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Review Article

Growth mindset in high school mathematics: A review of the literature since 2007

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Growth mindset has received more focus in schools in the past fifteen years as a possible way to improve various educational outcomes. There are important possible benefits if students believe in the malleability of intelligence and the potential to improve in ability and various human qualities. Students with growth mindsets set self-improvement as achievement goals, use all of their resources, seek feedback, attribute failure to something that is under their control, and work harder when faced with setbacks. For mathematics, these beliefs and outcomes of a growth mindset are especially important as students may view mathematics as too difficult and a barrier or detterent to a possible career. The notion that only some students can do well in mathematics is important to counter. The purpose of this article to review the research on growth mindset in high school mathematics education since 2007. Directions for future research are discussed including the importance of teachers in growth mindset interventions and students developing growth mindsets through having successful mathematics learning experiences.

Keywords: Growth mindset; High school; Mathematics education

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1. Introduction

The high school years are an important time for students' mathematical development which in turn can affect students' future careers. In the United States, the grades of students tend to decrease as students move into high school (Sutton et al., 2018). When students underperform in mathematics or opt out of more rigorous coursework, they are far less likely to leave high school prepared for college or university (Schiller et al., 2010). For all students, mathematical understanding will benefit students' daily lives and decision making no matter what careers they pursue (Charitaki et al., 2021). Mathematics instruction is an important field of research, but research productivity in mathematics has not risen to the level of research on reading (Clarke et al., 2016). Increasing the research and analysis of mathematics learning experiences and various educational outcomes that can be aligned with mathematics learning is important.

One factor that can affect whether students do well in mathematics is their mindset (Dweck, 2017). Mindsets are a collection of beliefs related to malleability of intelligence, seeking out resources, and being willing to engage in effortful learning (Dweck, 2006). Beliefs are vital because they are the best indicators of the decisions that individuals make throughout their lives (Pajares,

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1992). In recent years there has been considerable interest among various educational stakeholders on the use of growth mindset research to improve educational outcomes (Yeager, 2019). A growth mindset is the belief that intellectual skills can be cultivated through effort; on the opposite end of the spectrum, a fixed mindset is believing that if something is difficult it cannot be done. In other words, people have a certain amount of ability or knowledge and cannot do much to change it (Dweck, 2006). Fixed mindsets are particularly troubling because "fixed mindset beliefs contribute to inequalities in education as they particularly harm minority students and girls; they also contribute to overall low achievement and participation" (Boaler, 2013, p. 150).

Students with growth mindsets set self-improvement as achievement goals, attribute failures to something that is under their control, and work harder when faced with setbacks. These students actively try new learning strategies and seek all available resources. However, students with fixed mindsets aim for performance-oriented goals, see failures as something that is beyond their control, and give up when they experience setbacks (Stohlmann et al., 2018). Given the possible benefits of a growth mindset there is a need to encourage this mindset with students. It has been reported that mindsets tend to be evenly divided among students and adults with 40% to 42.5% fixed mindsets, 40% to 42.5% growth mindsets and 15% to 20% being indeterminate between the two (Dweck & Master, 2008). Determining ways to move more students to a growth mindset for mathematics is vital.

A general growth mindset orientation and a growth mindset specific for math is important. Students' mindsets can vary depending on the subject or activity in which they are engaged (Stipek & Gralinski, 1996). Too many students tend to associate the ability to learn mathematics with an innate aptitude rather than through hard work, practice, and effort (Ahn et al., 2016). Students can believe that some people are good at mathematics and some just are not. Mindset can be affected by cultural norms, expectations, and stereotypes that support fixed-mindset messages about what type of a person tends to have innate talent or be successful in particular areas (Leslie et al., 2015). Students are more motivated to learn when they believe they have the potential to develop their abilities and knowledge (Dweck, 1999, 2006).

The purpose of this article is to review the research on growth mindset in high school mathematics education since 2007. Analyzing this research provides insights for how to develop growth mindsets in high school mathematics education that can guide future research and implementation. This is important as researchers have debated the usefulness of mindset interventions in schools. Many schools have become interested in growth mindset in order to improve various student outcomes as previous studies have substantiated the relationship between growth mindset and mathematics achievement in students (Blackwell et al., 2007; Claro et al., 2016; Mueller & Dweck, 1998). However, there is a need to clarify under which conditions the positive relationship between growth mindset and educational outcomes is observed (Bernardo, 2021).

First, we describe general research on growth mindset. Then we discuss what has been found with prior reviews on growth mindset and mathematics. Next we describe the studies on growth mindset in high school mathematics since 2007. Dweck's (2006) book on growth mindset led to more interest in the subject, therefore, 2007 was chosen as the starting point for analyzing subsequent research. Twenty-three studies were identified by searching for empirical studies in journal articles on growth mindset in high school mathematics. The articles had to report on an empirical study but did not need to include an intervention and most of the articles did not include an intervention. The university search engine was used with the following search terms and combinations of these terms: growth mindset, implicit theories of intelligence, mathematics education, secondary education, and high school. Finally, we provide discussion on future research including ideas for implementing growth mindset interventions.

2. Growth Mindset

Growth mindset is not only about effort, but also trying new approaches and seeking assistance when needed. Students with a growth mindset seek available resources and can try new strategies (Yeager & Dweck, 2012). However, the benefits of a growth mindset are not always observed in studies. For example, Li and Bates (2019) did a replication study of Mueller and Dweck's (1998) study that found positives results associated with a growth mindset. Li and Bates (2019) found that growth mindset was not associated with students' focus on mastery goals, task persistence, or attribution of failure to effort. There are also studies that have found no positive benefits associated with having a growth mindset on school achievement (Kornilova et al., 2009; Rheinschmidt & Mendoza-Denton, 2014). There are even some studies that found a negative relationship between growth mindset and academic achievement (e.g. Corradi et al., 2019). It should be noted that heterogeneity of results is being seen as more commonplace (Bryan et al., 2021). Yeager et al. (2022) note that "Nothing, and particularly no psychological phenomenon, works the same way for all people in all contexts" (p. 20).

This leads to the question, is successfully teaching students a growth mindset enough? Should the benefits of a growth mindset be seen regardless of the context, even those that do not support a growth mindset. Growth mindsets may enable the potential for benefits in an environment that supports these beliefs (Yeager et al., 2022). If students believe that only some people can do well at mathematics, this could discourage them from enacting their growth mindset beliefs for mathematics if they come to find mathematics difficult. How mathematics is taught and how supportive the classroom environment is for growth mindset are important considerations.

It has been suggested that mindset interventions may be more beneficial if they are integrated with daily instruction in classrooms (Haimovitz & Dweck, 2017). Vongkulluksn et al. (2021) provide ideas for mindset interventions. The learning process should be emphasized rather than just the outcome. Students should learn how to learn and generalize strategies and resources in order to use these in future work. Teachers can help students see intelligence as malleable and that the brain can grow and improve. Effort and failure can be seen as part of the learning process. Feedback should be incorporated often and be aligned with goals that students are striving to meet. Finally, self-persuasion opportunities should be incorporated. Through classwork students can see firsthand that ability can be developed through hard work, feedback, and using available resources and strategies. This could help students internalize the benefits of a growth mindset.

2.1. Recent Prior Reviews on Growth Mindset

Prior reviews on growth mindset provide insight to what is known on growth mindset and what future research work is needed. Sisk et al. (2018) conducted two meta-analyses of growth mindset research with studies across all grade levels including adults. The meta-analyses included both published and unpublished research. The results of one of the meta-analyses indicated that achievement gains of growth mindset interventions were found only among lower SES students as SES was a significant moderator of growth mindset interventions. Yeager and Dweck (2020) have noted that mindset associations with outcomes are often stronger among those facing academic difficulties or setbacks. The other meta-analysis looked at studies without interventions and indicated a significant relationship between natural growth mindset and achievement for students across SES groups. However, the research studies were heterogenous in their results. Yeager and Dweck (2020) noted that meta-analyses have shown overall significant associations in the positive direction for growth mindsets and that there is a replicable and generalizable association between mindsets and achievement. It has been noted though that a greater understanding of where associations are likely and where they may be less likely is needed (Sisk et al., 2018).

In my prior work Stohlmann reviewed articles on growth mindset in K-8 STEM (Science, Technology, Engineering, & Mathematics) Education, science education, and mathematics education. In terms of mathematics education studies, there were seven, with five involving middle school students and two with elementary students (Stohlmann, 2022). Compared to the other four areas of STEM, mathematics is a subject that students are less likely to enjoy (Christensen & Knezek, 2020) and they are less likely to endorse a growth mindset for mathematics

(Ahn et al., 2016). Too many students tend to believe that the ability to learn mathematics is something that some have and some do not; rather than in the importance of hard work, practice, and effort (Ahn et al., 2016). The studies demonstrated the positive benefits of a growth mindset for mathematics in regards to motivation (Blackwell et al., 2007) and academic achievement and engagement (Bostwick et al., 2019). How mathematics is taught can have an impact on students' growth mindset orientations for mathematics. Students' mindsets were more likely to be fixed if their teachers emphasized performance outcomes rather than emphasizing mastery and growth (Hargreaves et al., 2021; Park et al., 2016). Too often students who struggle in mathematics are given greater amounts of rote instruction focused on procedures and memorization. When conceptual understanding and the learning process are emphasized, students are more likely to have growth mindsets (Park et al., 2016).

There are key aspects of growth mindset interventions that should be included for this. Interventions should describe concrete actions that can be taken to develop a growth mindset. An intervention should not just emphasize effort, but that ability has the potential to be developed. Stories about famous people or peers who have used a growth mindset can be beneficial. Also, students can be asked to write about how they have grown their abilities after struggling and how they aim to use a growth mindset for future goals. Self-persuasion opportunities can be incorporated like having students write a letter or discuss what they would share to a student who has a fixed mindset. On the teacher side, teachers should emphasize the learning process rather than just the outcome. Teachers should help students value effort and failure as part of the learning process. Feedback is important as well and should be aligned with goals that students are striving to meet (Stohlmann, 2022).

3. Growth Mindset in High School Mathematics

Now we discuss the findings of the articles that were identified for this review on growth mindset in high school mathematics. Focusing specifically on studies done in mathematics education at the high school level provides insight into future research for growth mindset in mathematics. The review is organized by studies that included students only, studies that included teachers only, and studies that included teachers and students. The studies are also separated by if there was an intervention or not.

3.1. Students-no Intervention

There were thirteen studies in this section that included students as participants and did not include an intervention. Three of the studies used data from the 2018 PISA mathematics assessment. A limitation noted in these studies was that growth mindset was measured with a single item. Kismiantini et al. (2021) examined the relationship between growth mindset and mathematics achievement for 9,196 Indonesian students. Growth mindset was a significant predictor of students' mathematics achievement.

A similar finding occurred for a study that examined how socioeconomic status (SES) moderates the relationship between Filipino students' growth mindset and learning in mathematics and science. The sample consisted of 7,233 fifteen-year-old students. A growth mindset was positively associated with learning in math and science, explaining a small portion of variations in learning. SES explained a larger portion of variations in learning as the positive association between growth mindset and math and science scores was only found among higher SES students (Bernardo, 2021).

Lou et al. (2023) used the 2018 PISA data to investigate how the role of students' mindsets may depend on societal-mindset norms. The sample included 612,004 students from 78 different countries/regions. Overall, growth mindsets positively and weakly predicted all performance outcomes. The associations were significantly stronger in societies with growth-mindset norms. In societies with fixed-mindset norms, growth mindsets were a negative predictor of positive affect and meaning in life for students. All three studies found that growth mindset was a significant predictor of students' mathematics achievement with this being stronger in societies with growth-mindset norms or for higher SES students in the case of the Philippines data.

Further support for the association between growth mindset and mathematics achievement was found by three studies done in Australia. Bostwick et al. (2017) adopted an integrative approach to analyze the impact of a growth construct (growth mindset, self-based growth goals, and task-based growth goals) on mathematics outcomes from a dataset of 4,411 Australian students in 7th grade to 9th grade. Results found that even when students' background factors were included students' growth orientations were positively associated with both their academic engagement and achievement. A similar result was found with a different sample of 2,949 Australian middle and high school students. Results demonstrated that students' growth construct in mathematics was a significant positive predictor of students' gains in mathematics engagement and achievement (Bostwick et al., 2019).

A cross sectional study in Australia investigated how mindset orientations may play a mediating role for indigenous status (Aboriginal or not) and academic achievement. The sample consisted of 87 Indigenous students and 87 non-indigenous students from the same high schools. It was found that being an Aboriginal student negatively predicted a growth mindset orientation. For all students more of a growth mindset positively predicted academic achievement. It was noted that the students in this sample were higher SES students than the average Australian student (Tarbetsky et al., 2016).

Providing more information related to SES and growth mindset, Hwang et al. (2019) used survey data from the 2002 Educational Longitudinal Study and follow up 2004 survey that was conducted with 10,850 tenth grade students. The findings showed that white students and students from higher SES backgrounds were more likely to view intelligence as a fixed trait. For lower-achieving students a fixed mindset at 10th grade predicted lower gains in achievement by 12th grade.

One study in this section looked at subject-specific mindsets and not just general growth mindsets of students. This cross-sectional study involved a sample of 1st grade students to college students. Of the 523 participants, there were 140 tenth and eleventh grade students. High school students' math specific mindsets were related to their motivation and achievement in math, controlling for reading and writing-specific mindsets. High school students felt that math involved more fixed ability than reading or writing. This was not the case with the elementary and middle school students in the study. All students believed that math involves more fixed ability than reading and writing for adult jobs (Gunderson et al., 2017).

Students may see mathematics as more related to a fixed mindset based on their teachers. A study that used data from the National Study of Learning Mindsets investigated stereotype threat and if it was associated with perceived classroom mindset culture. Stereotype threat refers to a situation where individuals are at risk of affirming negative stereotypes associated with their social positions (Spencer et al., 1999). The results showed that when students perceive their math teachers have created fixed mathematical mindset climates, they experience greater stereotype threat. Additionally, a perceived fixed teacher mathematical mindset climate had a statistically significant direct association with mathematics anxiety. Mathematics teachers may create a climate that promotes a fixed mindset by communicating intentionally or unintentionally that some students are smart and others are not or by sending signals that mathematics ability is unchangeable. In a growth mindset climate it is communicated that all students can learn and achieve well in mathematics (Seo & Lee, 2021).

Three longitudinal studies looked at how mindset impacts students as they transition to college. In the first study, data was used from the nationally representative Educational Longitudinal Study of 2002 to investigate how growth mindset orientations affected male and female high school students' selection of an intended STEM major. As female students' growth mindset scores increased it was found that they had a higher probability of selecting a health science major as opposed to a physics, engineering, math, or computer science major. The authors suggest that messages directly or indirectly given to students about what majors are a better fit may be one cause (Nix et al., 2015).

In the second study further support for a growth mindset and interest in STEM fields was found. A short-term longitudinal study that used a sample of 1449 high school students in the U.S. found that females had higher mathematics achievement than males when they endorsed a growth mindset (Degol et al., 2017). Male and female students who viewed that math takes time and effort were more likely to be interested in pursuing a STEM career. When female students view mathematics as effort-based and not based on innate ability this can have positive effects on students' mathematics achievement, mindsets, and interest in STEM careers (Degol et al., 2017).

The third longitudinal study looked at whether mindset orientations assessed in ninth grade predicted course-taking behaviors and utility value in college. The sample consisted of 165 U.S. high school students with 92% of the participants being white. It was found that mindset orientations predicted course-taking intentions and utility value (viewing math as useful). Self-concept of mathematics ability predicted courses taken, course-taking intentions, and utility value of mathematics, even after controlling for prior mathematics achievement. It was found that self-concept of mathematics ability was a stronger predictor than mindset orientations. The researchers suggest this may be in part to an emphasis on innate ability as an indicator of success in mathematics, which can lead students to attend more to their perceptions of current math ability than to their potential for growth in mathematics (Priess-Groben & Hyde, 2017).

The final study in this section investigated how mindsets and other educational constructs influenced student achievement among a sample of 535 students (age 14 to 16 years old) from England at the end of secondary school. Four profiles of students were found. Two profiles supported existing research with about two-thirds of the students in these profiles: a growth mindset-mastery goal focus (Growth-Focused) and a fixed mindset-performance goal focus (Ability-Focused). The other two profiles included growth mindset students that embraced performance goals alongside mastery goals (Growth-Competitive) and fixed mindset students that did not focus on performance goals (Disengaged). The two growth mindset-oriented profiles of students consistently performed well in math, with Growth-Competitive students even outperforming Growth-Focused students. Compared to girls, boys were likely to be found in Ability-Focused or Disengaged profiles. The authors suggested helping Disengaged students with persistence and to set mastery goals (Yu & McLellan, 2020).

Overall, the studies done in different countries showed that growth mindset is a significant predictor of students' mathematics achievement. The studies also showed that growth mindset increased students' probability of majoring in a STEM field. Along with growth mindset, self-concept of mathematics ability may affect the courses that students take in college. Only one of the studies looked at students' mathematics specific mindsets instead of general mindsets. The mathematical mindsets were related to achievement in math as well. The studies also showed that white students or higher SES students may be more likely to view intelligence as a fixed trait and that students' perceptions of the mindset culture created by their teacher can cause stereotype threat and mathematics anxiety.

3.2. Students-intervention

There were four studies that included students as participants along with a growth mindset intervention. All four studies used a similar intervention from Yeager et al. (2016). The U.S. growth mindset intervention is available for free at www.perts.net. The online intervention presents students with information on the malleability of the brain, neural connections, the benefits of challenging work, how growth mindset aids in coping with confusion and difficulty, and how growth mindset can be used to strive towards personal goals. Stories from older high school students and famous individuals are included on how they used stronger brains to achieve important goals. Self-persuasion exercises are included as well, including for students to provide advice to peers who struggle with school. Students in the control conditions for the first three studies learned more about the brain but not the brain's malleability or about growth mindset. In the fourth study the control group was a passive control group.

Two of the studies used data from the National Study of Learning Mindsets (NSLM). The first study involved a sample of 6,320 ninth grade students who were lower-achieving relative to students at their same school. The study sought to determine if a short mindset intervention (less than one hour) would improve grades among lower-achieving students and overall increase advanced mathematics course taking. The intervention caused intervention students to have more of a growth mindset orientation relative to the control group. Lower-achieving students in the growth mindset intervention condition also earned higher GPAs in core classes—math, science English, and social studies—at the end of the 9th grade (Yeager et al., 2019).

The second study used a U.S. population and a Norwegian population of students. Rege et al. (2021) report the results of a growth mindset intervention conducted in the U.S. (n= 14,472) and Norway (n= 6,541) that sought to inspire students to seek out challenging learning experiences. For the U.S. study, data was used from the National Study of Learning Mindsets (NSLM). The Norway study sought to replicate the effects of the first U.S. study described above (Yeager et al., 2019) for the growth mindset intervention on challenging-seeking and on increased advanced math course enrollment rates. In Norway, students who completed the growth mindset intervention took and passed advanced mathematics courses at a higher rate. To measure challenge-seeking students were presented either four (U.S.) or three (Norway) sets of six problems and could choose from 2 to 6 problems to solve. Each problem was described as "Not very challenging, and you probably won't learn very much", "Somewhat challenging, you might learn a medium amount", or "Very challenging, but you might learn a lot." After students made their choices, they were thanked for their choices but told there would not be time for them to solve the problems. The results showed that the growth mindset intervention increased the students' willingness to take on more challenging work in the U.S. and Norway. The results were found across student demographic groups and achievement levels. This was in contrast to past studies that found mainly benefits for low achieving students (Rege et al., 2021).

Another experimental study was conducted with 354 Norwegian high school students to determine the impact of a growth mindset intervention (Bettinger et al., 2018). The treatment involved two 45 minute web-based mindset interventions that were two weeks apart. In a third session students received a series of 34 multiple-choice algebra questions sequentially. The algebra questions were challenging, possibly making many students frustrated and tempted to give up. The experimental results demonstrated that students in the treatment group had significantly more correct answers on the first ten questions compared to students in the control group, but there was no significant difference between treated and control students when looking at the first 20 or all 34 questions. When looking just at students who entered the study with a pre-existing fixed mindset, the treatment effect was large and significant for the first 10 questions, 20 questions, and for all 34 questions. To measure growth mindset, general growth mindset questions and math specific growth mindset questions were included in this study (Bettinger et al., 2018).

The final study used a quasi-experimental design with 55 high school vocational education students enrolled in a mathematics course in the Netherlands. Pre and post math test scores and growth mindset scores were compared to a passive control group. Both groups scored higher on the mathematics test but there was no significant difference in the groups. Also, there was no significant difference in the mindset scores and no significant relation between mindset and mathematics test scores. The researchers provide several possible reasons for this including the cultural differences between the Netherlands and the U.S. and that countries like China, Netherlands, and New Zealand that score above average on the PISA mathematics assessment have not found a relation between mindset and achievement. A limitation was noted that the post mindset survey was done about 10 weeks after the intervention (Glerum et al., 2020).

3.3. Teachers-no Intervention

There were two studies that included teachers as participants without a growth mindset intervention. The studies found that compared to other teachers, high school mathematics teachers tended to be more towards a fixed mindset. Growth mindset orientations were investigated for 226 Swedish high school teachers from different disciplines. There were 30 math and science teachers in the study. The mathematics teachers were more towards a fixed mindset while the other subject teachers were more on the growth mindset side (Johnsson et al., 2012).

A survey study of 583 K-12 teachers investigated if mindset regarding mathematical ability was distinct from mindset regarding general intelligence. Approximately 62% of the participants were elementary teachers. The findings provided strong evidence that mindset regarding mathematical ability among K-12 teachers is a unique, measurable construct. Elementary grades teachers demonstrated a stronger growth mindset with regard to mathematical ability than did the secondary teachers. The researchers posed a question for further research: What is the nature of the relationship between a mathematics teacher's mathematical content knowledge and their mindset toward mathematical ability? (Willingham et al., 2021).

3.4. Teachers-intervention

There were two studies that included teachers as participants with a growth mindset intervention. The first study involved a professional learning community [PLC] as the intervention. Masterson and Koch (2021) investigated how Canadian teachers worked to foster growth mindset in lower level ninth grade mathematics courses. The teachers met monthly for two years in PLCs. The PLC groups included mathematics teachers, special education teachers, and a school administrator. The PLC groups found that a few things hindered the development of students' growth mindsets: students' ingrained fixed mindsets, seeing mathematics as always either right or wrong, and the lower math ability of students. Several members of the PLCs saw that students enjoyed the growth mindset activities but this did not seem to result in greater mathematical confidence or engagement. Students could explain a growth mindset and the benefits but when it came time to doing a challenging problem said they could not do it. The PLCs identified formative feedback, valuing the process of learning over grades, allowing retesting, and encouraging growth mindset across grades as strategies to support students' mathematics learning and growth mindset orientations.

The second study included information similar to past mindset interventions for students (e.g. Yeager et al., 2016) along with pedagogical practices that the teachers could use to support students' belief in the malleability of intelligence. An experimental study was conducted with 155 Israeli high school math teachers who taught advanced math courses. The teachers were randomly assigned to a one-year growth mindset intervention, designed to promote a growth mindset in the teachers, or to a passive (business as usual) control condition. It was found that growth mindset, professional well-being, and teaching efficacy improved significantly in the treatment group, but not in the control group. Teachers with a higher growth mindset were more engaged and enthusiastic and were more likely to experience professional well-being. They also had higher levels of teaching satisfaction. In addition, teachers' professional well-being was associated with an increase in students' grades (Shoshani, 2021).

3.5. Teachers and Students

There were two studies that looked at both teachers and students. The first study involved a student intervention and the second study a teacher intervention. Yeager et al. (2022) used data from the National Study of Learning Mindsets [NSLM], in which a U.S. representative sample of ninth grade students received a short growth mindset intervention. The study sought to determine if students can independently implement their growth mindsets in any classroom culture or if students' mindsets need to be supported by their teacher's own growth mindsets. The study involved 9,167 students matched with 223 math teachers. The results showed that a supportive classroom environment is important. Students who were in classrooms with teachers who had more of a fixed mindset did not show gains in their math grades over ninth grade compared with the control group. Students in classrooms with more growth-mindset teachers showed meaningful gains. In addition, students who formerly had more of a fixed mindset and who went into a classroom with a teacher who had more of a growth mindset showed larger gains in achievement than did students who began the study with more of a growth mindset. The researchers concluded that more research is needed on what teacher beliefs or practices are important for supportive learning environments (Yeager et al., 2022).

Thirty rural U.S. middle and high school mathematics teachers collaborated through virtual meetings to share and learn best practices for helping students develop growth mindset orientations and self-efficacy in mathematics. Survey data showed the teachers had significant increases in the belief of fostering growth mindset with their students. Students of the participating teachers also showed a significant positive difference in growth mindset as compared to a control group (Edwards, 2019).

4. Discussion

Growth mindset theory is a topic that has received attention internationally as a possible way to help improve various student outcomes. This review included studies done focused on growth mindset with high school mathematics. Twenty-three studies were identified that were published in peer-reviewed journal articles. Thirteen of the studies focused on students without a growth mindset intervention. The studies showed that growth mindset is a significant predictor of students' mathematics achievement and that a growth mindset can increase students' probability of majoring in a STEM field.

Only one of these studies looked at mathematical mindsets, while the other studies looked at general mindsets. This is an important note for future research as students' mindsets can vary depending on the subject they are engaged (Stipek & Gralinski, 1996). It is possible that mindsets specific to mathematics are more important than in other subjects because math can be perceived as more challenging than other subjects (Gunderson et al., 2017). In addition, Willingham et al. (2021) found that teachers' mindset regarding mathematical ability is distinct from a general growth mindset. In future research when investigating mindsets in mathematics with mathematics teachers and/or students both general mindsets and mathematical mindsets should be investigated.

Four studies included students and a growth mindset intervention. Three of the studies found positive results for the intervention for Norwegian and U.S. students including increased growth mindset orientation, (Yeager et al., 2019), higher GPAs in core classes (Yeager et al., 2019), taking and passing more advanced mathematics courses (Rege et al., 2021), and increased willingness to take on challenging work (Bettinger et al., 2018; Rege et al., 2021). In addition, the benefits in Rege et al. (2021) were found across achievement levels. The fourth study included a sample of students from the Netherlands and found that both groups increased their scores on a mathematics test but there was no significant difference between the groups (Glerum et al., 2020).

In looking at growth mindset it is important to keep in mind the contexts and populations for how this may have an impact. Glerum et al. (2020) stated that countries like Netherlands, New Zealand, and China that have higher achievement on the PISA mathematics assessment have not found a relation between mindset and achievement. With heterogenous results it is important to determine how the study was conducted as well. Glerum et al.'s (2020) study included a much smaller sample size and students also took the post mindset survey 10 weeks after the intervention.

This relates to the next group of studies as well in that the impact of teachers and the classroom environment they create is important. Yeager and Dweck (2020) note that students' growth mindsets alone may not be sufficient to lead to positive outcomes; that the effect may be highly dependent on the context. Compared to other discipline teachers (Johnsson et al., 2012) or other grade level teachers (Willingham et al., 2012) it was found that secondary mathematics teachers generally had less of a growth mindset. Growth mindset has benefits for high school mathematics teachers as those with a higher growth mindset experience more professional well-being, teaching satisfaction, and were more engaged (Shoshani, 2021). This is an important consideration for future research because if high school mathematics teachers have fixed mindsets this could limit the benefits of students' growth mindsets and cause students to experience stereotype threat, which could lead to underachievement (Dweck, 2014). In a study at the college level when faculty members firmly believed that intelligence is fixed there were greater racial achievement gaps (Canning et al., 2019). Further, Yeager et al. (2022) found that high school students whose mathematics teachers had more of a fixed mindset did not show gains in their math grades compared to a control group. Students in classes with more growth-mindset teachers showed significant gains. The findings demonstrate the importance of both teachers and students' mindsets for benefits to be realized.

Boaler (2016) suggests several mathematical mindset norms for teachers to communicate to students including everyone can learn mathematics to high levels and struggling and making mistakes will grow your brain. Boaler also suggests the inclusion of open-ended problems for students to apply their prior knowledge and have successful experiences on challenging, worthwhile, mathematical tasks. In Stohlmann's research, he incorporated open-ended problems with middle school students over a four-week time period. The students had significant increases in being more aligned with a growth mindset at the end of four weeks (Stohlmann et al., 2018). Students should have challenging higher level demand, creative, and open-ended tasks at each grade level. This gives students opportunities to develop a growth mindset and learn how to try new ideas, collaborate, and use available resources.

Through analysis of existing research and classroom observations Sun (2018) developed norms that are important for teachers to convey to students for a growth mindset climate. The first was sorting. This means having an expectation that all students contribute, highlighting a range of student work, and focusing on multiple dimensions of mathematical success. The next category was norm setting to convey that brains have the ability to grow, to encourage the importance of process in mathematics, the importance of mistakes, the importance of struggle, and to value student thinking. The next category was engaging in mathematics which includes problems with multiple entry points, students as active participants, praising students' effort and process, and communicating high standards through feedback. Similar to the ideas above Rissanen et al. (2019) suggests establishing a motivational climate in the classroom which encourages effort and persistence to meet challenges. Research is showing that fostering students' growth mindset should be coupled with a supportive classroom environment to help students be able to act in accordance with a growth mindset (Luo et al., 2023).

For the studies in this review, only eight of the 23 studies included an intervention. In contrast for a review of K-8 STEM education growth mindset studies, most included an intervention. Future work can focus on incorporation of interventions for teachers and students in high school mathematics. Research at the K-8 level has suggested that mindset interventions paired with challenging, open-ended collaborative STEM activities helps students to internalize their growth mindsets in the context of their subject specific learning (Dringenberg et al., 2020; Vongkulluksn et al., 2021). It has been suggested that the messages that teachers convey to students and how they teach the content may be more impactful on students' mindset orientations than any growth mindset program (Schmidt et al., 2017). Further research can focus on the classroom environment and teachers' practices and beliefs that cause the most benefit for students along with a growth mindset (Bernando, 2021; Bostwick et al., 2019).

Continuing to investigate the conditions, benefits, and challenges of growth mindset in different cultures, with students of different races, and paying attention to impacts on males and females is important. Promoting the malleability of mathematics intelligence could be one way to increase female representation in STEM fields where women are underrepresented.

A growth mindset can be beneficial for females as they may be more vulnerable to the detrimental effects of a fixed mindset for mathematics (Dweck 2007). This is seen as there are less women than men in fields that are perceived to rely on skill sets that are dependent on innate intelligence rather than hard work or effort (Meyer et al., 2015). Promoting the malleability of mathematics intelligence could be one way to increase female representation in STEM fields where women are underrepresented (Degol et al., 2017).

Growth mindset research has received more attention of late. The studies in this review show the possible benefits of students and teachers with a growth mindset. For mathematics this is especially important for students to see themselves as mathematically capable. Further research work is warranted at the high school mathematics level to determine how to best support all students to achieve success in mathematics.

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