated to prepare for the vote-counting process, which involved the tabulation of statistically significant and non-significant findings in quantitative studies and the reported impacts in qualitative and mixed-method studies. Lastly, the thematic analysis technique was employed to systematically identify the main, recurrent, and/or most important (guided by the research

Table 2
Intervention content, intervention target, and mode of delivery of included studies.

Authors (year)	General/ maths domain	Focus target	Group details	Duration	Intervention content	Mode of delivery	Mathematics intervention content
(O'Rourke et al., 2014)	Mathematics domain	Student-focused intervention	Children (details are unknown)	Average 3 min	- Teach growth mindset directly through game narrative & incentive structure in game - Incentive structures reward players' effort, use of strategy, and incremental progress in a mathematics game	Technology-based delivery (Game-based learning)	Fraction concept
O'Rourke et al. (2016)	Mathematics domain	Student-focused intervention	Children (details are unknown)	2.2–3 min	- Teach growth mindset directly through game narrative & incentive structure in game - Incentive structures reward players' effort, use of strategy, and incremental progress in a mathematics game.	Technology-based delivery (Game-based learning)	Fraction concept
Boaler et al. (2018)	Mathematics domain	Student-focused intervention	Middle school students (6th, 7th, and 8th grades)	Six modules, 15–20 min/each	- Everyone can learn mathematics to a high level - Mistakes, challenges, and struggles are the best times for brain growth - Depth of thinking is more important than speed - Mathematics is a creative and beautiful subject - Good strategies for learning mathematics including talking and drawing - Mathematics is all around us in life and is important	Technology-based delivery (MOOC online course)	N/A
Bagès et al. (2016)	Mathematics domain	Student-focused intervention	Middle school students (M age = 11 years 7 months)	Happened in a single period	A reading exercise about a 9th-grader role model who had been successful in mathematics. The role model's success is explained under 3 conditions: hardworking, gifted, & no reason given	In-contact delivery (In-class activities)	N/A
Wang et al. (2019)	Mathematics domain	Student-focused intervention	At-risk (low math achieving) 3rd-grade students	Three periods of 35-min/week for 13 weeks, time spent on self-regulation & growth mindset component averaged 4 to 7-min/period	- Week 1 + 2 focus on teaching students about brainpower and how to apply it - Week 3 shifted to goal-setting instruction; week 4 to week 13 heavily emphasized monitoring students' progress. - Students were encouraged to apply self-regulation strategies to fraction word problems, multiplication problems, etc.	In-contact delivery (In-class activities)	Fraction intervention Third Grade Super Solvers
Fuchs et al. (2021)	Mathematics domain	Student-focused intervention	At-risk (low math achieving) 3rd-grade students	Three periods of 35-min/week for 13 weeks, time spent on self-regulation & growth mindset component averaged 4 to 9-min/period.	- Week 1 to 3 teaching about brain malleability, training brain, mistakes' roles, tracking & goal setting. Students are explicitly taught to graph & interpret graphs, to set goals to beat their highest score. - Week 4 is about learning from mistakes. In Lesson 10, students review their	In-contact delivery (In-class activities)	Fraction intervention Third Grade Super Solvers - Revised

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Table 2 (*continued*)

Authors (year)	General/ maths domain	Focus target	Group details	Duration	Intervention content	Mode of delivery	Mathematics intervention content
					Lesson 9 to identify mistakes. Prompting examples *"Why did I get this type of problem wrong?"* or "*What can I do to get it right?"* - Week 5 is about fractions in daily life, persistence in learning fractions, & reflect why their scores increase, decrease, or stay the same. - Week 6 is about to setting SMART (specific, measurable, achievable, realistic, time-bound) goals. - Weeks 7-13, emphasizes working hard through challenges, prioritizing goals, adjusting plans to reach goals, & identifying strengths & weaknesses.		
Lee et al. (2021)	Mathematics domain	Student-focused intervention	Fourth graders (aged 9–11)	Six bi-weekly 40-min sessions that were evenly distribute over three months & administered during school hours.	The intervention emphasized the importance of GM &gender-fair beliefs in math through quizzes, cartoons, stories, and diverse range of math-specific materials. *Session 1*: Beliefs about effort; gender-fair messages about math ability & achievement. *Session 2*: Mindsets, overcoming difficulties in math. *Session 3:* Anti-stereotyping ("Anyone can do math regardless of their genders") *Session 4:* Neural plasticity & connectivity. *Session 5*: The importance of trying; overcoming setbacks. *Session 6*: Quiz & review	In-contact delivery (In-class activities)	N/A
Lee, Lee, Song, Kim, & Bong (2022)	Mathematics domain	Student-focused intervention	Third and fourth graders (aged 9–10)	Five evenly distributed 40-min intervention sessions & administered during school hours.	The intervention emphasized the importance of GM &gender-fair beliefs in math through quizzes, cartoons, stories, and diverse range of math-specific materials. *Session 1*: Beliefs about effort; gender-fair messages about math ability & achievement. *Session 2*: Mindsets, overcoming difficulties in math. *Session 3:* Anti- stereotyping ("Anyone can do math regardless of their genders") *Session 4:* Neural plasticity & connectivity. *Session 5*: The importance of trying; overcoming setbacks.	In-contact delivery (In-class activities)	N/A

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Table 2 (*continued*)

Authors (year)	General/ maths domain	Focus target	Group details	Duration	Intervention content	Mode of delivery	Mathematics intervention content
Gaspard et al. (2021)	Mathematics domain	Student-focused intervention	Students attending grade 9th in Germany	One 90-min lesson on the relevance of mathematics (psycho-educational presentation for the whole class about 45 min) & relevance-inducing tasks, on which the students worked individually (about 40 min)	The intervention content includes teaching students about effort vs talents (in math), self-image & its development, monitoring own progress, math's utility in school, college, jobs, and everyday life. Students had time to reflect on the content & on the utility of math in their lives on their own.	In-contact delivery (Content delivered through lesson presentation)	
Balan and Sjöwall (2022)	General	Student-focused intervention	Students attending grade 7th in Sweden (aged 12–13)	Four online modules conducted in a total of eight sessions. The modules were initially completed over 5 weeks and then repeated after a 2-week break. In the second round, there was a one-week break after each module. Each session lasted 25–35 min. Total intervention time of approximately 4 h.	The intervention teaches students the tenets of deliberate practice and growth mindset through 4 modules. Modules 1 and 3 focused on setting long-term goals, improving focus, and seeking feedback. Modules 2 and 4 explored the concept of deep practice, including the role of failure and frustration, and debunked the misconception that talent alone determines success. The modules comprised didactic slides, interactive elements, student quotes, illustrative videos, and letter-writing exercises. Additionally, each module concluded with three practical suggestions for independent progress.	Combination of in-contact & technology-based deliveries: -Students get access to the intervention content via a Googled Drive link. -Students work through the content with their teachers, teachers provided the introduction to the content of each week and opened for questions.	N/A
Dommett et al. (2013)	General	Student-focused intervention	Middle school students (aged 11–12)	Four periods of 50 min	Focusing on the plasticity of the brain, which would support the development of a flexible mindset, including a belief in incremental intelligence. - WS 1: What does the brain do? Brain areas, function, and basic brain needs. - WS 2: How does the brain work? Cellular level of the brain – the neurons, synapses, and effect of emotions on learning - WS 3: What happens when we learn? The flexibility of the brain, examples of learning brain and intelligence - WS 4: How do we remember things? Basic memory types, attention, and aiding memory	Two modes of delivery: One group had in-contact delivery through neuroscience workshops with an advanced skilled teacher. One group had technology-based delivery via computer software	N/A
Blackwell et al. (2007)	General	Student-focused intervention	Low achieving middle- school students (grade 7, aged 12–13)	Eight periods of 25 min	- Physiology of the brain, study skills, and anti-stereotypic thinking. - Reading aloud activity of incremental theory intervention 'You can grow your brain', activities show how learning makes your brain smarter	In-contact delivery (Workshops)	N/A

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Table 2 (*continued*)

Authors (year)	General/ maths domain	Focus target	Group details	Duration	Intervention content	Mode of delivery	Mathematics intervention content
					- Discussions about how learning makes your smarter and labels (dumb, stupid) to be avoided		
Star et al. (2014)	General	Student-focused intervention	Primary and middle school students (5th to 8th grade)	Two periods of 30 min	- An abridged version of the Mindset Works – Student Kit Brainology (designed for this program) - Modules to teach students about the incremental view of ability: how the brain works and grows stronger with effort - Brainology does not have any specific focus on mathematics or incorporate any mathematical problem solving	Technology-based delivery (Website-based learning program)	Two lessons on algebraic reasoning
Boyd and Ash (2018)	Mathematics domain	Teacher-focused intervention	School teachers (six teachers of classes 1–3 of primary schools, one teacher of a year 6 class)	Teachers have all been involved in the curriculum development project for between one and two years	Mastery approach focusing on collaborative learning strategy and developing a learning environment that embraces struggle and mistakes	In-contact delivery (On-site coaching/ observation & professional development workshops)	N/A
Anderson et al. (2018)	Mathematics domain	Teacher-focused intervention	Fifth-grade teachers from eight school districts	Three-year-long network with different modules of training. PD online course 'How to learn Math': 30–40 h. In-person network: seven meetings with all teachers, coaches, admin staff On-site coaching: The county office visited teachers in their school every month. Admin training: Site & district admin staff attended network meetings & an online course	1. PD online course 'How to learn Math': eight modules consisting of research on mathematics education (mindset, neuroscience, practice teaching ideas). The course challenged the myth of 'the mathematics person' and provided new ways of teaching mathematics, causing teachers to rethink their previous beliefs. 2. In-person network: meetings to discuss the content of the online course & make action plans. School sites worked on context-specific topics for their sites. Teachers worked on mathematics problems together, as an important part of constructing a different relationship with mathematics. Multiple opportunities to compare teaching practices in the course vs their teaching practices. 3. On-site coaching: The county office visited teachers in their school every month. Meetings ranged from lesson planning to sharing analysis of students' work. 4. Admin training: Site & district admins attended network meetings & online course. They engaged as learners &	Combination of in-contact & technology-based deliveries: (On-site coaching/ observation, professional meetings, admin training and online course)	N/A

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Table 2 (*continued*)

Authors (year)	General/ maths domain	Focus target	Group details	Duration	Intervention content	Mode of delivery	Mathematics intervention content
					reflected upon their experiences in teaching/learning mathematics		
Bonne and Johnston (2016)	Mathematics domain	Teacher-focused intervention	Teachers of seven–nine-year-old students in four suburban schools. The teaching experience ranged from one to over 20 years	Teachers in the intervention group attended three after-school professional learning and development workshops (from May to November)	Pedagogical strategies aimed at strengthening students' mathematics self-efficacy, including sharing achievable and specific learning goals with students, referring to these goals when giving feedback, drawing students' attention to the specific skills they have developed, having students keep a record of learning, prompting students to attribute poor performance to insufficient effort, encouraging them to try harder, providing coping models for students, making explicit strategies that can help with mistakes/failures, and using 'similar peers' models	In-contact delivery (Professional development workshops)	N/A
Dommett et al. (2013)	General domain	Teacher-focused intervention	Grade 7 mathematics teachers from three classes in five schools	Professional development workshops for teachers designed to be completed in 50 min in four sessions	- Workshop for teachers focusing on the plasticity of the brain, which would support the development of a flexible mindset including a belief in incremental intelligence. Four separate workshops: *(1) What does the brain do?* Brain areas, function, and basic brain needs *(2) How does the brain work?* Cellular level of the brain –neurons, synapses, and effect of emotions on learning *(3) What happens when we learn?* The flexibility of the brain, examples of learning brain and intelligence *(4) How do we remember things?* Basic memory types, attention, and aiding memory	Technology-based delivery (Computer software)	N/A

questions) themes and/or concepts across multiple studies. The thematic analysis process is presented in detail in the next section.

4.5. Thematic analysis

In the last step, the summaries of the 16 included studies were transferred to NVivo 12 software to be thematically categorized to synthesise the separate studies. Our objective was to extract the relevant information and analyse the qualitative summaries derived from the included studies by allowing categories to emerge inductively through codes from the data. At the same time, we used existing theoretical constructs and frameworks that we had discovered during the literature search to guide the data extraction and unify codes into themes. A preliminary coding scheme was created for the interventions (*the independent variable*) and outcomes and reported findings (*the dependent variable*). We made a distinction between teacher-focused interventions (*where the intervention targets teachers and the content were delivered to teachers directly*) and student-focused interventions (*where the intervention targets students directly and delivers content directly to students without having classroom teachers as intermediaries*) (Yeager & Dweck, 2020).

As regards the content of the intervention, differentiation was made between general ITI intervention content (e.g.*, when students were taught about the incremental view of ability, how the brain works, how the brain grows stronger with effort, etc*.), general ITI intervention in the mathematics domain (*in which the topics of incremental theories of intelligence were discussed specifically in the mathematics domain, such as the nature of mathematics tasks, struggles and mistakes in learning mathematics, and beliefs about mathematics learning*), and mathematical content (e.g.*, fraction concept and algebraic reasoning*).

For the outcomes and reported findings, a secondary coding scheme was used. A distinction was initially made between the outcomes of teacher-focused and student-focused interventions, and then the findings of overlapping-benefit clusters (e.g.*, students' mathematics achievement, students' incremental view of intelligence*) were integrated. Measurement variables were coded based on original individual studies (e.g.*, academic beliefs, effort beliefs, entity theory of intelligence, incremental theory of intelligence*), and several categories emerged, such as teachers' beliefs and practices before intervention, teachers' changes after intervention (e.g.*, teachers' changes in beliefs, teachers' changes in identity, and teachers' changes in practice*), and students' changes after intervention (e.g.*, students' mathematics achievement and students' beliefs*).

5. Results

5.1. Description of included studies

The review consisted of 16 eligible studies, namely 14 journal articles and two peer-reviewed conference proceedings (see Table 1). Most studies were conducted in the United States of America (8 studies), two in England, two in South Korea, and one each in France, Germany, Sweden and New Zealand.

Detailed explanation of the quality appraisal scores including Table of Average Scores for the Criteria of the QRC and EBLCAC checklist are included in Appendix B.

In the following section, we present the results for research question 1 regarding which types of mindset interventions have been aimed at students and/or teachers within math domain. Types of interventions are sorted according to (a) intervention target, (b) intervention content, and (c) delivery mode.

5.1.1. Intervention target

Two main types of intervention target were identified in the included studies: student-focused and teacher-focused. Mindset interventions that target students and deliver content directly to students without using classroom teachers as intermediaries were considered student-focused interventions (13 studies), whereas interventions in which teachers receive treatments directly were considered teacher-focused interventions (four studies) (see Table 2). In Gaspard et al. (2021), there are two conditions of student-focused interventions, in which the content in one condition is delivered by master's students, while the other is delivered by math teachers. Based on the description of the training for the math teachers provided by Gaspard et al. (2021), it is clear teachers received training in workshops where they were provided with theoretical background information of the content and given the necessary intervention materials, including a lesson plan, PowerPoint slides, and a script with detailed notes, to successfully deliver the intervention in the classroom. Since the teachers did not receive the interventions directly, we will also treat this condition as student-focused intervention. The study by Dommett et al. (2013), on the other hand, treated all targets as equally important, is an exception and therefore included in the review process for both teacher-focused and student-focused intervention.

Another target was identified was parents-focused intervention. In Lee et al., 2022, a joint intervention aimed at promoting children's math motivation for both children and parents was conducted. While children received intervention emphasized the importance of growth mindset &gender-fair beliefs specifically in math through quizzes, cartoons, stories, and diverse range of math-specific materials; parents were provided with letters that covered topics such as the significance of adopting a growth mindset, the negative effects of gender-stereotypical beliefs, and the beneficial effects of having high parental expectations on their child's achievement in mathematics.

Table 3
Outcomes of teacher-focused intervention: students' incremental view of intelligence and students' mathematics performance.

No	Authors Year of publication	Group details	Measures	Mindset effects	Mathematics performance effects
01	Anderson et al. (2018)	5th graders	Matched *t*-test Pre & Post	t = −8.69, p < 0.001 Effect side d = 1.48	Treatment group (N = 1068) mathematics achievement was 7.95 points higher (0.1SD); their concepts and procedures sub score were 0.06 points (0.09SD) higher; their data analysis and modelling sub score was 0.06 points (0.09SD) higher; and their communicating reasoning sub score was 0.09 points (0.15SD) higher than the control group (N = 2528)
02	Bonne and Johnston (2016)	Seven–nine-year-old students	Independent *t*-test	Significant differences between comparison and intervention groups Pre-intervention t (89) = 3.26, p <. 01; d = .65; Mid-intervention t (89) = 2.16, p = 0.03; d = .45, but not post-intervention; t < 1	Intervention group showed significant increases in mathematics achievements. No significant correlations between incremental theory of intelligence and mathematics achievement Weak negative correlations between each measure of entity beliefs & post-intervention achievement
03	Dommett et al. (2013)	7th graders (11–12 years old)			Examination within each group over time revealed that no group changed significantly over time (Neuroscience χ2 (3) = 4.63; p = 0.201, Study Skills χ2 (3) = 6.78; p = 0.079, Control χ2 (3) = 1.56; p = 0.668) suggesting no real effect of teacher training of either kind on mathematics performance

5.1.2. Intervention content

Generally, intervention content that aims at changing, shifting, or fostering teachers' and students' beliefs or mindset (*ITI, implicit beliefs, incremental view of intelligence, or beliefs about human attributes*) which was administered explicitly or inexplicitly to students and/or teachers of mathematics could be placed in two main categories: general ITI intervention in general domain and ITI content in the mathematics domain. Content in the general domain means that the intervention's core content teaches the incremental view of ability, or the idea that people's academic and intellectual abilities can be improved through efforts and strategies and should include the concrete actions or steps that participants can take to execute the growth mindset knowledge that they learn (Yeager & Dweck, 2020). General domain interventions have no specific focus on mathematics (or any specific subjects) and do not incorporate any mathematical problem solving. Examples of general domain interventions are Dommett et al. (2013), in which the content focuses on the plasticity of the brain, how the brain works, and what happens when we learn with examples of learning brain and intelligence.

Interventions are considered to belong to the "mathematics domain" when they focus on the specific content of teaching and learning mathematics. Examples of mathematics domain interventions are Anderson et al. (2018), in which the main content from the professional development course 'How to learn Math', consisting of research on mathematics education, challenged the myth of 'the mathematics person' and provided new ways of teaching mathematics, causing teachers to rethink their previous beliefs. Twelve studies' interventions (nine of which were student-focused) were considered to fall specifically within the mathematics domain, and five studies' interventions (one of which was teacher-focused) fell within the general domain (see Table 2).

The general domain interventions in the five studies exhibit notable similarity and consistency in their content. These interventions primarily aim to educate participants (students, teachers, or both) about brain physiology or plasticity, the mechanisms underlying learning and memory, and the enhancement of brain strength through effort. Conversely, the interventions focusing on mathematics domain display substantial variability in their core content. This disparity arises from the distinct aims, participants, and focal points of the individual studies, thereby necessitating divergent intervention content and implementation methods.

For student-focused interventions, in O'Rourke et al. (2014, 2016), growth mindset content was taught directly through game narratives and integrated through the incentive structure of the ("*Refraction*") game-based environment. In Boaler et al. (2018), the intervention content was delivered via a MOOC, in which the incremental view of ability is taught specifically in mathematics. The course included modules about how everyone can learn mathematics to a high level; that mistakes, challenges, and struggle are the best times for brain growth; that, in mathematics, depth of thinking is more important than speed; that mathematics is a creative and beautiful subject; good strategies for learning mathematics (including talking and drawing); and how mathematics is all around us.

In Bagès et al. (2016), the intervention content was delivered via a reading exercise about a 9th-grader role model who had been successful in mathematics. Three conditions were given for the role model's success: that they were hardworking; that they were gifted; and no reason given. In the hardworking condition, the role model description included strategies that they used to achieve mathematics success, such as devoting a lot of time and effort to reviewing mathematics lessons and working hard at mathematics problems. In the gifted condition, the role model's success was not explained by strategies or effort made to learn mathematics; rather, their success was attributed entirely to an innate ability to learn mathematics. In the no-reason condition, no reasons were given for the role model's success.

In Wang et al. (2019), the growth mindset components were embedded into a self-regulation fractions intervention for third-grade students at risk of mathematics disabilities. The self-regulation fractions intervention was designed to support a growth mindset (fostering the belief that intellectual and academic abilities can be developed) along with self-regulation processes in which students set goals, self-monitor, and use strategies to engage motivationally, meta-cognitively, and behaviourally through challenging tasks.

In line with Wang et al. (2019), Fuchs et al. (2021) replicated a fraction intervention condition that specifically targeted third-grade students at risk of experiencing math disabilities. This intervention incorporated components of self-regulation growth mindset (SR-GM), which were integrated into the instructional approach alongside self-assessment and goal setting strategies. Notably, this intervention component encompassed providing feedback and engaging in goal-directed discussions following each "super challenge," as well as incorporating a "Brain Boost adventure" that placed significant emphasis on fostering a growth mindset.

Gaspard et al. (2021) implemented two distinct interventions that targeted students, with one condition led by math teachers and the other facilitated by master's students who volunteered for the study. The intervention content remained consistent across both conditions, encompassing a 90-min lesson that specifically addressed the topics of effort versus talents in mathematics, self-image development and its impact on self-monitoring of progress, as well as the practical applications of mathematics in school, college, careers, and everyday life. Within the lesson, students were provided with dedicated time for individual reflection on the presented content and its relevance to their own lives. Additionally, students were given six interview quotations from young adults that described situations where mathematics proved useful, prompting them to reflect on the personal relevance of these quotations.

Two studies conducted by Lee, Lee, Song, Kim, & Bong (2022) and Lee et al. (2021) focused on students aged 9–11 years old and implemented similar intervention content. The interventions aimed to promote growth mindset and gender-fair beliefs specifically in mathematics using quizzes, cartoons, stories, and a diverse range of math-related materials. Key components of the growth mindset intervention included beliefs about effort, mindsets, strategies to overcome math difficulties, neural plasticity and connectivity, and the importance of perseverance and resilience. Additionally, both studies emphasized gender-fair beliefs, teaching children about equal abilities of males and females in learning and practicing mathematics. In Lee et al. (2021), the intervention lasted for 6 weeks, including a review week, while in Lee, Lee, Song, Kim, & Bong (2022), the intervention spanned 5 weeks without a review week. Notably, Lee, Lee, Song, Kim, & Bong (2022) introduced a joint intervention approach, targeting both children and parents to enhance children's math motivation. While children received the aforementioned treatment, parents were provided with letters discussing the significance of embracing a growth mindset, the adverse effects of gender-stereotypical beliefs, and the positive impact of having high parental expectations on their child's mathematics achievement.

For teacher-focused interventions, in Anderson et al. (2018), the incremental view of ability in mathematics learning and teaching is the main content of the three-year-long network with different modules and modes of training. The first mode of training is the professional development online course 'How to learn Math', which includes eight modules consisting of research on mathematics education (mindset, neuroscience, and practice teaching ideas). The course challenges the myth of 'the math person', provided new practices in teaching mathematics, and allowed teacher-participants to rethink their previous beliefs. Other modes of training are in-person network meetings, in which mathematics teachers can discuss the content of the online course, create action plans, compare teaching practices in the course and their actual practices, and work on mathematics problems together as an important part of constructing a different relationship with mathematics. On-site coaching, another training module, allowed the county office to visit mathematics teachers in their school every month, with meetings ranging from lesson planning to sharing analysis of students' work. Admin training was also utilised in this study, where district administrators attended network meetings and participated in the professional development course. They engaged as learners and reflected upon their experiences in teaching and learning mathematics.

In Boyd and Ash's study (2018), the intervention did not explicitly focus on the incremental view of ability in mathematics learning and teaching; however, it had impacts on changing teachers' beliefs about the nature of school mathematics, the importance of struggling and making mistakes in learning mathematics, mindset, expectation, and grouping practices. Teachers participated in the study and received training in the mastery approach to a professional development project, focusing on collaborative learning strategy, and developing a learning environment that embraces struggle and mistakes.

Bonne and Johnston's (2016) study investigated whether the intervention, designed to make students' progress explicit to teachers and to students themselves, would engender an incremental theory of intelligence and increase mathematics self-efficacy and achievement over time. Teachers in the intervention group attended three after-school professional learning and development workshops about pedagogical strategies aimed at strengthening students' mathematics self-efficacy. These strategies included sharing achievable and specific learning goals with students, referring to these goals when giving feedback, drawing students' attention to the specific skills they have developed, having students keep records of learning (thus prompting students to attribute poor performance to insufficient effort), encouraging them to try harder, providing coping models for students, and making explicit strategies that can help with mistakes/failures using 'similar peers' models.

5.1.3. Delivery modes

Different types of delivery modes were employed in the included studies, namely technology-based delivery, or in-contact (see Table 2). Some studies made use of one of these modes or compared the two (Dommett et al., 2013), whereas others took a mixed approach by using both technology-based and in-contact delivery (Anderson et al., 2018; Balan & Sjöwall, 2022). Technology-based modes includes website-based programs (*Brainology* in Star et al. (2014), MOOC online courses (Anderson et al., 2018; Boaler et al., 2018), game-based learning (*Refraction* in O'Rourke et al., 2014; 2016), online learning (Balan & Sjöwall, 2022) and computer software (Dommett et al., 2013). The most popular delivery method in the in-contact mode was the workshop (five studies), some of which were professional development workshops (Bonne & Johnston, 2016; Boyd & Ash, 2018), while others were structured workshops to teach students about ITI (Blackwell et al., 2007; Dommett et al., 2013). Another popular in-contact delivery was in-class activities (five studies) which were used in Bagès et al. (2016), Fuchs et al. (2021), Lee, Lee, Song, Kim, & Bong (2022), Lee et al. (2021), and Wang et al. (2019). On-site coaching and observation were employed in two studies (Anderson et al., 2018; Boyd & Ash, 2018), and in-person network meetings and administrator training were both utilised in Anderson et al. (2018).

In the subsequent section, we present the findings pertaining to research question 2, which examines the reported effects of growth-mindset interventions on students' beliefs, motivation, and engagement in mathematics learning. Additionally, we address research question 3, which explores the reported effects of growth-mindset interventions on mathematics teachers' beliefs and instructional practices related to mathematics learning. The reported impacts are categorized based on the specific targets of the interventions.

5.2. Outcomes of teacher-focused interventions

5.2.1. Teachers' beliefs and practices before interventions

Of the four teacher-focused intervention studies, two discussed themes related to teachers' beliefs and practices about mathematics before interventions (Anderson et al., 2018; Boyd & Ash, 2018). This is understandable since such in-depth discussion and analysis are only possible with mixed-method or qualitative studies. The most emergent sub-themes are teachers' beliefs about mathematics, teachers' beliefs about themselves, and teachers' practices and expectations of students.

Teachers' beliefs about mathematics: Before interventions, some teacher-participants shared their beliefs about mathematics or 'school mathematics' as a 'fixed' subject in which the task usually requires one method and one solution or requires a quick resolution to find the 'correct' answer. Such beliefs were accompanied with an attitude of avoidance of 'open' tasks, as teachers thought 'open' tasks might be too difficult for students.

Teachers' beliefs about themselves: Teacher-participants reflected on their own relationships with mathematics as a learner (past learning experiences) and as a teacher (past teaching experience). Many teachers had believed that they were not a 'math person' or believed in the idea of a 'math person'; they also carried a fear of failure, feeling incapable of learning (and, later, teaching) mathematics well, and internalised these ideas as they became teachers. These beliefs had shaped their identities and experiences both as learners and teachers. Some teachers reflected on what they were taught as learners and what they continued doing and learning at work as teachers.

Teachers' practices and expectations of students: Before the interventions, teachers' practices in mathematics classrooms were reported to be largely indicative of a teacher-led environment, where teachers provided direct instruction and demonstrated methods, and students passively followed.

5.2.2. Teachers' beliefs and practices after interventions

Teachers' beliefs and practices after interventions were also reported in the two above-mentioned teacher-focused intervention studies (Anderson et al., 2018; Boyd & Ash, 2018). The most emerging sub-themes were teachers' change in beliefs about mathematics, teachers' change in beliefs about themselves, and teachers' change in practices and expectations of students.

Teachers' changes in beliefs about mathematics: Teachers recognised the value of 'open' tasks and considered them more 'enjoyable,' 'playful,' 'open' tasks that allow students to share and discuss ideas and consequently lead to more deeper learning. There was a shift from thinking about mathematics (or 'school mathematics') as a fixed subject which requires one method and a fast solution from students to seeing mathematics as 'collaborative problem solving' and deep thinking where one is continually learning and improving with different ways and different methods. Teachers valued the depths in mathematics and the possibilities to learn and approach mathematics in different ways (for instance, visual mathematics from a paper-folding activity), and they became open to changes and embracing new teaching ideas that encourage a growth mindset in students.

Teachers' changes in beliefs about themselves: Teachers reported that they 'let go' of the damaging myth they had previously internalised (that they were not a 'math person') as they realized this belief had held back their learning. Starting to see themselves differently also allowed them to see students differently, thus altering their expectations of students in learning mathematics. Teachers' changes in beliefs about themselves were described as 'radical' as they had the time and space to take part in the 'critical emotional work' necessary for them to re-examine their past experiences and change how they feel about themselves as learners and teachers of mathematics. Teachers were also reported to have more confidence in learning and teaching mathematics – 'less frightened about making mistakes during a lesson' – as they understood and valued the power of struggle and mistakes.

Teachers' changes in practices and expectations of students: Changes in teachers' practices and expectations of students were reported in the following categories: struggle and mistakes, fostering a learning culture, and reducing scaffolding.

Struggle and mistakes: This was the most prominent change in teachers' attitudes, practices, and expectations of students. Teachers adopted a positive view towards struggle and mistakes, reported being more 'patient' with students, developed a learning environment that embraced mistakes and struggles (allocating time for peers to question each other's mistakes, etc.), or reminded students of the importance of struggle in learning. Teachers also became more relaxed and less tense when students made mistakes.

Fostering a learning culture: Fostering a learning culture or positive learning environment entailed students engaging, exploring, playing, and discussing ideas together. Teachers integrated mindset messages in the classrooms, talked with students about brain growth and neuroplasticity, and created a mistake-friendly learning environment.

Reducing scaffolding: Another change in teachers' practices was a shift from a teacher-led environment to one where students explored and discussed ideas together. Teachers allowed students to engage in 'productive struggling' and 'held (themselves) back' from scaffolding or 'rescuing' students. They became more patient and willing for students to solve the tasks themselves without intervention. Instead of pacing their instructions or providing methods, teachers asked more questions and slowed down to allow students to go into mathematics in greater depth and more conceptually.

5.2.3. Students' changes after teacher-focused intervention

Students' attitudes and behaviours: Changes in students' attitudes and behaviours in mathematics class were reported in Anderson et al. (2018). Teachers shared that a learning mistake-friendly environment had deeply impacted students, and there was a 'wave' of change, especially in terms of students' taking more initiative in discussing, exploring, and sharing their ideas together. Teachers also reported changes in students who had previously thought they were not 'math people' because they were not fast enough or those who did not want to do mathematics if they could not finish it in 5 min.

Students' incremental view of intelligence: Of four teacher-focused intervention studies, two reported on the impacts of a teacher-focused intervention on students' incremental view of intelligence (Anderson et al., 2018; Bonne & Johnston, 2016). In Anderson et al. (2018), results indicated that students had a statistically significant increase in their average score on this mindset scale before and after the teacher-focused intervention. In Bonne and Johnston (2016), the intervention group showed significant increases in incremental beliefs about intelligence compared to the comparison group.

Students' mathematics performance: Of four teacher-focused intervention studies, three reported on students' mathematics achievement (Anderson et al., 2018; Bonne & Johnston, 2016; Dommett et al., 2013)(see Table 3). In Dommett et al. (2013), it was observed that teacher-focused interventions on a general incremental view of intelligence intervention did not improve students' mathematics performances. In Anderson et al. (2018), the results indicated that students had a statistically significant increase in their average Smarter Balanced Assessment Consortium (SBAC) Summative Assessment for California scores. In Bonne and Johnston (2016), the intervention group showed significant increases in mathematics performance compared to the comparison group, even though there was no significant correlation between incremental theory of intelligence and mathematics achievement.

5.3. Outcomes of student-focused interventions

Students' incremental view of intelligence: Of 13 student-focused intervention studies, eight discussed changes in students' incremental view of intelligence (Balan & Sjöwall, 2022; Blackwell et al., 2007; Boaler et al., 2018; Dommett et al., 2013; Gaspard et al., 2021; Lee et al., 2021, Lee, Lee, Song, Kim, & Bong, 2022; Star et al., 2014). Out of the eight studies analysed, six of them reported statistically significant improvements in students' belief in incremental intelligence following the interventions (see Table 4). Among these six studies, Lee et al. (2021), Gaspard et al. (2021), and Boaler et al. (2018) specifically implemented interventions targeting incremental intelligence in the mathematics domain, while the remaining studies employed general interventions focusing on incremental intelligence. Interestingly, two studies that specifically targeted the mathematics domain, namely Lee, Lee, Song, Kim, & Bong (2022) and Balan and Sjöwall (2022), did not observe significant improvements in students' growth mindset. Additionally, Gaspard et al. (2021) noted that one intervention condition, where participants received the intervention content directly from mathematics teachers, did not yield significant gains in the belief in incremental intelligence among students.

Students' mathematics performance: Of 13 student-focused intervention studies, 11 reported and discussed students' mathematics performance, with four studies implementing a general ITI content intervention (Balan & Sjöwall, 2022; Blackwell et al., 2007; Dommett et al., 2013; Star et al., 2014) and seven implementing an ITI intervention specifically in the mathematics domain (Bagès et al., 2016; Boaler et al., 2018; Fuchs et al., 2021; Gaspard et al., 2021; Lee et al., 2021, Lee, Lee, Song, Kim, & Bong, 2022; Wang et al., 2019).

Among the 13 student-focused intervention studies, six (Bagès et al., 2016; Blackwell et al., 2007; Boaler et al., 2018; Fuchs et al., 2021; Gaspard et al., 2021; Wang et al., 2019) reported improvements in students' math performance. However, it is important to note that in Fuchs et al. (2021), those in the self-regulation growth mindset intervention group demonstrated significantly better performance only when compared to the control group. There was no significant difference when compared to the base fraction intervention group. In the study by Gaspard et al. (2021), which included two student-focused interventions and a control group, only participants in the intervention condition delivered by master's students reported significant gains in math performance in the post-test assessment.

Out of the five remaining studies examined (Balan & Sjöwall, 2022; Dommett et al., 2013; Lee et al., 2021, Lee, Lee, Song, Kim, & Bong, 2022; Star et al., 2014), mixed results were found. Among these studies, both Lee et al. (2021) & Lee, Lee, Song, Kim, & Bong (2022) implemented a mindset intervention specifically targeting the mathematics domain, while the others focused on interventions in the general domain. Notably, Lee, Lee, Song, Kim, & Bong (2022) conducted a revised replication of their previous study, Lee et al. (2021), which reported no significant differences in mathematics achievement between the experimental and the control group, although there was a significant decline in the control group's mathematics performance. Similarly, Balan and Sjöwall (2022) and Star et al. (2014) reported no significant differences between the control and experimental groups. Additionally, Dommett et al. (2013) found that while both the control and experimental groups exhibited some gains in math performance, students in the experimental group reported comparatively lower gains than those in the control group.

Students' engagement, motivation, and growth mindset behaviours: Five studies (Lee et al., 2021; Balan & Sjöwall, 2022; Boaler et al., 2018; O'Rourke et al., 2014; O'Rourke et al., 2016) reported changes in students' growth mindset behaviours, perceived competence in mathematics, perceived persistence in mathematics and "deliberate behaviour" (persistence behaviour). Balan and Sjöwall (2022) reported that the intervention group showing an increase in deliberate practice behaviour, or persistence behaviour, as reflected by an elevated frequency of taking the mathematics test (pre-intervention Mean = 1.12, post-intervention Mean = 1.21). Lee et al. (2021) reported similar effects as students in the intervention group demonstrated significant stronger growth mindset, perceived math competence and persistence in math compared with those in the control group. Likewise, Boaler et al. (2018) also observed a comparable trend. They assessed students' engagement in four aspects (participation in class discussions, effort put into work, involvement in class activities, and tendency to give up quickly) before and after the intervention in both experimental and control classrooms. Significant effects were observed in the experimental group, with increased participation in class discussions and reduced

Table 4
Outcomes of student-focused interventions: students' incremental view of intelligence, students' mathematics performance & growth mindset behaviours.

No	Authors Year of publication	Control intervention	Duration	Group details	Results	
	Incremental view of intelligence					
01	Blackwell et al. (2007)	Memory	Eight periods of 25 min	At-risk 7th graders (12–13 years old)	EXP > CON	The experimental group showed a significantly greater change in theory of intelligence than the control group and was significantly higher in incremental theory than the control group after the intervention.
02	Dommett et al. (2013)	Control group without intervention	Four periods of 50 min	7th graders (11–12 years old)	EXP > CON	The experimental group showed a longer-term increase in belief in incremental intelligence that remained over a year after the intervention as opposed to no significant differences from baseline at any point in the control group
03	Star et al. (2014)	Virtual environment & video on mathematical patterns	Two periods of 30 min	5th graders to 8th graders	EXP > CON	The experimental group had higher incremental views of mathematics ability than the two control groups, especially for students in grade 7 and 8.
04	Boaler et al. (2018)	Control group without intervention	Six modules, 15–20 min/each	Middle school students (6th, 7th, 8th grade)	EXP > CON	The experimental group had significantly higher reports of growth mindset and perceptions of mathematics being an interesting and creative subject (mathematics creative). They also reported feeling less fearful (fear of mathematics) than the control group
05	Lee et al. (2021)	Wait-list control condition	Six bi-weekly 40-min sessions	4th graders	EXP > CON	Students who received the intervention exhibited significantly stronger growth mindset.
06	Gaspard et al. (2021)	Two intervention conditions (master's student × and mathematics teacher**) vs control condition	One 90-min lesson (presentation for the whole class 45-min) & relevance-inducing tasks, on which students worked individually for about 40-min.	9th graders	EXP* > CON No significant differences between EXP** & CON	Participants in the experimental group where the intervention content was delivered by master's degree students reported higher importance of effort & lower importance of talent compared to those in the control group. No similar effects were observed between the intervention led by mathematics teachers and the control group.
07	Balan and Sjöwall (2022)	Active control group (Quizzes on news)	Four online modules consisting of 8 sessions (25–35 min) were completed over 5 weeks, with a 2-week break before repeating the modules. In the second round, there was a 1-week break after each module.	7th graders (aged 12–13)	No significant differences	
08	Lee, Lee, Song, Kim, & Bong (2022)	Control group without intervention	Five bi-weekly 40-min sessions	3rd & 4th graders	No significant differences	
	Mathematics performance					
01	Blackwell et al. (2007)	Memory	Eight periods of 25 min	At-risk 7th graders (12–13 years old)	EXP > CON	The experimental group showed no decline in mathematics performance after the intervention as

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Table 4 (*continued*)

No	Authors Year of publication	Control intervention	Duration	Group details	Results	
						opposed to the decline found among them before and the continued declining grades found for the control group
02	Dommett et al. (2013)	Control group without intervention	Four periods of 50 min	7th graders (11–12 years old)	EXP < CON	At baseline the control group showed significantly poorer mathematics performance than the neuroscience group. However, at all post-assessment times there were no differences between the two groups
03	Star et al. (2014)	Virtual environment & video on mathematical patterns	Two periods of 30 min	Students from grade 5 to grade 8	No significant differences	
04	Bagès et al. (2016)	'Gifted' explanation & No reason given	One period	Middle school students (M age = 11 years 7 months)	EXP > CON	The experimental group performed significantly better than the two control groups
05	Boaler et al. (2018)	Control group without intervention	Six modules, 15–20 min/each	Middle school students (grade 6, 7, 8)	EXP > CON	The experimental group performed significantly better than the control group
06	Wang et al. (2019)	Base condition of fraction intervention without self-regulation & growth mindset (SR-GM) component & control condition without intervention	Three periods of 35 min per week for 13 weeks, in which time spent on SR & growth mindset component averaged 4–7 min per period	Low math achieving 3rd-grade students	EXP > CON	The experimental group outperformed the control condition in several areas where the base condition alone did not.
07	Lee et al. (2021)	Wait-list control condition	Six bi-weekly 40-min sessions	4th graders	No significant differences	The control group mathematics achievement fell significantly over time, while the intervention group did not have similar decline.
08	Gaspard et al. (2021)	Two intervention conditions (master's student × and mathematics teacher**) vs control condition	One 90-min lesson (presentation for the whole class 45-min) & relevance-inducing tasks, on which students worked individually for about 40-min.	9th graders	EXP* > CON No significant differences EXP** & CON; EXP* & EXP**	Participants in the experimental group where the intervention content was delivered by master's degree students reported higher mathematics' achievement in the math speed test.
09	Fuchs et al. (2021)	Base condition of fraction (FRAX) intervention without self-regulation & growth mindset (FRAX SR-GM) component & control condition without intervention	Three periods of 35-min/ week for 13 weeks, time spent on self-regulation & growth mindset component averaged 4 to 9-min/ period.	Low math achieving (at risk) 3rd-grade students	EXP_{FRAX} > CON $EXP_{SR\text{-}GM}$ > CON No significant differences between EXP_{FRAX} & $EXP_{SR\text{-}GM}$	Both the base fraction condition (FRAX) & the self-regulation growth mindset fraction condition (FRAX SR-GM) demonstrated significantly better performance when compared to the control group. There was no significant differences between the base fraction condition (FRAX) & the self-regulation growth mindset fraction condition (FRAX SR-GM).
10	Lee, Lee, Song, Kim, & Bong (2022)	Wait-list control condition	Five bi-weekly 40-min sessions	3rd & 4th graders	No significant differences	Only a sub-group of students who considered math to be more important experienced an enhancement in math self-efficacy following the intervention for students, subsequently leading to improved math achievement.
11	Balan and Sjöwall (2022)	Active control group (Quizzes on news)	Four online modules consisting of 8 sessions (25–35 min) were completed over 5 weeks, with a 2-week	7th graders (aged 12–13)	No significant differences	

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Table 4 (*continued*)

No	Authors Year of publication	Control intervention	Duration	Group details	Results	
			break before repeating the modules. In the second round, there was a 1-week break after each module.			
	Students' engagement, motivation, and growth mindset behaviours					
01	Blackwell et al. (2007)	Memory	Eight periods of 25 min	At-risk 7th graders (12–13 years old)	EXP > CON	Teachers reported that 27% of students in the experimental group displayed improved motivation in their mathematics classrooms, while only 9% of students in the control group showed similar changes.
02	Star et al. (2014)	Virtual environment & video on mathematical patterns	Two periods of 30 min	Students from grade 5 to grade 8	No significant differences	
03	O'Rourke et al. (2014)	Control condition played the Refraction game without the 'growth mindset' narratives, feedback, & incentive structures	Average 3 min	Elementary students	EXP > CON	1.The experimental group played more levels (a mean of 6.5 levels compared to 5.5 for those in control); they also stayed in the game significantly longer, but these effects are very small 2.The experimental group learned to use the strategies incentivised by the 'Brain points' system, exhibiting strategic behaviour more often than students in the control condition (2.49 metrics per minute compared to 2.18 triggers per minute for the control) 3. The intervention encouraged more low-performing students to persist for extended periods of time in Refraction (49% of students in the experimental version were labelled as struggling, 29% were advanced, and 22% were average, compared to 37% struggling, 40% advanced, and 23% average for the control) 4.The intervention may improve reaction to challenge: a promising trend showing students in the experimental version may play longer after experiencing struggle and failure in the Challenge level
04	O'Rourke et al. (2016)	Four experimental versions of Refraction: No Narrative, No Point, Random Point, No Progress Visualisation Control version is a growth mindset narrative through animations, brain point incentive, and progress visualisation	Average 2–3 min	Elementary students	No Narrative > CON No difference between No point & CON Random Point < CON No Progress Viz < CON	Students in the No Narrative condition played significantly longer; they completed significantly more levels and exhibited higher growth mindset behaviours per minute than those in the control. Students in the No Point condition played for less time; however, no significant differences in the number of levels completed compared to the control group. Students in the No Point condition exhibited more significant GM behaviours

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Table 4 (*continued*)

No	Authors Year of publication	Control intervention	Duration	Group details	Results	
						during gameplay Students in the control condition played significantly longer; they also completed significantly more levels and exhibited higher GM behaviours per minute than to those in the Random Point condition. Students in the control condition played significantly longer; they also completed significantly more levels. However, there is no difference in terms of GM behaviours to those in the No Progress Visualisation condition.
05	Boaler et al. (2018)	Control group without intervention	Six modules, 15–20 min/each	Middle school students (6th, 7th, 8th grade)	EXP > CON	Students' engagement was evaluated in four areas (*class discussion participation, work effort, class involvement, and perseverance*) pre & post-intervention in both experimental and control classes. The experimental group showed significant improvements, including increased participation in class discussions and decreased tendency to give up quickly, compared to the control group.
06	Lee et al. (2021)	Wait-list control condition	Six bi-weekly 40-min sessions	4th graders	EXP > CON	Students in the experimental condition demonstrated stronger perceived competence, and persistence in math, while also displaying significantly weaker math-gender stereotypic beliefs compared to the control group.
07	Balan and Sjöwall (2022)	Active control group (Quizzes on news)	Four online modules consisting of 8 sessions (25–35 min) were completed over 5 weeks, with a 2-week break before repeating the modules. In the second round, there was a 1-week break after each module.	7th graders (aged 12–13)	EXP > CON	The intervention group showed significantly difference in *deliberate practice behaviour*, or persistence behaviour, in attempts to take the mathematics test compared with the control group.

tendency to give up quickly compared to the control group. O'Rourke et al., (2014) reported the same effects on students' growth mindset behaviours as the experimental group played more levels, stayed longer (although with small effects). They exhibited strategic behaviours more frequently compared with the control group (2.49 metrics per minute compared to 2.18), the intervention also encouraged persistence in struggling low-performing students, and there are some potential improvements in response to challenge observed in the experimental group. O'Rourke et al. (2016) extended the investigation to examine how different aspects of the Refraction game design might influence students' growth mindset behaviours (see Table 4).

Two studies (Blackwell et al., 2007; Star et al., 2014) examined students' engagement and motivation following student-focused interventions. Blackwell et al. (2007) found that 27% of students in the experimental group exhibited positive changes in motivation in their mathematics classrooms, compared to only 9% in the control group, as reported by their teachers. In contrast, Star et al. (2014) did not find any significant changes in students' motivation across all intervention conditions.

6. Discussion and implications

This study provides a systematic review of mindset interventions in primary and secondary mathematics classrooms with the aim of deepening our understanding of what types of interventions have been carried out and their reported impacts. We have extended previous review studies and meta-analyses on mindset interventions in two ways. Considering the distinctive nature of individuals' beliefs about mathematics, our primary objective was to explore the extent of research conducted on mindset interventions within mathematics education. In doing so, we aimed to isolate the potentially idiosyncratic impacts of mindset interventions specifically within the domain of mathematics education. Secondly, our intention was to enhance the existing literature on mindset interventions by employing a systematic review methodology that encompassed a wide range of study types, including quantitative, mixed-method, and qualitative research. By doing so, we aimed to capture a diverse and authentic perspective on potential outcomes of such interventions. Our study's findings, presented through a comprehensive synthesis of the research, provide a detailed and illuminating understanding of the key features and characteristics of mindset interventions. By systematically analysing and synthesizing the available literature, we have identified and elucidated the specific elements that constitute mindset interventions in mathematics domain. Furthermore, we examined the advantages and limitations of various growth mindset interventions in the mathematics domain and explored the possibility that previous research may have overlooked the potential positive effects of mindset interventions in the mathematics classroom on students' learning outcomes and academic performance.

6.1. Intervention content

Interventions aimed at changing teachers' and students' beliefs or mindsets can be categorized into two main categories: general and mathematics-specific interventions. General interventions aim to foster an incremental view of ability, emphasizing that academic and intellectual skills can be developed through effort and strategies. These interventions often provide practical steps for participants to apply their newfound growth mindset knowledge. Typically, general interventions educate participants about brain plasticity, brain function, and the learning process, using examples related to intelligence and the brain (Blackwell et al., 2007; Dommett et al., 2013; Star et al., 2014). They are not focused on specific subject domains. Additionally, some general mindset interventions go beyond the incremental view of ability and teach participants other concepts like deliberate practice (Balan & Sjöwall, 2022).

Math-specific mindset interventions are specifically designed to target the teaching and learning of mathematics. Based on the examined studies, these interventions can be categorized further into two groups: In the first group, the interventions integrate the incremental view of ability directly into learning a specific mathematical content (O'Rourke et al., 2014; O'Rourke et al., 2016; Wang et al., 2019; Fuchs et al., 2021). These studies only focus on students as the intervention target. For instance, both Wang et al. (2019) and Fuchs et al. (2021) interventions embedded the growth mindset components into a self-regulation fractions intervention for at-risk third-grade students. The self-regulation fractions intervention was designed to support a growth mindset along with self-regulation processes, in which students set goals, self-monitor, and use strategies to engage motivationally, meta-cognitively and behaviourally through challenging tasks in fractions. The second group consists of mindset interventions that promote an incremental view of ability with more general content that focus on mathematics. These interventions center on imparting the belief to participants (whether teachers, students, or both) that one's mathematical skills can be cultivated and improved through dedicated efforts. They emphasize the significance of mistakes and challenges in the development of mathematical abilities. (Bonne & Johnston; 2016; Boaler et al., 2018; Anderson et al., 2018; Gaspard et al., 2021; Lee et al., 2021; Lee, Lee, Song, Kim, & Bong, 2022; Balan & Sjöwall, 2022). The content in these interventions often challenge persisting myths about mathematics (e.g., math brain, math person, talent vs effort in mathematics, etc.) emphasized gender-fair beliefs that both females and males can be equally good at mathematics, or teaching participants about mathematics' utility and value in everyday life. In summary, mathematics-specific mindset interventions can be classified into two categories: those that integrate the incremental view of ability directly into the mathematical content, and those that have a broader objective of fostering an incremental view of ability within the context of mathematics.

6.2. Student-focused interventions

The modal intervention (Blackwell et al., 2007) was conducted in the USA, employed quantitative methods, had a student-focused domain-general intervention, and used an in-person delivery method. Our findings are in line with the research conducted by Zhang et al. (2017), indicating that there has been limited emphasis on exploring the influence of teachers' mindset on students' learning and achievement (Yeager et al., 2022). Moreover, the majority of efforts have primarily concentrated on implementing direct-to-student programs with the goal of instilling a growth mindset among students (Yeager & Dweck, 2020). Furthermore, all the examined student-focused interventions were quantitative studies. Thus, there is also a lack of clear understanding of the context and why and how these interventions support students' shift in mindsets, as no in-depth insights or qualitative reports were offered by these studies. These results suggest that further research is needed to provide a comprehensive view of whether, and how best, to employ mindset interventions in mathematics classrooms. Another significant limitation we observed is the absence of follow-up periods in many studies. Most of the studies that focused on interventions for students did not gather follow-up data, leaving the sustainability of the effects unknown. These examined studies typically implemented a pre-post design, meaning they assess mindset before and after the intervention. Only Gaspard et al. (2021) reported follow-up with students on average 3 months after the intervention (time point 3), however they also did not include the results of time point 3 measurements on students' mindset to see if the changes in mindset brought about by the intervention persist over time or transfer to other contexts outside of the intervention. Similar observation has been reported by (Ku & Stager, 2022) in a review about the effectiveness of growth mindset in young adults. This represents a notable limitation given that the primary objective of these interventions typically involves empowering students, altering their beliefs regarding the inherent nature of talent and the significance of diligent effort, and ultimately facilitating their autonomy in learning. As a result, our understanding of the long-term durability and generalizability of intervention effects beyond the immediate context is hindered, impeding comprehensive assessments of their lasting impact. Therefore, further research is needed to investigate the sustainability of the interventions and applied in contexts outside of the research settings.

Regarding the reported impacts of these interventions, of 4 domain general mindset interventions targeting students, only Blackwell et al. (2007) reported to be successful at improving students' mathematics performances. Mathematics-specific mindset interventions are more commonplace compared to domain general mindset interventions as there are 9 included studies that fell into this category. It is noteworthy that the majority of these interventions showed positive effects on students' math performance to varying degrees. In other words, while the majority of the mathematics-specific mindset interventions had a positive impact on students' mathematics performance, the magnitude or degree of improvement differed from one intervention to another. For example, in Lee et al. (2021), although there was no significant difference between the control and experimental groups, the control group experienced a significant decline in math achievement over time, whereas the intervention group did not exhibit a similar decline. Similarly, in Gaspard et al. (2021), students in the experimental group, where the intervention was conducted by master's degree students, demonstrated higher achievement in math speed tests. Notably, two studies (Fuchs et al., 2021; Lee, Lee, Song, Kim, & Bong, 2022) aimed to replicate previously successful interventions (Lee et al., 2021; Wang et al., 2019). The results of the two replication studies did not show the same positive effects as the original studies they sought to replicate. It is, however, important to point out that in Fuchs et al. (2021), both the base fraction condition (FRAX) & the self-regulation growth mindset fraction condition (FRAX SR-GM) demonstrated significantly better post-test performance than the control group. Hence, it is plausible that while the self-regulation growth mindset fraction condition did not offer additional advantages in terms of fraction performance compared to the base fraction condition, it might have other unmeasured benefits on other outcomes. In Lee, Lee, Song, Kim, & Bong (2022), while they did not find similar success as in Lee et al. (2021), the authors also reported that a sub-group of students who considered mathematics to be more important experienced a development in mathematics self-efficacy following the intervention, subsequently leading to improved mathematics achievement.

It seems that mathematics domain specific interventions were more successful at improving students' mathematics performances than those using general ITI content. While none of the general-domain mindset interventions targeting students (Balan & Sjöwall, 2022; Dommett et al., 2013; Star et al., 2014) were able to replicate the success from Blackwell et al. (2007), most interventions that focused specifically on mathematics reported greater improvements in students' mathematics performance, and positive changes in students' engagement and motivation regardless of delivery methods or specific content. This finding suggests that the idiosyncratic nature of beliefs about mathematical ability may require targeted interventions. Targeted interventions can take into account the specific challenges and misconceptions that individual may have regarding mathematical ability or mathematics as a subject. For instance, within the realm of mathematics education, the prevailing belief that strongly persists is the notion of a "math brain," wherein individuals are considered to either possess innate mathematical abilities or lack them altogether. Teachers and students often consider mathematics achievement to represent an inborn ability rather than an achievement compared to achievements in other domains (Beach & Dovemark, 2007; Jonsson et al., 2012). By addressing these idiosyncratic beliefs through specific strategies and intervention content, it is possible to promote a more positive mindset and improve mathematical performance (O'Rourke et al., 2014; O'Rourke et al., 2016; Bagès et al., 2016; Boaler et al., 2018; Wang et al., 2019; Gaspard et al., 2021; Lee et al., 2021). However, additional research is required to offer a comprehensive understanding of the effectiveness and optimal implementation of mindset interventions in mathematics classrooms for students. As well, it may be possibly that other domains hold similar potential for targeted intervention, which is another topic for future research.

6.3. Teacher-focused interventions

In contrast, interventions focused on teachers were relatively much less prominent in the literature, despite their apparent potential for broad scalability and greater impact. In line with previous research on teacher-focused growth-mindset interventions (Foliano et al., 2019; Rienzo et al., 2015; Yeager & Dweck, 2020), the present study found mixed effects on students' mathematics achievement. However, once again more positive effects were found in those teacher-focused interventions which focused on the specific content of teaching and learning mathematics. Importantly, Anderson et al.'s (2018) main content was taken from a professional development course, which provided new ways of teaching mathematics, causing teachers to rethink teaching practices along with their previous beliefs. Results found a clear shift not only in teachers' beliefs about mathematics and about themselves, but also in their practices and expectations of students after the interventions. Teachers did not only learn about mindsets, but also had a chance to examine their own beliefs about mathematics, their relationships, and experiences with mathematics as learners and teachers. The potential for belief changes arose from grounding the expansive content of the growth mindset within the specific context of mathematics, while providing participants with sufficient time and space within the intervention activities for such changes to occur. In Boyd and Ash's study (2018), while the intervention did not explicitly focus on the incremental view of ability in mathematics learning and teaching, it had impacts on changing teachers' beliefs about the nature of mathematics, the importance of struggling and making mistakes in learning mathematics, mindset, expectations, and grouping practices.

On the other hand, as seen in Foliano et al.'s (2019) study, participants in the teacher-focused mindset intervention in Dommett et al.'s (2013) received a general domain intervention. Teachers received two general training sessions about growth mindset, how to encourage, reinforce and teach their students about the malleability of their intelligence. While these training sessions were beneficial in introducing a growth mindset to the teachers, they did not have any specific focus on mathematics (or any subjects); nor did they incorporate any (mathematical) teaching practices. It is difficult to say and evaluate in what ways teachers could have made the connections between the content of the incremental view of intelligence that they received and the subject in practice.

Another possible explanation is that the length and intensiveness of the interventions supported more sustained changes in classroom practices. Both studies (Anderson et al., 2018; Boyd & Ash, 2018) were conducted with teachers participating in larger-scale research that lasted between one and three years, and the professional development support extended past the interventions themselves. For instance, in Anderson et al. (2018), the main intervention content was delivered via an online course that took teacher-participants 30–40 h to finish. Teacher-participants also had various support and reflection opportunities with other colleagues and researchers. Given that, for example, in Dommett et al.'s (2013) and Foliano et al.'s (2019) interventions teachers received four general ITI training sessions (50 min per session) via software passively and two training sessions, respectively, these studies lasted less time and were presumably less intense, and there was little room for reflective work or interactive discussion.

6.4. Implications and limitations

One possibility is that mindset interventions in isolation from changes in classroom practices or other mathematical beliefs may not be sufficient. Mathematical norms and standard classroom interactions should be considered from a complex systems perspective, which suggests lasting change requires a focus on the interaction-dominant dynamics of a system. Without including changes in classroom practice, a temporary change in beliefs cannot have a large and sustained impact on learning outcomes (Orosz et al., 2017). In a double-blind clinical trial conducted by Yeager et al. (2022), the results indicated that implementing a brief, general domain growth mindset intervention led to overall improvements in mathematics achievements. However, the extent of these benefits varied depending on the classroom environment. Notably, Yeager et al. (2022) demonstrated that students in classrooms with growth-mindset teachers experienced significant gains, whereas those with fixed-mindset teachers did not observe the same positive effects. This highlights the crucial role of the learning environment and the mindset of teachers in influencing student outcomes. Given these findings, further research is necessary to delve into the causal relationship between teacher mindsets and student performance, as well as to develop interventions that effectively target both students and teachers. By considering the importance of context of the learning environment, future studies can explore innovative approaches that enhance teacher mindsets and implement comprehensive interventions that positively impact students' academic achievements and mindset development. Furthermore, opportunities to make behavioural changes based on changed beliefs are also necessary. Social-psychological interventions have great potential to inform changes in educational settings; however, they are not "magic" (Yeager & Walton, 2011). If a change in beliefs is met with a return to procedurally heavy outcome-oriented instruction, as is typical in most classrooms around the world, it may not be sufficient for students to change their behaviour or have meaningful effects on their learning. Schoenfeld (1988) highlighted the systematic nature of the instructional origins of students' and teachers' beliefs about mathematics. It is noteworthy that the existence of "fixed" beliefs (e.g., Anderson et al., 2018; Sun, 2018) about mathematics among teachers and students is not a recent phenomenon, as also noted by Schoenfeld (2016). Efforts to cultivate teachers' and students' beliefs about the subject, without concurrent changes in instructional approaches or the nature of mathematical tasks and learning environments, are unlikely to have lasting effects. Therefore, it is crucial for learning environments to promote challenges and engage students in deliberate and effortful practices. Mathematical tasks should involve open-ended, non-routine problems that enable students to explore, reflect, discuss, and share their ideas until they discover a suitable strategy. Providing opportunities to engage in, for instance, deliberate practice in learning mathematical content, paired with a changing mindset, may prove more beneficial in the long run (Lehtinen et al., 2017).

Learning environments that support flexibility, encourage trials and errors and promote the development of more adaptive expertise may also provide avenues to employ the benefits of a mindset intervention, as they allow mathematical content to be approached from multiple perspectives and encourage the engagement with learning that crosses typical content boundaries (Bui et al., 2022). For example, in a game-based learning environment that promotes the development of adaptive expertise with arithmetic, students can engage in practising their arithmetic skills at multiple levels of difficulty within the same task. Crucially, they receive immediate feedback on their performance and can retry an activity to improve said performance (Lehtinen et al., 2015). Moreover, this improvement in performance does not come from a procedural improvement, such as a faster response time, but from deeper and more complex engagement with the mathematical content by making more complex connections between different concepts within arithmetic (McMullen et al., 2016, 2017). This type of environment may be particularly fruitful for supporting the personal experience of seeing meaningful improvement after practice that would solidify an understanding of the true nature of the source of mathematical skill.

Our study is limited by the timeframes and studies available during our research. It is also possible that we missed some studies that fit our criteria regardless of our efforts to expand or search for suitable studies. We are also aware of studies published in languages other than English that could have fit our review as growth-mindset interventions are popular all over the world. However, the use of systematic search strategies minimised the chance of missing relevant studies.

In addition, another possible limitation of this systematic review is the potential for publication bias (Macnamara & Burgoyne, 2022). The reliance on peer-reviewed published studies could introduce a bias towards studies with positive or statistically significant results being more likely to be published, while studies with negative or inconclusive findings might be underrepresented. This could affect the overall picture presented in the review, as it may not fully capture the range of outcomes and effects observed in all studies conducted on growth-mindset interventions in mathematics classrooms. It is important to acknowledge this limitation and recognize the need for caution when interpreting the overall findings of the review.

6.5. Conclusions

The question of whether growth-mindset interventions work has been asked many times over the last decades (Macnamara & Burgoyne, 2022; Yeager & Dweck, 2020) as this theory promises great benefits, such as academic improvement, better focus on learning, and positive attitudes towards mistakes and challenges, which lead to motivational and behavioural changes. However, our findings show that not all growth-mindset interventions worked as intended, whether the targets were students, teachers, or both. As discussed by Yeager and Dweck (2020), 'context' plays a significant role in the success of a growth-mindset intervention. Too many variables need to be considered when such social-psychological interventions are implemented in an educational context. The idea of having a growth mindset means holding the key to success might be too abstract without the right environment and support or 'context' in which one can develop. In mathematics education, the 'key' to a growth-mindset intervention might be domain specificity. Among all our reviewed studies, those that were domain-specific consistently reported more positive students' improvement in mathematics than generic-domain studies, regardless of intervention target, intervention content, or mode of delivery. By embedding the comprehensive principles of the growth mindset specifically within the realm of mathematics and allowing participants time and space for engagement with mathematical content, the interventions created opportunities for transformative changes in beliefs and subsequently improving learning outcomes. Evidently, for growth-mindset interventions to work, students need to be presented with opportunities where they can engage with mathematical content through practice. In some cases, the presence of a growth-mindset narrative is not even necessary when the environment is embedded with elements that support and encourage effortful practices and progress was made visible to students (O'Rourke et al., 2016).

In conclusion, a learning environment where mistakes and challenges are welcomed and students' efforts in learning are made visible to them through supportive practices is critical to maintain such beliefs. Given the prevalence of popular beliefs about the innateness of mathematical ability, it is important for researchers, educators, and teachers of mathematics to consider the impacts of domain-specific mindset beliefs when designing mathematics interventions.

Author statement

Bui Phuong: Conceptualization, Methodology, Formal analysis, Data curation, Writing-Original draft, Writing- Review & Editing; Pongsakdi Nonmanut: Data curation, Formal analysis, Reviewing & Editing. McMullen Jake: Formal analysis, Writing-Reviewing and Editing, Visualisation. Lehtinen Erno: Conceptualization, Methodology, Validation, Supervision. Hanula-Sormunen Minna: Conceptualization, Methodology, Validation, Supervision.

Conflicts of interest

We have no known conflict of interest to disclose.

Data availability

Data will be made available on request.

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.edurev.2023.100554.

Appendix A

Mindset interventions in Mathematics Classrooms Review Coding Book.

Theme/code	Description/definition
Studies' information	Information about the studies
Authors	Authors of the study
Year	Year study was published
Location (geography)	Where the intervention(s) were conducted and reported
Type of publication	Type of study: peer-reviewed journal, peer-reviewed conference proceeding, book chapter, etc.
Language(s)	What language the study is published in
Delivery modes	How intervention content is delivered to participants
In-person/in-contact delivery	Researcher(s) or teacher(s) or expert(s) provide the intervention content in person
Workshops	Workshop is mentioned as the mean of the intervention delivery for participants
Professional development workshops/trainings events	Specific training events for participants (teachers, experts, admin staff, etc.) who are receiving professional development skills/behaviors/intervention content.
Administration training	Training events specifically for admin staff or teacher(s).
Professional meeting	Meeting(s) are held for participants taking part in the intervention(s) to discuss about professional development related topics
On-site coaching	Coaching that happening at school(s) and/or lesson(s) related to the intervention(s) content.
Observation	Classroom observation
In-class activities	Activities related to the intervention(s) that are held in-class, during the lesson(s)/intervention(s).

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Theme/code	Description/definition
Technology-based delivery	The intervention(s) content is delivered via technology-based methods directly to the participants without human intervening (for instance: via software, program, website, etc.)
Website	Website-based learning program(s) where participants receive the intervention content from without human intervening.
Computer software	Software(s) that are designed to provide the intervention content directly to participants without human intervening.
Game-based program	Online or offline game-based learning programs that are designed to provide the intervention content directly to participants without human intervening.
MOOC/Online courses	Mass open online courses or online courses that designed to provide the intervention content directly to participants without human intervening.
Letters	Letters sent by researchers to participants.
Participants characteristics	Who the intervention(s) are for?
Student(s)	Participants who are students
Ages	Age range
Class	Grade level
School	School information
Location	Geographic location (state, country if available)
Social – economic background	Social economic background of participants (if available)
Academic ability	Students' academic ability or achievement (at-risk or low-achieving, good, typical etc.)
Math achievement/math ability	Students' mathematical ability or achievement (grades, ranks, or levels if specific)
Teachers	Participants who are teachers
Ages	Teachers' ages
Teaching experience	Teachers' teaching experiences (if available)
Class level	Class level that teacher(s) are teaching
Subject(s)	Subject(s) that teachers teach (beside mathematics) – if available
Intervention characteristics	
Intervention target(s)	Who the intervention(s) are for?
Student-focused intervention	Mindset interventions that target students and that deliver content directly to students without having classroom teachers as intermediaries are considered student-focused interventions.
Teacher-focused intervention	Mindset interventions that target teachers and that deliver content directly to teachers.
Intervention duration	Length of the intervention and related information about the duration of the intervention (minutes of sessions, total length of intervention, time allocation for specific tasks if available).
General implicit theories of intelligence intervention in general domains	This means that the intervention's core content teaches incremental view of ability or the idea that people's academic and intellectual abilities can be improved through efforts and strategies, and it should include the concrete actions or steps that participants can take to execute the growth mindset knowledge that they learn. General domain interventions would not have any specific focus on mathematics (or any specific subjects), nor does it incorporate any mathematical problem solving.
General implicit theories of intelligence intervention in mathematics domain	General implicit theories of intelligence intervention in mathematics domain are the interventions focusing on the specific content of teaching and learning mathematics through the implicit theories of intelligence perspectives. For instance, the intervention content focuses on math education specifically or provides new ways of learning or teaching math or provides the content of general implicit theories of intelligence with explicit examples in mathematics.
Mathematical intervention context	Specific content of mathematics subject that are integrated/combined with in the intervention such as mathematics concepts, specific math tasks, or mathematical thinking in problem solving.
Implicit theories of intelligence intervention content	Content of the implicit theories of intelligence that the intervention(s) deliver to participants.
Outcome measurements	Measurements that are used to assess outcome(s) of the intervention(s)
Motivational measures	Instruments that are used to measure motivation.
Game analytics	Data related to gameplay: Time play, number of games/levels, length, difficulties, etc.
In-class practices	In-class teaching practices and strategies (observed or reflected) by teachers.
Teachers' beliefs (general)	Teachers' beliefs (in general) about learning and teaching practices (questionnaire or interview or reflection logs).
Teachers' beliefs about mathematics	Teachers' beliefs about learning and teaching mathematics as learners or as teachers of the subject (questionnaire or interview or reflection logs)
Students' mathematics achievement measurement(s)	Students' mathematics achievement measurement(s) could include tests or exams, or specific mathematics achievement assessments chosen by the studies.
Students' engagement survey/questionnaire	Surveys or questionnaire that collect data about students' engagement in mathematics.
Students' mindset survey/questionnaire (general domain)	Surveys or questionnaire that collect data about students' mindset (general domain)
Students' mindset survey/questionnaire (mathematics domain)	Surveys or questionnaire that collect data about students' mindset (mathematics domain)
Reported impacts	Reported impacts on interventions
Student-focused impacts	Reported impacts on student-focused interventions
Students' incremental view of intelligence	Changes, or gains or impacts on students' incremental view of intelligence are mentioned, such as: fostering growth mindset, shifting mindset, shifting self-belief, higher students' incremental view of ability than pre-test/or control-groups.

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Theme/code	Description/definition
Students' mathematics performance	Students' math performance measured with study-specific mathematic tasks or post-test used to compared between groups or pre and post-interventions.
Students' growth mindset behaviours	Students' growth mindset behaviors were measured and reported in specifically in O'Rourke et al., (2014) & O'Rourke, et al. (2016) using in-game data analytics in which students played different versions of the game Refraction.
Effort beliefs	Beliefs about efforts, for instance: the importance of trying and making efforts to practice, the importance of learning and making mistakes and learning from mistakes, embracing "struggling" or making mistakes.
Intelligence beliefs	Beliefs about one's own intelligence, ability or capacity to learn or develop a certain skill or knowledge (in general); or beliefs about one's own intelligence, ability or capacity to learn or develop a certain skill or knowledge in mathematics, or to do a certain type of mathematic tasks; beliefs about one's own capacity that expressed that whether one has the "ability" to be a math person (or not) or to have a "math brain" (or not).
Students' engagement and motivation	Studies reported measurements of students' engagement and motivation (study specific).
Teacher-focused impacts	Reported impacts on teacher-focused intervention
External support	Value and importance of external support such as administration support, Network (project) support, peer support from professional meetings/workshops/forums or platforms for supportive and reflective works, sharing about experiences and reflections.
Teachers' beliefs about mathematics (as a subject) before intervention	Teachers' beliefs about mathematics as a subject, general beliefs about learning mathematics, nature of mathematics tasks, beliefs about mathematics learning ability of students, general beliefs about learning and teaching mathematics (at school context).
Teachers' beliefs about teaching practices before intervention	Teachers' beliefs about practices of teaching mathematics: for instance, what are the roles of teachers in a mathematics lesson, how should lessons be conducted, general beliefs about practices that related to students' ability (i.e. grouping), general beliefs about learning environment (in a mathematics lessons).
Teachers' beliefs about themselves before intervention	Teachers shared or reflected on their own beliefs as a learner and/or as a teacher. Teachers shared or reflected about their identities, past experiences, what they had been taught to believe about themselves, about their relationships with learning (mathematics) or their relationships with mathematics or as mathematicians.
Teachers' practices before intervention	Practices or activities or guiding instructions were mentioned as teachers' practices before interventions.
Teachers' expectations of students before interventions	Teachers' expectations of students in a math classroom – students' role, ability, contribution, responsibilities, etc.
Teachers' beliefs about mathematics (as a subject) after intervention	Teachers' beliefs about mathematics as a subject, general beliefs about learning mathematics, nature of mathematics tasks, beliefs about mathematics learning ability of students, general beliefs about learning and teaching mathematics (school context) – comparison with their previous beliefs (if any).
Teachers' beliefs about teaching practices after intervention	Teachers' beliefs about practices of teaching mathematics; changes and comparison with their beliefs before what they think the roles of teachers in a mathematics lesson now, how should lessons be conducted, general beliefs about practices that related to students' ability (i.e. grouping), general beliefs about learning environment (in a mathematics lessons).
Teachers' beliefs about themselves after intervention	Teachers shared or reflected on their own beliefs as a learner and/or as a teacher. Teachers shared or reflected about their identities, changes or compared with past experiences/beliefs, what they had realized/internalised/changed after interventions, about their relationships with learning (mathematics) or their relationships with mathematics or as mathematicians.
Teachers' practices after intervention	Practices or activities or guiding instructions were mentioned as teachers' practices after interventions.
Teachers' expectations of students after interventions	Teachers' expectations of students in a math classroom – students' role, ability, contribution, responsibilities.
Struggles and mistakes	Attitudes toward struggles and mistakes in learning and teaching mathematics shared by teachers.
Learning culture/environment	Teachers shared their (previous/changed) beliefs of what are characteristics of a supporting learning culture/environment: mistakes, struggles, activities in a supporting environment, open discussion, teacher-student's role, efforts and practices, types of practices, etc.
Scaffolding practice	Practices where teachers provide support to help student or demonstrate how to solve a problem.
Students' attitudes and behaviours	Information related to students' changed attitudes towards learning math or activities or students' behaviours in a mathematics lesson.

Appendix B

Average scores for the criteria of the QRC and EBLCAC checklists.

#	QRC	*M*	*SD*	n
1	Was there a clear statement of the aims of the research?	1	0	2
2	Is a qualitative methodology appropriate?	1	0	2
3	Was the research design appropriate to address the aims of the research?	1	0	2
4	Was the recruitment strategy appropriate to the aims of the research?	1	0	2
5	Was the data collected in a way that addressed the research issue?	1	0	2
6	Has the relationship between researcher and participants been adequately considered?	0.5	0.7	2
7	Have ethical issues been taken into consideration?	0.5	0.7	2
8	Was the data analysis sufficiently rigorous?	1	0	2

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#	QRC	*M*	*SD*	n
9	Is there a clear statement of findings?	1	0	2
10	Is the research valuable?	1	0	2
#	EBLCAC	M	SD	n
1	Is the study population representative of all users, actual and eligible, who might be included in the study?	0.07	0.8	14
2	Are inclusion and exclusion criteria definitively outlined?	0.96	0.18	14
3	Is the sample size large enough for sufficiently precise estimates?	1	0	14
4	Is the response rate large enough for sufficiently precise estimates?	0.96	0.18	14
5	Is the choice of population bias-free?	0.46	0.74	14
6	If a comparative study:	1	0	13
7	Was informed consent obtained?	0.71	0.46	14
8	Are data collection methods clearly described?	1	0	14
9	If a face-to-face survey: were inter-observer and intra-observer bias reduced?	N/A	N/A	0
10	Is the data collection instrument validated?	0.91	0.28	12
11	If based on regularly collected statistics, are the statistics free from subjectivity?	0.93	0.26	14
12	Does the study measure the outcome at a time appropriate for capturing the intervention's effect?	0.81	0.55	14
13	Is the instrument included in the publication?	0.5	0.51	9
14	Are questions posed clearly enough to be able to elicit precise answers?	0.96	0.19	14
15	Were those involved in data collection not involved in delivering a service to the target population?	0.93	0.26	14
16	Is the study type/methodology utilised appropriate?	1	0	14
17	Is there face validity?	1	0	14
18	Is the research methodology clearly stated at a level of detail that would allow for its replication?	0.89	0.31	14
19	Was ethics approval obtained?	0.7	0.46	14
20	Are the outcome clearly stated and discussed in relation to the data collection?	1	0	14
21	Are all the results clearly outlined?	1	0	14
22	Are confounding variables accounted for?	0.93	0.26	14
23	Do the conclusions accurately reflect the analysis?	1	0	14
24	Is subset analysis a minor, rather than a major, focus of the article?	1	0	14
25	Are suggestions provided for further areas to research?	1	0	14
26	Is there external validity?	1	0	14
27	Was there a clear statement of the aims of the research?	1	0	14
28	Is the research valuable?	1	0	14

As the scores of QRC and EBLCAC checklists determined the weight of each article for answering the research question, they are also the measurements of the studies' quality. The QRC are used during the quality appraisal for two qualitative and/or mixed-methods studies, and on average the two studies scored 0.9 ($SD = 0.2$) on a scale from 0 to 1. Most criteria score at 1, except for criteria 6 and 7 at 0.5 concerning the relationship between the researcher(s) and participants and ethical issues. Regarding item 6 – about the relationship between researcher(s) and participants – there are discussions in the studies about the roles of researcher(s) and how the intervention(s) were performed. However, it is not always clearly stated how the relationship between researcher(s) and participants could affect the intervention(s) and observations. As about item 7 – ethical issues are not always explicitly discussed. It is likely that ethical issues were taken into consideration, but not stated explicitly how they obtain the informed consents from participant(s) and related parties.

The EBLCAC checklist is used to assess 14 quantitative studies. On average, these studies scored 0.85 ($SD = 0.07$) on a scale from 0 to 1. Since not all criteria are applicable for all studies, the number of studies is provided for each individual item. Majority of the items are 0.5 and higher with the exceptions of item 1 and 5 with regard to the sample of the studies. It is very often that participants were selected by means of convenience sampling and sample sizes are usually not enough to include all actual and eligible participants. Understandably, items related to study population scored rather low.

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