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Towards an Understanding of STEM Engagement: a Review of the Literature on Motivation and Academic Emotions

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Abstract There are international calls to enhance learner engagement in STEM. Further, there are international concerns about the gender disparity in interest, aspiration, and participation in STEM. These calls recognise the role that learners' motivation in, and emotional response to, STEM plays in their participation and achievement in STEM education. However, there is a lack of understanding as to what constitutes "engagement" in STEM education. In this article, we adopt an educational psychology-based definition of engagement that is influenced by motivational and emotional constructs. We review a purposive sample of student motivation and academic emotion literature to reveal pertinent insights about student STEM engagement. The review pays particular attention to findings associated with gender and offers a summary of the limited research around educational interventions informed by motivational models. This review reveals that self-concept, self-efficacy, and task value are important for STEM engagement, performance, subject selection, and career aspirations. Mastery goals are linked to high effort and persistence in STEM, while autonomy, relatedness, and growth mindsets improve STEM participation and achievement. Further, girls have lower self-concept in STEM, are less likely to hold interest and utility value, and are more likely to attribute failure to a lack of ability. Finally, negative emotional responses to STEM can form early and persist throughout schooling. These affective aspects need to be understood and explicitly addressed as part of any successful strategy to improve engagement in STEM education, and to address the significant gender equity issues associated with STEM.

Résumé Il y a des appels internationaux visant à accroitre le niveau d'engagement dans les STEM. De plus, on note une préoccupation au niveau international quant à la disparité entre les sexes lorsqu'il est question d'intérêt, d'aspirations et de participation à l'égard des STEM. Ces appels reconnaissent le rôle que jouent la motivation des étudiants et leurs réactions émotives dans la participation et la performance en enseignement /apprentissage

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des STEM. Cependant, un manque de compréhension persiste en ce qui concerne la définition exacte de ce qu'est l'engagement dans les STEM. Dans cet article, nous adoptons une définition de cet engagement fondée sur la psychologie éducative, influencée par des construits motivationnels et émotionnels. Nous analysons un échantillonnage raisonné de documents sur la motivation étudiante et sur le comportement affectif afin de révéler des informations pertinentes au sujet de l'engagement des étudiants dans les STEM. L'analyse se penche en particulier sur les résultats liés à la différence de sexe, et présente un résumé des quelques travaux portant sur les interventions pédagogiques qui tiennent compte de modèles motivationnels. L'analyse révèle que l'image de soi, l'efficacité personnelle et la valeur de la tâche sont importantes pour ce qui a trait à l'engagement, à la performance, au choix du sujet et aux aspirations professionnelles dans les domaines STEM. Les buts de maîtrise sont liés à l'effort soutenu et à la persévérance dans ces domaines, tandis qu'une mentalité axée sur l'autonomie, la relation et le perfectionnement améliorent la participation et les résultats. De plus, les filles ont une image de soi moins positive en STEM, ont une probabilité moins élevée de valoriser les STEM ou de soutenir leur intérêt pour ces domaines, et sont plus facilement prêtes à attribuer leurs échecs à un manque d'habileté. Enfin, des réponses émotives négatives à l'égard des STEM peuvent se développer très tôt et persister pendant toute la formation scolaire. Il est nécessaire de comprendre et d'affronter explicitement ces aspects affectifs si on veut promouvoir une stratégie efficace pour améliorer l'engagement envers l'enseignement/apprentissage des STEM, et enrayer les problèmes significatifs de disparité entre les sexes associés aux STEM.

Keywords STEM education · Engagement · Motivation · Academic emotions · Gender

Introduction

"STEM education" is a term that rose to prominence in the late 2000s and refers to formal and informal education programmes from pre-school to tertiary level (Shanahan et al., 2016). It builds knowledge of the STEM disciplines of science, technology, engineering, and mathematics, as well as interdisciplinary skills such as complex problem solving, critical thinking, and creativity (Murphy et al., 2019). Worldwide, nations are looking to STEM to manage a rapidly changing environment; to supply food, water, and resources; to preserve health and well-being; to innovate new technologies; and to ensure prosperity and security (Council of Canadian Academies, 2015; ICF & Cedefop, 2014; National Science and Technology Council, 2013; Office of the Chief Scientist, 2013). Internationally, the STEM education movement is responding to these challenges by aiming to prepare future citizens and workers for an increasingly complex, dynamic, technical, and uncertain world (Gough, 2015). Given the importance and urgency of this mission, STEM education has attracted wide support from industry, policymakers, and educators alike (Myers & Berkowicz, 2015; Shanahan et al., 2016). All recognise that there is a need to adopt educational practices that better prepare students to live, work, and contribute to a technology-driven world.

At the same time, as the STEM movement has gained strength internationally, in Western countries, there has been growing recognition of significant concerns in STEM education (Blackley & Howell, 2015). International testing reveals that students' STEM skills in these nations are not as strong as in the emerging Asian economies (Thomson et al., 2016), a significant concern given the accepted correlation between strong performing education systems and nations with thriving economies (Marginson et al., 2013). Also concerning is that OECD nations have on average seen a decline in both mathematical and scientific literacy in recent years (Thomson et al., 2017a). Further, enrolments in senior secondary and tertiary STEM subjects in these nations have declined relative to other subjects (Marginson et al., 2013). In Australia, for example, participation in all but entry level Year 12 Mathematics has declined over the past 20 years, as has participation in Year 12 Biology, Chemistry, and Physics (Office of the Chief Scientist, 2017). This may be unsurprising, given research showing older Australian students lose interest and self-confidence in mathematics and science (Thomson et al., 2017b).

In response, there are calls internationally to better engage learners in STEM, and to encourage them to aspire to pursuing STEM careers (for example, Council of Canadian Academies, 2015; Education Council, 2015; National Science and Technology Council, 2013). These calls recognise the role that learners' motivation in, and emotional response to, STEM plays in their participation and achievement in STEM education. Taking this stance, "STEM engagement" can be defined as students' active involvement in STEM learning activities (Christenson et al., 2012), encompassing cognitive, behavioural, and emotional aspects (Fredricks et al., 2004). Cognitive engagement can be defined as including the use of cognitive self-regulation strategies. Behavioural engagement involves behaviours such as exerting effort, concentrating, and persisting (Fredricks et al., 2004; Patrick et al., 2007). Emotional engagement refers to students' positive and negative emotions towards tasks at hand and learning in general, such as enjoyment, boredom, anxiety, and interest (Fredricks et al., 2004). These affective aspects need to be understood and explicitly addressed as part of any successful strategy to improve engagement in STEM education.

Further, explicitly addressing the affective aspects of STEM education is vital for addressing the significant gender equity issues associated with STEM. There are international concerns about the gender disparity in interest, aspiration, and participation in STEM (Council of Canadian Academies, 2015; Education Council, 2015; Hoyle, 2016; Office of Innovation and Improvement, 2016). Despite international testing showing females achieving at similar levels to males in STEM education (Thomson et al., 2017a, b), they are significantly underrepresented in STEM careers and industry. In Australia, only 16% of STEM-qualified people are female, with females making up 29% of university-qualified workers and only 9% of those with Vocational Education and Training (VET) qualifications (Office of the Chief Scientist, 2016). This situation is not dissimilar in other nations. In Canada, females make up just 26.9% of the STEM-intensive workforce (Council of Canadian Academies, 2015); in the USA, females hold only 25% of STEM jobs (National Science and Technology Council, 2013); and in the UK, women only make up 8% of the engineering workforce (Morgan & Kirby, 2016). Despite females having the capacity to succeed in STEM careers, they are choosing not to pursue these pathways. Much of the writings exploring why these inequities exist suggest that females tend to have lower aspirations in, confidence in, and affinity with, STEM subjects (for example, Morgan & Kirby, 2016).

The extant STEM education literature indicates a strong interest in engagement; however, this work typically claims impact on student motivation and/or academic emotions without explicitly considering psychological constructs. The existing STEM education research tends to describe pedagogies that authors suggest improve student engagement or aspiration (for example, McDonald, 2016), with very few exploring the motivational mechanism for this improvement (for example, Rosenzweig & Wigfield, 2016). In response to this gap in the STEM education field, this paper synthesises the literature concerning student motivation and academic emotion to reveal pertinent insights about students' STEM affect. It pays particular attention to findings associated with gender and offers a summary of the limited research around educational interventions informed by motivational models. Finally, it highlights the constructs with best promise for improving STEM education, and for closing achievement and participation gaps, and suggests areas for future research.

Method

To conduct this review, we began by identifying a taxonomy of major concepts (Burke & Hutchins, 2007) related to motivation and academic emotions. There are a number of contemporary theories of motivation, such as expectancy-value theory, self-determination theory, attribution theory, and achievement goal orientation theory. These theories, different from the historical behavioural (for example, conditioning) and physiological (for example, instinct, arousal) perspectives, recognise the role of cognition, such as thoughts, beliefs, expectations, values, and goals, as central to motivation and generally agree on the definition of motivation as "the process whereby goal-directed activity is instigated and sustained" (Schunk et al., 2008, p. 4). It is beyond the scope of the current paper to review each theory; instead, six key constructs drawn from these cognitive theories of motivation were identified, namely, self-efficacy/self-concept, task value, achievement goals, beliefs about intelligence, sense of autonomy, and sense of relatedness. Academic emotions are similarly multifaceted phenomena including affective, cognitive, physiological, motivational, and expressive components (Pekrun & Linnenbrink-Garcia, 2012). These emotions are experienced by students in learning contexts, and they influence their effort, motivation to persist, and strategies for learning (Pekrun & Linnenbrink-Garcia, 2012). Academic emotions may be positive (e.g. joy, enjoyment, hope) or negative (e.g. angry, tense, anxious). The differing emotions experienced by students will impact their experiences of, and attitudes toward, STEM learning.

Using this taxonomy of major concepts, we examined and evaluated the literature with the goal of appraising the available evidence as to how motivation and academic emotions impact upon STEM engagement and outcomes, with a particular interest in gendered effects. We focused our review on empirical findings grounded in theory (Burke & Hutchins, 2007). Our review was not limited to a particular time range, and we sought publications from a range of perspectives including generalist educational research, educational psychology, and STEM education and its component disciplines. Due to the size of these fields, our review is not exhaustive (Sutton & Wheatley, 2003); rather, we have gathered a purposive sample of literature in order to provide broad coverage of a range of perspectives on engagement and STEM education, with a total of 116 papers reviewed.

Below, we offer a synthesis of the research on each of the key motivation and emotion constructs and how they are linked to students' STEM ability, engagement, participation, and aspiration. We also canvass a range of interventions designed to impact upon these constructs. While we do not review specifically the interconnectedness among the key constructs, we acknowledge that they are closely related (Carmichael et al., 2017; Chouinard & Roy, 2008).

Self-concept, Self-efficacy, and Task Value

The most prominent theory in the study of affect and STEM outcomes is expectancy-value theory (Eccles, 2009), which posits that students' expectancies and task value are linked to a range of outcomes such as task choice, persistence, engagement, effort, course enrolment decisions, intentions to attend postgraduate school, and achievement (Battle & Wigfield, 2003; Eccles et al., 1983; Hulleman et al., 2008). "Expectancy" refers to students' expectancies of success in upcoming academic activities or future events and has been empirically linked to two important self-related ability belief constructs—self-concept and self-efficacy (Andersen & Chen, 2016; Guo et al., 2017; Schunk et al., 2008). Self-concept and self-efficacy bear similarities (Schunk et al., 2008), although self-concept is more globally defined as one's belief about their ability in a specific domain (e.g. I am good at math), whereas self-efficacy is one's perception of their ability to complete a specific given task (e.g. doing multiplication) effectively (Bandura, 1997).

Task value refers to the values that individuals attach to the activities and answers the question of "Why should I do this task" (Eccles et al., 1983; Schunk et al., 2008). Four components of task value were proposed. *Attainment value* is the importance individuals attach to doing well on a task. One is more likely to value tasks that are central to their sense of self; that is, doing well on a task contributes to and confirms the valued characteristics of themselves (Eccles, 2005). *Interest value* is the enjoyment one gains from doing the task. Individuals are more likely to engage in a task that they find interesting or intrinsically rewarding (Eccles, 2005). *Utility value* is the usefulness of the task, especially its long-term utility beyond the immediate situation (Eccles, 2005; Hulleman et al., 2008) such as career and educational plans. Individuals are more likely to value a particular math class if it is useful for their desired career in engineering. Last, *cost* is conceptualized to impact individuals' value of a task in terms of cost/benefit ratio (Eccles et al., 1983) and involves the amount of effort needed to do the task and the psychological cost of anxiety and failure. Individuals who perceive the required amount of effort as too high or failure as costly are less likely to value and pursue the task (Eccles, 2005; Eccles et al., 1983). Australia's national STEM strategies of highlighting the relevance and importance of STEM-related skills among students and broader community from early years throughout schooling reflect this theoretical perspective (Education Council, 2015).

Self-concept/self-efficacy and task value are all found to be important for students' STEM engagement, performance, coursework selections, and career aspirations (Andersen & Chen, 2016; Guo et al., 2017; Hiller & Kitsantas, 2014; Petersen & Hyde, 2017; Robnett & Leaper, 2013; see Wang & Degol, 2013 for a review) over and beyond prior achievement. However, their predictive value varies based on the outcomes of interest. Self-concept/self-efficacy is particularly predictive of STEM performance. For instance, in a US longitudinal study, math self-concept at 5th grade predicted their math achievement even 5 years later, after controlling for prior math achievement (Petersen & Hyde, 2017). In another international study across 26 countries, students' science self-concept has more predictive value than intrinsic and utility value on students' science achievement (Liou, 2017). Students' task values, especially interest and utility value, however, are more predictive of students' long-term STEM educational and career choice, compared with self-concept/self-efficacy (Andersen & Chen, 2016; Guo et al., 2015). Importantly, both self-concept/self-efficacy and task value are needed for students to engage in STEM and have career aspirations in STEM (Guo et al., 2017). However, performance is not always found to be associated with self-efficacy or task value. In a large-scale national longitudinal study among US high school students ($n = 19{,}259$), only 13.5% of the students with above average ability had indicated high utility value and only 15.5% of students with above average abilities had indicated high self-efficacy in science (Andersen & Chen, 2016). This suggests a level of disidentification with STEM subjects among students, even students with above average ability; that is, students who could have high potential for science achievement do not possess high self-efficacy or endorse a value for science subjects. Further, cultural factors need to be considered in the link between motivational belief and STEM outcomes. For instance, East Asian countries have lower motivational beliefs (i.e. self-concept) yet higher STEM achievement (i.e. science achievement), compared with Western countries (Liou, 2017).

Students' self-concept/self-efficacy and subjective task value tend to change over time. Most longitudinal research has focused on the subject of mathematics which has been viewed as a difficult subject for which motivational factors are especially important (Köller et al., 2001). Math self-concept has, in general, decreased across school years from 1st to 12th grade among US students (Fredricks & Eccles, 2002; Jacobs et al., 2002) and this pattern of decrease has been found across secondary years (7th to 11th grade) in other Western countries, including Australia, and Germany (Nagy et al., 2010). A long-term longitudinal study among US students found that math value (a combination of interest and utility value) declined across school years from 1st to 12th grade, particularly sharply during high school years (Jacobs et al., 2002). In studies that examined math interest and utility value separately, a declining trend of math interest has been found across middle school and early adolescence, for instance, from 5th to 9th grade among a US sample (Petersen & Hyde, 2017) and from 7th to 12th grade among a German sample (Köller et al., 2001). Math utility value has decreased from 1st to 9th grade and slightly increased from 10th to 12th grade (Fredricks & Eccles, 2002), which might reflect the increasingly more salient message during high school about the importance of math.

There have been notable gender differences in math self-concept/self-efficacy, interest, and utility value. Girls tend to have lower math self-concept, interest, and utility value than boys even though they perform similarly in math (Guo et al., 2015; Petersen & Hyde, 2017). Such gender differences in motivational beliefs have been linked to girls being less likely to choose high school math courses, select STEM majors in postsecondary academic life, or pursue STEM career, compared with boys (Guo et al., 2015; Robnett & Leaper, 2013). Some studies found that gender differences in math self-concept emerges in the early school years, especially from 1st to 6th grade, and such gender gap has been shown to reduce over middle school years, and by high school years, boys and girls have similar math self-concept (Fredricks & Eccles, 2002; Jacobs et al., 2002). Others, however, found the gender gap in math self-concept remained from 7th to 11th grade (Nagy et al., 2010). Little gender differences were found in the trajectories of change in math value across school years (Jacobs et al., 2002).

This section demonstrates that self-concept/self-efficacy and task value constructs interact in complex ways as they impact on students' motivation in STEM. Self-concept/self-efficacy is predictive of performance in mathematics and science, though high performance in science has not always been found to be associated with high self-efficacy. Students' task values are more predictive of aspirations in STEM. Self-concept and task value tend to decrease from the beginning of primary school to the senior secondary school years in mathematics; however, there is little similar research into longitudinal changes in these constructs in other STEM disciplines. Research also suggests that the impact of these motivational constructs on STEM performance varies with cultural background. Further, girls tend to have lower self-concept/self-efficacy and task value in STEM than boys, despite similar performance, and this has been associated with lower STEM aspirations. The weight of evidence demonstrates that these motivational constructs are useful for exploring student engagement with STEM; however, the many elements of these constructs do not always impact engagement in a predictable fashion, varying somewhat depending on STEM discipline, context, and participants.

Achievement Goals

Achievement goals are defined as the purpose and reasons for engaging in academic tasks and achievement behaviours (Ames, 1992). A trichotomous framework has been widely accepted in the literature which empirically supported three different achievement goals: *Mastery goals* are undergirded by a need for achievement and focus on learning, understanding, and developing academic competence; *performance approach goals* are undergirded by both a need for achievement and a fear of failure and focus on demonstrating competence, being judged favourably by others and outperforming others; *performance avoidance goals* are undergirded by a fear of failure and focus on masking incompetence (Ames, 1992; Schunk et al., 2008).

The achievement goals that students endorse have important implications for their academic engagement, task choice, and performance in learning overall (Ames, 1992). Mastery goals have been consistently related to enhanced cognitive engagement, such as using deep learning strategies and self-regulatory strategies (Elliot & McGregor, 2001; Liem et al., 2008). Mastery goals have also been linked to sustained and high-quality behavioural engagement in learning, higher levels of persistence (Elliott & Dweck, 1988; Pintrich, 2000), choosing challenging tasks, and positive affect towards learning and school (Dweck & Leggett, 1988). Further, mastery goals have been associated with enhanced intrinsic motivation, self-efficacy/self-concept, and task value (Ames & Archer, 1988; Harackiewicz et al., 2002; Zusho et al., 2005). Performance avoidance goals, on the other hand, have been consistently linked to using surface learning strategies, self-handicapping strategies, disruptive behaviour, task disengagement, and lower academic grades (Durik et al., 2009; Elliot & McGregor, 2001; Kaplan et al., 2002; Liem et al., 2008; Urdan, 2004). Further, performance avoidance goals are also found to predict lower hope, pride, and interest, and higher test anxiety, boredom, and anger (Pekrun et al., 2006, 2009).

Findings for performance approach goals have been mixed. Some studies found performance approach goals to be maladaptive, relating to superficial cognitive strategies and self-handicapping strategies (Elliot & McGregor, 2001; Midgley & Urdan, 2001), as well as lower self-efficacy and higher anxiety (Skaalvik, 1997; Daniels et al., 2009), whereas others found performance approach goals to be related to deep learning strategies, self-regulation, effort (Meece et al., 1988; Urdan, 2004; Vrugt & Oort, 2008), as well as hope and pride (Pekrun et al., 2006, 2009), higher self-efficacy, interest, and performance (Durik et al., 2009; Elliot & McGregor, 2001).

The same pattern applies to STEM-specific subjects. For instance, mastery goals have been related to enhanced use of cognitive and metacognitive strategies in science and math (Meece et al., 1988; Wolters et al., 1996) and been linked to heightened effort, persistence in times of difficulty and boredom, lower incidents of disruptive behaviour, and lower levels of avoiding seeking help in math among secondary school students (Chouinard et al., 2007; Gonida et al., 2014; Kaplan et al., 2002; Lazarides & Rubach, 2017; Middleton & Midgley, 1997; Wolters, 2004). Students with mastery goals are also more likely to have higher math and science self-efficacy/self-concept, choose advanced math courses, and are less likely to procrastinate in completing required mathematics tasks (Friedel et al., 2007; Middleton & Midgley, 1997; Wolters, 2004; Pajares et al., 2000). Performance avoidance goals have been linked to heightened disruptive behaviours, higher levels of avoiding seeking help, and maladaptive coping strategies when students had a bad experience in mathematics learning (Friedel et al., 2007; Gonida et al., 2014; Kaplan et al., 2002; Middleton & Midgley, 1997) and lower science and mathematics self-efficacy/self-concept (Middleton & Midgley, 1997; Murayama & Elliot, 2009; Pajares et al., 2000). Findings for the role of performance approach goals in STEM learning are also inconsistent. They have been linked to more disruptive behaviour in mathematics classrooms, as well as high science and mathematics self-efficacy/self-concept (Kaplan et al., 2002; Murayama & Elliot, 2009; Pajares et al., 2000).

Longitudinal studies tracking the changes of achievement goals in STEM have mostly focused on the subject of mathematics. In a study among students transitioning from elementary to middle school from 5th to 6th grade, students reported higher mastery goals before than after the transition (Anderman & Midgley, 1997). Middleton and colleagues found that all three types of achievement goals (i.e. mastery goals, performance approach goals, and performance avoidance goals) stayed moderately stable over time from 6th to 7th grade during middle school (Middleton et al., 2004). However, in a study among high school students, students' mastery goals in mathematics declined through high school, whereas performance approach goals and avoidance goals stayed moderately stable (Chouinard & Roy, 2008).

Gender differences on achievement goals in STEM do not always emerge (Pajares et al., 2000) but when they do emerge, for instance, in the context of mathematics, boys tend to endorse performance approach goals more than girls, whereas girls tend to endorse mastery goals more than boys (Chouinard et al., 2007; Chouinard & Roy, 2008; Friedel et al., 2007; Middleton & Midgley, 1997). Such gender differences are suggested to be attributed to boys perceiving a stronger emphasis from parents and teachers on performance and demonstrating ability, consistent with performance approach goals, and that girls tend to perceive a stronger emphasis from parents and teachers on learning and exerting effort, in line with mastery goals (Friedel et al., 2007). Gender differences on performance avoidance goals are not usually found (Pajares et al., 2000), but boys were reported to have higher avoidance goals than girls in some studies (Chouinard & Roy, 2008).

This section has shown that the achievement goal constructs impact upon both students' behavioural and cognitive engagement with STEM. Mastery goals are associated with improved effort and less disruptive behaviour in mathematics and science, whereas the reverse is true for performance avoidance goals. There is concerning evidence that student mastery goals in mathematics decline in the transition from elementary to middle school, and through high school. Also, in mathematics, the genders tend to be motivated by different achievement goals, with girls more likely to adopt mastery goals, and boys more likely to adopt performance approach goals. However, there is a lack of research around changes in achievement goals over time or between genders for disciplines other than mathematics.

Sense of Autonomy and Sense of Relatedness

Students' sense of autonomy and relatedness is important for their academic engagement, personal well-being, and the development of self-determination (Carmichael et al., 2017; Deci & Ryan, 1985; Wang & Holcombe, 2010). The need of autonomy is students' need to feel a sense of control and agency and have an internal locus of causality. Students prefer to have an option and the opportunity to alter the environment if they need to or want to. Students can be autonomous but dependent. That is, they have the control over their own learning process but also understand that if they need to, they can ask for assistance. The need of relatedness is students' need to feel that they are connected to their environment (e.g. peers, teachers) and feeling loved, cared for, and important. Given that learning activities are not always intrinsically motivating, students' sense of relatedness is especially important for the process of assimilating the values and beliefs that are deemed as important by their significant others for academically important albeit uninteresting and arduous activities (Ryan & Deci, 2000).

Fulfilling students' sense of autonomy and relatedness has important implications for students' STEM engagement, participation, and achievement. In a large study among students aged between 8 and 16 years in Australia, students in schools that are autonomy-supportive were found to have more adaptive motivation and higher engagement in mathematics (Carmichael et al., 2017). In another study among high school students in Pakistan, students' perceived autonomy support from teachers was linked to higher mathematics homework completion and grade (Hagger et al., 2015). Secondary school students' perceptions of teachers' autonomy-supportive behaviours such as taking and understanding students' perspectives have been linked to higher interest experience in mathematics lessons (Tsai et al., 2008) and higher intrinsic motivation, self-efficacy, and achievement in mathematics and science, including physics, biology, and chemistry, over time (Bieg et al., 2011; Jungert & Koestner, 2015). These findings provide evidence to encourage teachers to incorporate autonomy-supportive strategies in their teaching practices. Autonomy-supportive strategies may include taking students' perspectives, welcoming students' feelings and thoughts, providing students with choices, allowing multiple ways and approaches to problem solving, and at the same time, providing students with clear instructions, strong support and guidance, and constructive feedback (Jang et al., 2010; Reeve, 2009; Stefanou et al., 2004; Vansteenkiste et al., 2006).

Similar benefits were reported in the literature for students' sense of relatedness. Students who have warm and close relationships with teachers and peers had higher academic engagement, achievement, school liking, and school belongingness (Furrer & Skinner, 2003; Hamre & Pianta, 2001; King, 2015; O'Connor & McCartney, 2007; Spilt et al., 2012; Wang et al., 2016, 2017). With regards to STEM subjects specifically, research has shown that students' perception of care from teachers was linked to higher intrinsic motivation in physics among 8th grade students (Bieg et al., 2011). Further, students' perceptions of teacher social support were linked to heightened school participation, school identification, and students' academic achievement (average of students' mathematics, science, English, and social sciences grades) (Wang & Holcombe, 2010). Girls tend to have higher levels of relatedness with teachers and peers (Furrer & Skinner, 2003; Wang et al., 2016); however, the benefits of relatedness were reported to be more salient for boys (Furrer & Skinner, 2003). Given the evidence, incorporating strategies of building positive relationships with teachers and peers in the curriculum is likely to prove effective in achieving positive outcomes among students in STEM subjects.

This section offers some emerging evidence about the impact of relatedness and autonomy on STEM engagement. There is some evidence suggesting these constructs are associated with achievement in mathematics and science, as well as evidence suggesting a connection with other motivational constructs such as self-efficacy and task value. The impact of these constructs in STEM education warrants further research; however, the available evidence suggests that fostering positive relationships and supporting autonomy can support the achievement of positive outcomes among students in STEM subjects.

Beliefs About Intelligence

There are individual differences in people's beliefs about intelligence. Some students have *growth* mindset who believe that intelligence is malleable and controllable, and that ability and effort covary, whereas students with *fixed* mindset believe that intelligence is fixed, unchangeable, and uncontrollable (Dweck & Leggett, 1988). In general, students with growth mindset are more likely to endorse adaptive motivation such as mastery goals, seek challenges, and persist. For them, failure does not threaten their positive self-concept or affect their emotional well-being negatively but suggests a need to improve. However, students with a fixed mindset see ability as a stable trait which makes the lack of academic competence a daunting reality. This reality may lead to students developing negative self-schemas, low self-efficacy/self-concept, low emotional well-being, adopting performance avoidance goals, avoiding challenging and novel tasks, and withdrawing in times of difficulties (Cole, 1991; see Dweck & Leggett, 1988 for a review).

Research literatures in STEM-specific subject domains echo the general pattern. In a study among secondary school students in Australia, students' growth orientation, a combination of growth mindset and growth goals, was linked to heightened engagement and achievement in mathematics (Bostwick et al., 2017). Studies among 6th and 10th grade science students in the USA showed that students with growth mindset toward science ability had adaptive motivation (i.e. mastery goals, higher science self-efficacy and science achievement, and lower science anxiety compared with students with fixed mindset (Chen & Pajares, 2010; Chen & Tutwiler, 2017)). A study tracking 373 students transitioning from 7th to 8th grade found students with growth mindsets significantly improved their mathematics performance, while the mathematics performance of students with fixed mindsets stagnated (Blackwell et al., 2007). A study that followed senior secondary students through to tertiary study found that growth mindsets were associated with higher math achievement and continuing study in a tertiary STEM degree (Cheng et al., 2017). Degol and colleagues found that growth mindset was associated with higher task value in mathematics and with STEM career aspirations (Degol et al., 2018).

Younger children tend to have growth mindset. From middle childhood, especially after the age of 7, however, children start to differentiate ability from effort and are more inclined to have a fixed mindset (Schunk et al., 2008). This change of mindset seems to be more pronounced for girls, who are considerably more likely to hold a fixed mindset of intelligence and attribute failure to a lack of ability from the early school years, especially in STEM areas such as mathematics and science (Chen & Pajares, 2010; see Dweck, 2002 for a review). Studies have also demonstrated that females who do adopt a growth mindset achieve better outcomes. A study of 1449 high school students found that females who endorsed a growth mindset had higher STEM achievement than males (Degol et al., 2018). A study of female university students found that those who were presented with arguments endorsing growth mindset outperformed those presented with fixed mindset arguments in mathematics tasks (Dar-Nimrod & Heine, 2006).

This section demonstrates that, though somewhat limited, the research into the impact of mindsets on STEM education reflects the trends noted in the mindset literature in general. Growth mindsets are associated with higher self-efficacy and higher achievement in both mathematics and science. Children tend to have a growth mindset during early childhood, and tend to become more fixed as they progress through school. Females tend to have a fixed mindset in STEM; however, females who endorse a growth mindset see benefits in achievement.

Academic Emotions

There is a reciprocal relationship between learners' academic emotions and their achievement (Pekrun et al., 2017). As described by Pekrun and Linnenbrink-Garcia (2012), students' feelings towards STEM learning may manifest as either positive or negative emotions. A summary of positive and negative academic emotions is presented in Table 1.

There are few studies focused upon academic emotions in relation to STEM, most of which examine the impact of negative academic emotions upon students' STEM learning and outcomes, and strategies for mitigating against these emotions. As explained by Pekrun et al. (2017), negative emotions such as anger, anxiety, shame, boredom, and hopelessness negatively predict achievement, and inversely, achievement negatively predicts these emotions. Dettmers et al. (2011) examined a longitudinal dataset of 3483 grade 9 and 10 students and found that the perceived quality of homework tasks affected students' experience of negative homework-related emotions. These emotions were negatively related to homework effort, and also negatively predicted students' later achievement in mathematics. Wegner et al. (2014) examined the impact of a science tutoring programme for 9–11-year-olds and found that the programme was able to lower students' frustration, boredom, and insecurity in relation to science education.

Table 1 Positive and negative academic emotions (adapted from Pekrun et al. (2002, p. 92))

Positive emotions	Negative emotions
Enjoyment	Boredom
Anticipatory joy	Hopelessness
Hope	Anxiety
Joy about success	Sadness
Satisfaction	Disappointment
Pride	Shame and guilt
Relief	
Gratitude	Anger
Empathy	Jealousy and envy
Admiration	Contempt
Sympathy and love	Antipathy and hate

A significant body of literature focuses upon mathematics anxiety, specifically. Mathematics anxiety is an accepted phenomenon in the mathematics education literature, and its prominence in upper primary and secondary is well established (Larkin & Jorgensen, 2016). A study by Larkin and Jorgensen (2016) found that mathematics anxiety was experienced by students in Year 6, and among this sample, the emotions of boredom, sadness, and hate were characteristic of students experiencing this anxiety. Moreover, Larkin and Jorgensen's study demonstrated that not only is mathematics anxiety evident among Year 6 students, it is prevalent from earlier ages than previously thought (Year 3) and remains consistent. This is a similar finding to that of Sorvo et al. (2017) who identified mathematics anxiety among students as young as Year 2. This suggests that negative academic emotions may establish early in learner development.

A small number of studies focus on positive emotions in STEM education. Simon et al. (2015) demonstrated that positive emotions such as enjoyment led to improved learner persistence and ultimately achievement. The majority of studies exploring positive emotions in STEM learning explored ways of activating positive emotions. Nicolaou et al. (2015) showed that a range of activities and success in knowledge acquisition helps generate positive emotions in students. Goetz et al. (2013) suggest that pedagogies that encourage student control and autonomy are able to support positive emotions. Further, a supportive teaching style and appropriate lesson demands were found to generate emotions of enjoyment and pride. Thus, high value and control appraisals, combined with a responsive teacher, can foster positive emotions as well as reduce negative emotions such as anger, helplessness, and boredom (Goetz et al., 2013).

This section has highlighted the impact of emotions on student achievement in STEM, as well as mechanisms for impacting these emotions through STEM education. Negative emotions both precipitate, and are generated by, poor achievement in STEM. The impact of negative emotions is particularly well explored in mathematics education, with "mathematics anxiety" a recognised phenomenon. There are teaching practices that foster positive emotions in STEM, including variety in learning activities, student autonomy, and supportive teaching.

Interventions

There are a range of ways that educators can impact on affect in STEM education. The authors have canvassed a range of research describing interventions built around the constructs discussed that successfully improve motivation and/or academic emotion. While several of these papers do not tie their findings explicitly to particular affective constructs, most have implications for enhancing motivation and/or emotion of learners in STEM. This section presents an overview of interventions targeting affect constructs as they relate to STEM evident in the literature. These interventions have targeted student populations from preschool to senior secondary, and variously target "STEM" as a whole, or the individual STEM disciplines. The interventions typically take one of two forms: (1) Interventions embedded within classroom/school practice or (2) extracurricular interventions.

Embedded interventions were those seen to be able to be delivered by educators as part of their everyday educational programme. These interventions targeted self-efficacy, value, relatedness, and academic emotions. For example, Master et al. (2017a) examined the impact of group participation on preschoolers' performance on STEM-related tasks and found that children working in groups showed better self-efficacy, performance, interest, and persistence than those completing the tasks individually. The Scientific Literacy Project (SLP) (Patrick et al., 2009) integrated science inquiry and literacy activities while aiming to improve the motivation of kindergarten students. The researchers found that participation in the SLP improved girls' liking of science, and the confidence of all students (boys and girls) increased. Jansen et al. (2013) used a computer-based mathematics problem-solving game with an adaptive learning design to build self-efficacy (independent of ability) in grades 3 to 6 students. Students were presented with 15 problems per game and problem difficulty was constantly adjusted in response to their success in solving previous problems. The researchers found positive but low improvement in relation to self-efficacy, and found that girls' self-efficacy improved more than boys. Nieto Moreno de Diezmas and Dondarza Manzano (2016) implemented a programme that capitalised on grades 5 and 6 students' positive emotions towards technology to facilitate learning. Tzohar-Rozen and Kramarski (2014) found that coaching grade students in cognitive regulation and emotional regulation both positively impact on mathematics emotion and achievement. Finally, Schukajlow and Rakoczy (2016) demonstrated that grade 9 students found cognitively demanding modelling problems enjoyable, impacting positively on interest and performance.

Extracurricular interventions were most prominent among the studies canvassed by the authors. These were taken to include camps, after-school programmes, special visits and excursions, and additional mentoring/monitoring of student activities. Extracurricular interventions were aimed at enhancing self-efficacy, value, relatedness, and interest. It was clear from the studies examined that the use of robotics has a positive influence upon students' interest and self-efficacy in STEM. A robotics camp was found to improve interest levels among middle school students (Nugent et al., 2010), while experiences with programming robots were found to increase Year 1 girls' interest and self-efficacy in STEM (Master et al., 2017b). An intervention for Year 6 students based on cooperative learning with robots was found to increase interest for both boys and girls; however, it was not clear if the effect was attributed to the use of robots or the cooperative learning approach (Mosley et al., 2016). Targeted enrichment programmes were found to be effective for enhancing both motivational and emotional aspects of STEM education. Access to enrichment laboratory activities improved self-efficacy for Year 9 students in regard to science lab work, particularly for girls (Itzek-Greulich & Vollmer, 2017). Similarly, studio STEM programmes providing middle school students with access to after-school STEM enrichment materials had consistently and mostly positive effects on students' motivation and engagement in STEM (Chittum et al., 2017), while Wegner et al. (2014) found that specifically designed tutoring for high-performing science students can lower boredom, frustration, and insecurity. An out-of-school mathematics programme for upper secondary students resulted in increased value, interest, and enjoyment in STEM education and potential STEM careers (Jensen & Sjaastad, 2013). Furthermore, a 9-week career development intervention for upper secondary girls had a positive impact on students' STEM career decision-making, and STEM self-efficacy more broadly (Falco & Summers, 2017).

In this section, we canvassed a range of projects aimed to impact student motivation and engagement in STEM. These interventions included those embedded in regular classroom practice, as well as those involving students in extracurricular activity. Collectively, they demonstrate that teachers can support student engagement with STEM across the learning journey, from early childhood through to secondary school. They also suggest that access to specialist or enrichment materials, like robots or scientific equipment, has a positive impact on student motivation, as does additional tutoring or out-of-school programmes in mathematics and science. Many of these interventions were found to be particularly effective for improving STEM engagement for girls.

Conclusion

The purpose of this review paper was to develop an initial understanding of the motivational and emotional mechanisms for STEM engagement. This review contributes new understandings to the field of STEM education research, which has typically described impacts related to affective outcomes without making explicit links to constructs associated with motivation and/or academic emotions.

This review canvassed research associated with a set of interrelated motivation and emotion constructs, as they impact on STEM education. Expectancy-value theory links the related constructs of self-concept, self-efficacy, and task value; all of which have all been found to be important for students' STEM engagement, performance, subject selections, and career aspirations. Mastery goals in science and mathematics were found to enhance the use of cognitive and metacognitive strategies, and linked to high effort and persistence. Learning environments that support autonomy, relatedness, and growth mindsets were found to improve STEM participation and achievement. Finally, there is a reciprocal relationship between learners' academic emotions and their achievement in STEM.

Some interesting trends were observed in relation to the affective domain of STEM education. The most prominent theory among studies of affects and STEM education was expectancy-value theory, with a range of evidence that the constructs of self-concept, self-efficacy, and task value have a great deal of impact upon students' STEM engagement. There was an observed dominance of literature focused on mathematics, followed by science, with very little affect-based research attending to technology or engineering. In particular, literature related to academic emotions was dominated by a focus on mathematics anxiety, which is consistent with affect-based research in the field of mathematics education. The literature was also dominated by studies focusing on middle years and secondary school students, with very few studies attending to early or pre-primary.

The literature pointed to notable gender differences regarding STEM education. Girls were more likely to hold fixed mindsets and attribute failure to lack of ability in STEM subjects. Furthermore, girls indicated lower self-concept in relation to STEM, and were less likely to hold interest and utility value in STEM, even when achieving at a similar level to boys. The literature also indicated some significant time effects in STEM education. Perhaps of the greatest concern were findings indicating that negative emotional responses to STEM subjects may form early, and persist throughout schooling. Moreover, students perceive their learning environments to be less optimal as they proceed through schooling levels, and both their self-concept and the value they place upon STEM learning may also decline over time.

This initial review provides a brief overview of the literature on motivation and academic emotion as it relates to the STEM disciplines. This serves as a useful starting point for researchers and educators to begin systematically exploring STEM engagement. It is acknowledged that the literature points to a complex interplay of the various motivational constructs and academic emotions presented that was beyond the scope of this review. A further limitation is the dearth of meta-analyses in this area; hence, the review may contain biased or non-robust findings. There remains the opportunity for a more thorough explanation of particular motivational constructs and their implications for STEM education in the future. The review does suggest certain gaps in the literature, particularly related to STEM engagement in early childhood, and also to STEM engagement for students from different cultures, localities, and socio-economic status groups. The review also indicates that there is value in further exploring how different teacher characteristics and teaching styles may support learner motivation and positive emotional responses in STEM education.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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