Journal of Pedagogical Research
Volume 6, Issue 2, 2022
https://dx.doi.org/10.33902/JPR.202213029

Review Article

Growth mindset in K-8 STEM education: 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. Helping students to believe in the malleability of intelligence and the potential to improve in ability and various human qualities is important. 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 the Science, Technology, Engineering, and Mathematics (STEM) subjects these beliefs and outcomes of a growth mindset are especially important. The notion that only some students can do well in STEM subjects is important to counter. Growth mindset research has most often concentrated on students beyond middle school. Given the possible benefits of a growth mindset, the elementary and middle grades should receive more focus with growth mindset research and interventions. The purpose of this article to review the research on growth mindset in K-8 STEM education, science education, and mathematics education since 2007. Directions for future research are discussed including the importance of teachers in growth mindset interventions and integrated STEM education lessons as a method for students to develop and internalize growth mindset orientations.

Keywords: Growth mindset; Mathematics education; Science education; STEM education

Article History: Submitted 23 August 2021; Revised 11 January 2022; Published online 20 April 2022

1. Introduction

Science, Technology, Engineering, and Mathematics (STEM) education has received increased interest in the past decade due to its importance. There are many potential benefits for students when participating in STEM education including developing 21st century competencies, development of STEM knowledge, and increased awareness and interest in STEM careers (Stohlmann, 2019a). One of the focuses of STEM education research has been studying how to design learning experiences so that all students can be successful in STEM subjects. This is important because whether students pursue a STEM career or not the competencies and knowledge they learn can benefit them in their lives.

A factor that can affect whether students do well in STEM education is their mindset (Dweck, 2017a). Mindsets are a collection of beliefs related to continual learning and malleability of intelligence (Dweck, 2006). Beliefs are vital because they are the best indicators of the decisions

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How to cite: Stohlmann, M. (2022). Growth mindset in K-8 STEM education: A review of the literature since 2007. *Journal of Pedagogical Research, 6*(2), 149-163. https://dx.doi.org/10.33902/JPR.202213029

that individuals make throughout their lives (Pajares, 1992). In recent years there has been considerable interest among researchers, policymakers, and educators on the use of growth mindset research to improve educational outcomes (Yeager, 2019). The concept of a growth mindset has received more attention since Dweck's (2006) book on the subject. 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 qualities are carved in stone or fixed (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).

A general growth mindset orientation and a growth mindset specific for STEM education is important. Students are more motivated to learn when they believe they have the potential to develop their abilities and knowledge (Dweck, 1999, 2006). Students may have a general growth mindset, but for a specific subject such as mathematics or science they may hold more fixed mindset beliefs (Stipek & Gralinski, 1996). Students may believe that some people are good at mathematics and science 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; Wonch Hill et al., 2017). Dweck (2015) has noted that, "We're all a mixture of fixed and growth mindsets" (p. 3). For STEM education, understanding how to develop growth mindsets in students is vital to helping all students do well in STEM education and see themselves as capable of learning and improving in STEM subjects.

The purpose of this article is to review the research on growth mindset in K-8 STEM education since 2007. Developing growth mindsets with elementary and middle school students is important as students in these grades maybe be more open to adopting a growth mindset that could persist in future grades (Schmidt et al., 2017). Analyzing this research provides insights for how to develop growth mindsets in K-8 students and can guide future research and implementation of K-8 STEM education. First, I describe general research on growth mindset. Then, I discuss heterogeneous results of growth mindset research. Next, I detail what has been found effective for growth mindset interventions.

Next, I describe the studies on growth mindset in K-8 STEM education since 2007. Dweck's (2006) book on growth mindset led to more interest in growth mindset, so 2007 was chosen to analyze the research since this book. The studies were identified by searching for empirical studies in journal articles on growth mindset in K-8 mathematics, science, and or STEM education. Engineering education and technology education are included in the STEM education category. The articles had to report on an empirical study but did not need to include an intervention; though most of the articles did include an intervention. The university search engine was used with the following search terms and combinations of these terms: growth mindset, implicit theory, mathematics education, science education, engineering education, technology education, STEM education, middle school, and elementary school, Finally, I provide discussion on future research including ideas for implementing growth mindset interventions.

2. Growth Mindset

In Carol Dweck's early research she had young children solve a series of difficult puzzles. She found the young children were not discouraged by failure and did not even think they were failing. They just thought they were learning (Dweck, 2006). This mindset aligns with a growth mindset. Students who hold a growth mindset see intelligence skills or human qualities as something that can be developed over time, while students who hold a fixed mindset tend to see intelligence skills or human qualities as an inherent and unchangeable trait (Dweck, 2006). Theories of mindset allow us to understand how mindset fosters goals, attributions, and reactions to setbacks (Dweck, 2017b; Yeager & Dweck, 2012). Students who hold growth mindsets set self-improvement as achievement goals, attribute failures to something that is under their control, and

work harder when faced with setbacks. Growth mindset is not only about effort, but also trying new approaches and seeking assistance when needed. Students with a growth mindset actively try new learning strategies and seek all available resources. However, students who hold fixed mindsets aim for performance-oriented goals, see failures as something that is beyond their control, and give up when they experience setbacks (Yeager & Dweck, 2012). Students with more of a growth mindset may have higher levels of self-efficacy (Dweck & Master, 2009). Self-efficacy is a person's belief in his or her ability to achieve specific goals (Bandura, 1997). Self-efficacy like growth mindset can be context specific (Bandura, 1997). The relationship between self-efficacy and growth mindset is not always related though. Students may do well in a STEM subject and hold positive self-efficacy beliefs in their ability to do well, but could still believe that a STEM subject is only able to be learned by people with natural ability (Aalderen-Smeets et al., 2018).

Research with students beyond middle school has provided evidence that students who hold growth mindsets are better equipped to pursue and persist in educational pathways that could prepare them for STEM occupations (Claro et al., 2016; Yeager et al., 2016). Fostering growth mindsets can improve students' academic performance, increase students' motivation, and reduce social class gaps. For example, a mindset intervention significantly helped at-risk high school students raise their semester grade point average in core academic courses (Paunesku et al., 2015). Yeager et al. (2016) found that students who were in the transition to high school in the United States had academic progress after receiving a growth mindset intervention. In addition, growth mindset helped black college students resist the stereotype threat (Steele & Aronson, 1995), increased the enjoyment of academic success, and improved their academic engagement and GPA (Aronson et al., 2002). In a sample across all of the socioeconomic levels in Chile, Claro et al. (2016) found that growth mindset was a relative strong predictor of mathematics and language performance for tenth grade students. It is suggested that students' growth mindset might play a role in mediating the effects of economic disadvantages.

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. 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).

2.1. Heterogeneous Results of Growth Mindset Research

In conducting research on growth mindset some studies have shown no significant benefits for students who hold growth mindsets and that mindset interventions have not significantly improved students' growth mindset orientations. Recently Yeager and Dweck (2020) have written an article summarizing what can be learned from the mixed results of past growth mindset research. Meta-analyses have shown overall significant associations in the direction expected for growth mindsets, but the effects have been heterogenous and thus it has been noted that a greater understanding of where these associations are likely and where they may be less likely is needed (Burnette et al., 2013; Sisk et al., 2018). Yeager and Dweck (2020) have not seen this as an issue that should cause growth mindset to not receive further work with students. They stated that there is a replicable and generalizable association between mindsets and achievement. Also, mindset associations with outcomes are often stronger among those facing academic difficulties or setbacks. It is likely that there will continue to be some unexplained heterogeneity across studies

done with different populations of students in different contexts and with varying interventions. The structure and implementation of interventions is important (Yeager & Dweck, 2020).

One issue that may lead to varied results from emphasizing growth mindset is the way growth mindset has been presented in some schools has differed from how Dweck has conceptualized it. Dweck (2017a) has described a few misconceptions of growth mindset. The first misconception is that growth mindset means being open-minded. A growth mindset is much more than this in that it is a proactive process to develop one's talent through hard work and working through challenges. The second misconception is that growth mindset is just about students' effort and praising this effort. Effort is important but must be linked to outcomes. If a student does not meet a goal, then the student and teacher should focus on what strategies, resources, and support can be used to improve learning.

2.2. Growth Mindset Interventions

The design of mindset interventions used in schools is important to ensure the best results are seen. The effects of mindset interventions on student outcomes have been replicated but the research results are heterogenous (Sisk et al., 2018; Yeager et al., 2019). Yeager and Dweck (2020) described key characteristics of effective mindset interventions. An intervention should describe concrete actions that can be taken to implement a growth mindset. For example, that people exercise their brain by doing work that makes them think hard in school. Hearing stories about famous people or peers who have used a growth mindset can be beneficial. An intervention should not be a passive activity though. Students can be asked to write a short essay about how they have grown their abilities after struggling and how they aim to use a growth mindset for future goals. Students can also write a letter or discuss what they would share to a student who had a fixed mindset. The intervention should not just emphasize effort, but that ability has the potential to be developed. This does not mean that ability is easily changed or that it will be greatly changed, but that there is the potential for change (Yeager & Dweck, 2020).

Vongkulluksn et al. (2021) provided further 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 they use in order to use these in future work. Teachers can help students value effort and failure as part of the learning process. Failure can provide important feedback on corrections and help develop understanding. Feedback is important and should be aligned with goals that students are striving to meet. Finally, self-persuasion opportunities should be incorporated. Students can see firsthand that ability can be developed through hard work, feedback, and using available resources and strategies. Students can experience the benefits of a growth mindset and internalize it this way.

A recent literature review focused on the use of growth mindsets in primary schools to examine how the interventions were operationalized (Savvides & Bond, 2021). This review only included one study that looked at STEM education outcomes from the intervention. Two main general interventions were found—a bespoke intervention and a whole-school cultural approach. A bespoke intervention is where a specific group of children receive targeted support on growth mindset in addition to their classroom curriculum. A whole-school cultural approach is where the concept of growth mindset informs all aspects of school practice including teachers' lessons and school reward systems. Growth mindset was mainly implemented by teachers by using specific language to encourage a growth mindset in students including praising the process students used instead of praising ability, encouraging students to take on challenges (Schordt, 2015), and emphasizing that mistakes are part of the learning process (Fraser, 2017). Most of the studies in the review were completed by teachers as researchers and it was stated that more rigorous implementation and outcome studies are needed in this emerging field at the primary level (Savvides & Bond, 2021). The researchers noted that studies on growth mindset interventions generally tend to be brief interventions and more aimed at the secondary level.

A specific intervention that has been used internationally is the Brainology program (www.mindsetworks.com). This interactive intervention includes brain science education as well as information about how nutrition, sleep, stress, and study strategies affect learning. As students are presented with content, they interact with the ideas inside of the program by playing games, participating in computer simulations, and reflecting in electronic journals. Students learn about the malleability of intelligence, the importance of effort and deliberate practice, and how to overcome challenges. This program also includes teaching training sessions focused on instructional strategies to foster students' growth mindset (Mindset Works, 2021). The strategies include emphasizing student effort in learning, recognizing incremental achievements towards learning goals, and focusing on learning processes rather than outcomes (Haimovitz & Dweck, 2017). It has been suggested that mindset interventions may be more beneficial if they are integrated with daily instruction in classrooms (Haimovitz & Dweck, 2017). Overall, there is support for positive benefits of students holding growth mindsets and that well-structured interventions can assist students to move towards more growth mindset orientations. For more specific analyses on K-8 STEM education I now describe studies done since 2007 on growth mindset in K-8 science education, STEM education, and mathematics education.

3. Growth Mindset in K-8 Science Education

Four studies were identified with growth mindset in K-8 science education, with all four of the studies involving middle school students. The first study investigated gifted and regular middle school students' mindsets in science. The intervention was the Brainology program (Mindset Works, 2021), which was described in the previous section. There were 380 U.S. 7th graders that participated, of which 80 were gifted students. Results showed that gifted students were more aligned with a growth mindset as they were more likely to believe that intelligence in science was malleable. The intervention had a more significant effect on aligning the gifted students' mindsets with a growth mindset than for the regular students (Ezparza et al., 2014).

The next study also made use of the Brainology program (Mindset Works, 2021) to investigate the impact on 7th grade U.S. students' mindset orientations about science (Schmidt et al., 2015). This study looked at teacher-related effects as well. Analyses of quantitative data from seven science classrooms across two teachers revealed significant teacher effects in the extent to which students' beliefs about mindset, students' mastery-oriented learning goals, and students' achievement were sustained several months following the intervention. Classroom observational data and teacher reports of their beliefs offered possible insight into these differences. The teacher whose students had better outcomes placed more emphasis on mastery goals, growth mindset, conceptual development, and use of learning strategies in her daily interactions with students than did the other teacher. The other teacher emphasized grades and points more as well as rewards for performance. The researchers recommend that those who implement growth mindset interventions should design and study ways to impact teachers' practices and mindsets in order for the interventions to have the most benefit with students (Schmidt et al., 2015).

The next study was conducted by the same researchers and made use of the Brainology program again. This was a quasi-experimental study looking at the effects of the growth mindset intervention on U.S. students' daily quality of experience in 7th grade and 9th grade science classrooms (Schmidt et al., 2017). Students provided self-reports on multiple aspects of their daily classroom experience 11 times across the school year. These aspects were the feeling of being in control of learning, the perception of the potential to obtain the skills to address and tackle academic challenges, the perception that they were learning, and the feeling of interest in the science class. There were 370 students that participated in the study and students were randomly assigned to the mindset intervention or a content writing task condition. In the writing condition students were asked to write about specific science content they were studying at the time. Students discussed what they wrote and reflected on how the content they were learning could be useful to them or other people (Schmidt et al., 2017).

Analysis using hierarchical linear modeling indicated that 7th and 9th grade students in the content writing condition intervention showed declines in perceived control, skill, interest, and learning. In contrast, 9th graders in the mindset intervention reported increased control and interest, and maintained constant levels in skill and learning. Contrary to the findings for the 9th grade sample, there was not evidence of positive impacts for the 7th grade students in the mindset intervention. These 7th grade students showed declines in perceived control and skill that were similar to the declines observed among students in the content writing condition. Seventh graders in the mindset intervention showed even greater declines in perceived learning and interest relative to their peers in the content writing group. The researchers felt that the results might have been different if the teachers were involved in the mindset intervention. The researchers implemented this intervention with the students. If the teachers had been involved with this intervention and reinforced growth mindset throughout the year, the results may have been different (Schmidt et al., 2017).

The final study in this section investigated the impact of mathematics self-efficacy, mathematics anxiety, and growth mindset on 7th grade U.S. students' mathematics and science career interest (Huang et al., 2019). One hundred fifty-two 7th grade students participated in the study. The path analyses showed that, for boys, mathematics self-efficacy mediated the relation between mindset and mathematics and science career interest. In addition, student mathematics level exerted a direct impact on mathematics anxiety, growth mindset, and career interest for boys. For girls, mathematics anxiety exerted a direct impact on their career interest (Huang et al., 2019). Other studies as well have shown that mathematics anxiety and mathematics self-efficacy impact STEM participation in that those with low mathematics self-efficacy (Zeldin et al., 2008) and/or high mathematics anxiety (Ashcraft & Krause, 2007) tend to avoid mathematics, either by taking fewer mathematics courses or by choosing non-mathematics-related occupations. It might seem logical that generally high-achievers, holding positive self-efficacy beliefs, are more likely to have a growth mindset, while those that have low self-efficacy might be more likely to hold fixed mindset beliefs. However, other research that has investigated this relation showed that this is not the case (Aalderen-Smeets et al., 2018). For a STEM subject students may do well in the subject and hold positive self-efficacy beliefs but could still believe that mathematics is only able to be learned by people with natural ability.

Table 1 has a summary of the findings on growth mindset for the four studies described in this section. The Brainology program was used as the intervention in three of the studies, but the results of the studies suggest that how science teachers' support a growth mindset over the course of a year may be more important than an intervention. Schmidt et al. (2015) found that the teacher who emphasized conceptual understanding, that learning is a process, and the use of strategies for learning had better outcomes in terms of students' mindset orientations and science achievement. In addition, Schmidt et al. (2017) stated the importance of the teachers' role in students' mindset orientations for the best possible outcomes.

Table 1
Summary of K-8 Science Education Growth Mindset Research

-Gifted students were more aligned with a growth mindset and the Brainology program intervention had a more significant effect on improving growth mindset orientation of gifted students than regular students (Ezparza et al., 2014).
-Placing emphasis on mastery goals, conceptual development, and learning strategies can promote a growth mindset (Schmidt et al., 2015).
-The structure of a growth mindset intervention and who implements it matters. Teachers should be involved in the intervention and reinforce a growth mindset throughout the school year (Schmidt et al., 2017).
-For boys, mathematics self-efficacy mediated the relation between mindset and mathematics and science career interest (Huang et al., 2019).

The results of the studies suggest that further research should consider how growth mindset interventions impact specific populations of students. Ezparza et al. (2014) found gifted students were more positively impacted by the Brainology program. Huang et al. (2019) found that, only for boys, mathematics self-efficacy mediated the relation between mindset and mathematics and science career interest. It is vital to consider how to help all students be successful in science and growth mindset is one important consideration.

4. Growth Mindset in K-8 STEM Education

Four studies were identified with growth mindset in K-8 STEM education, with two of the studies involving middle school students and two of the studies with elementary students. In my research I looked at the impact of integrated STEM education game-based learning (Stohlmann, 2019b) with a class of middle school U.S. students that were part of a four-week Saturday STEM program. The intervention in this study was the game-based learning that students participated in. To be successful students needed to persevere in problem solving, try new approaches, use all of their resources, and continue to develop their ideas when encountering setbacks or failures. The students in this study were on-task while working on the open-ended problems and used the Internet when needed, their group members, and other groups to persevere in problem solving. The students had statistically significant improvements in aligning their mindsets with a growth mindset. They also improved in the quality of their solutions to the games and tasks from the first to the last week of the program (Stohlmann et al., 2018).

The second study that involved middle school students also occurred in an out of school setting at a STEM summer camp for middle school girls. The study investigated the impact of a one-hour session on growth mindset during the three-day STEM camp (Dringenberg et al., 2020). During the one-hour intervention students reflected on the question if some people are just better at mathematics and science than others; as well as who can be successful in STEM. Information on the neuroplasticity of the brain was presented and discussed along with stories of those who have struggled, faced challenges, and persevered. Oprah and Albert Einstein were two examples given. One hundred and two girls in grades 5th to 7th from the U.S. participated in the study. A quasi-experimental design was used and the students in the mindset intervention had statistically significant greater growth mindset aligned beliefs at the end of the camp. At the beginning of the camp on average all of the participants generally had a growth mindset orientation. The one-hour intervention did help improve this. The research showed that a mindset intervention paired with STEM activities can be beneficial to aligning students' mindsets with a growth mindset. The researchers stated that it would not be certain if this same intervention would have had an impact on students who generally had fixed mindsets or who did not self-select to attend the STEM camp. They also mentioned that incorporating more of an engineering focus in the camp may have more of an impact on students' mindsets (Dringenberg et al., 2020).

The first study at the elementary level involved a design-based makerspace class as the intervention. Design-based makerspaces allow for creative production in art, science, and engineering blending digital and physical technologies to explore ideas, learn technical skills, and create new products. The study examined how growth mindset of 3rd to 6th grade U.S. students developed over two years in the design-based makerspace course (Vongkulluksn et al., 2021). Growth modeling was used to examine how students' growth mindset changed and two associative factors were also looked at—self-efficacy and creative mindset. Creative mindset is students' implicit beliefs about the malleability of creativity (Karwowski, 2014). Results showed that students' growth mindset initially decreased slightly in the first year, but significantly improved during the intervening period and remained high throughout the second year. Students with higher creative mindsets showed more adaptive growth mindset trends. The researchers state that when students encounter classroom activities that boost positive mindset, it may be better developed and maintained over time. To explain the initial decrease, it was noted the growth mindset messages in this study were not explicitly stated to students as often done in other

mindset research. The students may have needed more time to translate their makerspace experiences into abstract concepts about the malleability of intelligence and ability (Vongkulluksn et al., 2021).

The second study with elementary students analyzed the general and engineering specific mindsets of 2,086 U.S. fifth grade students who received engineering instruction (Lottero-Perdue & Lachapelle, 2020). In reviewing the prior research, the researchers described that in general elementary students who have a growth mindset tend to have more positive learning outcomes. They also stated that it is unclear whether elementary students' domain-specific mindsets differ from their general mindsets. Failure in engineering may be more readily accepted by students as a part of the learning process than failure in general. This could be because learning from failure is emphasized more in school with engineering than other subjects. Students can learn and experience that engineers learn from failure as they express and test ideas and go through the redesign process. It is possible that engaging in engineering design may help facilitate more growth-minded responses to failure in and beyond the context of engineering. The study in this article was part of a larger project on exploring the efficacy of the Engineering is Elementary curriculum. Students' pre and post science and engineering assessments from the engineering units were collected. Teachers completed structured implementation logs and students completed general mindset and engineering mindset surveys. Students with higher growth mindset scores had higher engineering post-assessment scores. Students who were more likely to have a more growth-minded engineering mindset score were those who had a higher socioeconomic status, did not receive special education services, experienced more whole-class discussion and activity, or had a higher growth mindset score. Gender and race/ethnicity did not predict an engineering mindset score, meaning all students had the same opportunity to exhibit a growth or a fixed mindset. A less positive finding was that low SES students and special education students had lower engineering mindset scores. It is important that teachers and researchers engage in further work on investigating ways to support all students to engage in productive struggle (Lottero-Perdue & Lachapelle, 2020).

Table 2 has a summary of the four studies in this section. Students' classroom experiences can have a positive impact on their mindset orientations. Integrated STEM education activities provide an excellent opportunity for students to persevere in problem solving, try new approaches, use all of their resources, and continue to develop their ideas when encountering setbacks or failures.

Table 2
Summary of K-8 STEM Education Growth Mindset Research

-Integrated STEM classroom activities can help align students with a growth mindset (Stohlmann et al., 2018).
-A mindset intervention paired with STEM activities can be beneficial to aligning students' mindsets with a growth mindset. The intervention can include reflection and discussion about the neuroplasticity of the brain and that success in STEM is not just based on innate ability (Dringenberg et al., 2020).
-Teachers should explicitly state positive messages about a growth mindset to students and connect this to students' class experiences (Vongkulluksn et al., 2021).
-Students with higher growth mindset scores had higher engineering post-assessment scores. Students were more likely to have a more growth-minded engineering mindset score if they had a higher socioeconomic status, did not receive special education services, experienced more whole-class discussion and activity, or had a higher growth mindset score. Low SES students and special education students had lower engineering mindset scores (Lottero-Perdue & Lachapelle, 2020).

In this way students can internalize the benefits of a growth mindset through their own experience. Similar to the previous section on K-8 science education, future research should consider how growth mindset interventions impact specific populations of students as Lottero-Perdue and Lachapelle (2020) found that low SES students and special education students had

lower engineering growth mindset scores. Growth mindset can be context specific (Dweck, 2015) so it is important to consider how the structure of a class and how the content is taught may affect students' mindset orientations.

5. Growth Mindset in K-8 Mathematics Education

Seven articles were identified with growth mindset in K-8 mathematics education, with five of the articles involving middle school students and two of the articles with elementary students.

The first middle school study involved 48 U.S. seventh graders in the intervention group and 43 seventh graders in the control group (Blackwell et al., 2007). The intervention was delivered by highly trained facilitators who were not the teachers of the students. The key messages were that learning changes the brain by forming new connections, and that students are in charge of this process. Students completed readings supported by activities and discussions. It was found that teaching students about growth mindset theory promoted positive change in classroom motivation, compared to a control group. Students in the control group displayed a continuing downward trajectory in grades, while this decline was reversed for students in the experimental group (Blackwell et al., 2007).

The next four articles did not involve an intervention but an exploration of the relationship of growth mindset with other variables. The role of growth mindset in 373 seventh grade U.S. students' mathematics achievement was examined. There was not a significant correlation between students' mathematics test scores in 6th grade and their belief in a growth mindset at the beginning of the year. A growth mindset was a significant predictor of students' mathematics achievement for the students as they were followed into 8th grade though (Blackwell et al., 2007). 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).

Three longitudinal studies were conducted with 207, 897, and 2,325 eleven to fifteen year-old U.S. students from socioeconomically disadvantaged schools to examine students' mindsets, metacognitive skills, and mathematics engagement (Wang et al., 2021). Across the three studies, students' growth mindset beliefs only predicted higher mathematics achievement among students possessing the metacognitive skills to reflect upon and be aware of their learning progress. By metacognitively processing learning tasks, students are also more likely to have mastery experiences and see the benefits of a growth mindset. Without metacognitive skills, students with growth mindsets may not have a means by which to gauge progress and growth. Thus, metacognitive skills may be necessary for students to realize the benefits of a growth mindset. It is interesting to note, students from the low-SES schools had lower metacognitive skills on average than their peers in high-SES schools, but there were fewer differences in students' growth mindsets between low and high-SES schools (Wang et al., 2021). Research has shown that students from low SES schools frequently encounter underqualified mathematics teachers, limited learning resources, and stereotype threat (Nasir, 2020), all of which undermine students' access to mathematics learning opportunities. Wang et al. (2021) have made an important point that growth mindset is only one factor to consider. "Hence, it might be risky to solely focus on promoting growth mindsets without adequate support for maintaining it. For instance, educators may attribute socioeconomically disadvantaged students' low engagement to fixed mindsets rather than focusing on how to change their teaching to better support these students' development of metacognition" (p. 15).

The two elementary grades studies did not involve an intervention. A study with racially diverse U.S. students in first through third grade examined the mindsets of children in general and with respect to mathematics and compared this to students' mathematics achievement. Students with a more growth-oriented mindset outperformed those with a more fixed-oriented mindset on a standardized mathematics test. In looking at the impact of the students' teachers, students' mindsets were more likely to be fixed if their teachers emphasized performance outcomes rather than emphasizing mastery and growth (Park et al., 2016).

The second elementary grades study drew on data from 84 interviews over two years with 23 students starting in grade 3 in London who had been designated as lower-attainers in mathematics, English or both. The researchers found that the effects of hard work and a growth mindset can be reduced based on the structure of how a class is taught. The results showed that a growth mindset, involving children's willing and enjoyable engagement with learning challenges, was threatened in the primary school by the promotion of passive learning, competition, and comparisons of students' respective attainments. The children seemed to accept that the key to school success was listening. Learning by listening suggested that learning meant being taught rather than making their sense of concepts themselves (Hargreaves et al., 2021).

Students often enter elementary school with great capabilities for creativity, exploration, and willingness to take on challenging tasks. As students progress through school, too often their creative thinking is stifled and becomes more a matter of producing work that they think the teacher wants (Stohlmann, 2013). Creative thinking has been decreasing since more of a focus on standardized testing (Kim, 2011). This can have negative consequences because when students' creative needs are not met, they often become underachievers (Kim, 2010).

Table 3 has a summary of the seven articles in this section. 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 associate the ability to learn mathematics with an innate aptitude rather than through hard work, practice, and effort (Ahn et al., 2016). The studies demonstrate the positive benefits of students believing in a growth mindset for mathematics including motivation (Blackwell et al., 2007) and academic achievement and engagement (Bostwick et al. 2017, 2019). Wang et al. (2021) found the importance of metacognitive skills paired with a growth mindset for higher mathematics achievement. With a growth mindset students seek feedback and try different strategies, which aligns well with metacognitive skills for students to be aware of what they know and what they need to work on.

Table 3
Summary of K-8 Mathematics Education Growth Mindset Research

-Teaching students about growth mindset theory promoted positive change in classroom motivation, compared to a control group (Blackwell et al., 2007).
-Even when students' background factors were included, students' growth orientations (growth mindset, self-based growth goals, and task-based growth goals) were positively associated with both their academic engagement and achievement (Bostwick et al. 2017, 2019).
-Students' growth mindset beliefs only predicted higher mathematics achievement among students possessing the metacognitive skills to reflect upon and be aware of their learning progress (Wang et al., 2021).
-Students from low-SES schools had lower metacognitive skills on average than their peers in high-SES schools, but there were fewer differences in students' growth mindsets between low and high-SES schools (Wang et al., 2021).
-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).

How mathematics is taught can have an impact on students' growth mindset orientations for mathematics. 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 is emphasized, students are more likely to hold growth mindsets (Park et al., 2016).

6. Discussion

Growth mindset theory is a topic that has received attention internationally as a possible way to help improve various student outcomes. Most growth mindset interventions have focused on programs for high school students or older (Vongkulluksn et al., 2021). The research reviewed in this article shows that there is more work being done recently with growth mindset in K-8 STEM education. Empirical studies published in journal articles from 2007 to 2021 on growth mindset in K-8 STEM, science, and mathematics education were identified and summarized.

Table 4 describes general growth mindset research findings found across age ranges as well as key characteristics of growth mindset interventions that have been noted in the literature. Helping students hold growth mindsets for STEM subjects is important so that students do not feel that only certain people are able to learn the STEM subjects. Promoting a growth mindset can help students see that the brain can grow and change and that hard work on challenging tasks helps this growth (Dweck, 2017a). Students should believe in hard work and effort, but they should know that this alone does not guarantee success (Hargreaves et al., 2021). A growth mindset is more than just effort. Students should learn how to try new approaches, use all available resources, and seek feedback. A growth mindset by itself is not enough to predict success. Resources, opportunities, and relationships are important (Dweck, 2006).

Table 4
Summary of General Growth Mindset Research

General growth mindset findings
-Students may have a general growth mindset, but for a specific subject such as mathematics or science they may hold more fixed mindset beliefs.
-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.
-Fixed mindset beliefs contribute to inequities in education as they particularly harm minority students and girls.
-Promoting the malleability of mathematics intelligence could be one way to increase female representation in STEM fields where women are underrepresented.
-Fostering growth mindsets can improve students' academic performance, increase students' motivation, and reduce social class gaps.
-Mindset associations with outcomes are often stronger among those facing academic difficulties or setbacks.
General growth mindset interventions
-Interventions should describe concrete actions that can be taken to develop a growth mindset.
-Hearing stories about famous people or peers who have used a growth mindset can be beneficial.
-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. Students can also write a letter or discuss what they would share to a student who has a fixed mindset
-The intervention should not just emphasize effort, but that ability has the potential to be developed.
-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 and should be aligned with goals that students are striving to meet.
-Self-persuasion opportunities should be incorporated.

If students are not exposed to challenging work they may not have the opportunity to develop a growth mindset. The drawbacks of a fixed mindset might only become apparent when a student is faced with setbacks, challenges, or failures. If students only experience success they have no opportunity to learn how to positively cope with challenges (Aalderen-Smeets 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.

The teacher is vital for reinforcing growth mindset and teaching STEM subjects in a way that students can experience the benefits of a growth mindset. Dweck (2006) notes that, "with the right mindset and the right teaching, people are capable of a lot more than we think" (p. 64). Any growth mindset intervention should include teachers for the most impact. Further research is needed to design and study ways to impact teachers' practices and mindsets in order for the interventions to have the most benefit with students (Park et al., 2016; Schmidt et al., 2017). In fact 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., 2015, 2017).

Self-persuasion classroom activities deserve further research focus as well with growth mindset. When students can participate in STEM activities and experience learning from failure, perseverance, collaboration, and using all their available resources they will likely better internalize a growth mindset orientation (Stohlmann et al., 2018; Vongkulluksn et al., 2021). While there are numerous studies on growth mindset interventions, understanding how students develop growth mindset in naturalistic classroom settings through the way content is taught has been suggested as critical for future work (Bostwick et al., 2019; Haimovitz & Dweck, 2017; Schmidt et al., 2015).

Integrated STEM education can especially encourage a growth-minded approach to failure experiences. Through open-ended problems students can focus on the process of learning, receive and use feedback, metacognitively monitor their progress, and use all of their resources (Lottero-Perdue & Lachapelle, 2020; Stohlmann et al., 2018; Stohlmann, 2019a). Students can participate in challenging tasks with multiple solutions and use creativity and problem solving. Integrated STEM education tasks can also help students see STEM subjects as relevant, useful, and enjoyable (Stohlmann, 2020). Through open-ended problems students can persevere in problem solving, use multiple representations in their solutions, see there is more than one right answer to a problem, that there is not one type of person that can be successful in mathematics, and learn from others (Stohlmann, 2017). Teachers can explicitly state growth mindset messages to students as part of these tasks to help students connect a growth mindset to the specific context of STEM education, science education, or mathematics education. Though important for all STEM subjects, in particular, research has found holding a growth mindset for mathematics can be a great benefit to students (Bostwick et al., 2017, 2019).

The teacher is an important part of students' growth mindset development. It should be conveyed to students that all students are capable of learning STEM subjects. Further research work is needed to investigate how to structure growth mindset implementations integrated with classroom tasks to best benefit all students. A growth mindset can help students strive to do their best, seek to improve, and to be a life-long learner. With a growth mindset students can find setbacks motivating and beneficial based on the feedback that comes from it. Growth mindset has received increased focus with K-8 students and further research work is needed with students in this grade band to determine the most impactful interventions to help students develop and maintain a growth mindset for STEM subjects.

Funding: No funding source is reported for this study.

Declaration of interest: No conflict of interest is declared by author.

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