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ORIGINAL PAPER

Tracing mathematics engagement in the first year of high school: relationships between prior experience, observed support, and task-level emotion and motivation

James A. Middleton[1] · **Adi Wiezel**[2] · **Amanda Jansen**[3] · **Ethan P. Smith**[3]

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Abstract

We examined the relationships between different aspects of mathematics engagement for 285 students in their first year of high school in the United States. Path Analyses were used to trace the relationships between students' self-reported prior motivation and appraisals of control and value of mathematics, perceptions of teacher support and peer support. These variables and observed teacher and peer support as coded from video by researchers, were examined as potentially impacting students' self-reported in-the moment affect and task-level control and value appraisals Our results showed three key contributions. First, significant paths corresponded to relationships predicted by Control Value Theory (CVT) across a particularly robust set of variables and over the course of their first semester in high school. Second, results added further nuance by considering the objects that students' in-the-moment emotions were directed toward, showing distinctions between positive and negative emotions directed at the mathematics task, students' teachers and peers, and selves. Third, results more closely considered the impact of both observed and perceived aspect of support from peers and teachers in the classroom, in both its academic and social forms. Implications are discussed for theory and practice.

1 Introduction

Supporting productive engagement in mathematics is an enduring challenge. Engagement in, and the motivation to continue, mathematics has been shown to decrease as students progress through compulsory education (Collie et al., 2019). Moreover, engagement is complex, involving the integration of emotional appraisals of mathematics learning experiences along with other social and cognitive characteristics (Fredricks et al., 2004; Middleton et al., 2017). Mathematics engagement also occurs in the context of a classroom, in which the teachers and peers enact strategies that sometimes enhance and sometimes diminish one feature of engagement in favor of another (Reindl et al., 2015; Strati et al., 2017). In this paper, we attempt to integrate these and other studies of mathematics engagement under a coherent framework that can predict many of the causal relationships among engagement factors and describe their interaction in the realities of secondary mathematics classrooms.

One of the perspectives on motivation that we draw upon comes from the work on Control Value Theory (CVT), which is among the most well-researched approaches to the study of the relationships between academic engagement, prior-level motivations and appraisals, task-level affect, and task-level motivations (e.g., Pekrun 2006). The CVT framework begins by considering both (1) learner's expectations

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✉ James A. Middleton
james.middleton@asu.edu

[1] School of Engineering for Matter, Transport and Energy Adi Wiezel, Arizona State University, Tempe, Arizona, USA

[2] Department of Psychology, Arizona State University, Tempe, Arizona, USA

[3] School of Education, University of Delaware, Newark, USA

and of success and sense of control over that success, and (2) learners' perceptions of the intrinsic and extrinsic value of academic tasks. These appraisals are also influenced by elements of the environment, such as the quality and demands of instruction, but of particular note here, is their influence on current emotions related to the learners' activity and outcomes. Those in-the-moment emotions, in turn, impact students' persistence in the task, self-regulation during the task, and feelings of situational efficacy and interest (Putwain, 2021). Collectively, the combined affect and value attributions update the learner's longer-term schemata, which can then be recruited for future, math-related choices (Pekrun, 2006).

However, as suggested in the introduction, and in the consideration of the environment in the CVT, elements of teacher and peer support should also play a role in fostering engagement. Some recent work builds on this notion, finding that students' perceptions of teacher support behaviors—such as positive reinforcement of achievement, teacher enthusiasm, and elaborative instruction— positively relate to students' enjoyment and pride in their work, and negatively relate to their anxiety, boredom, and anger. Likewise, peer regard is a strong predictor of students' positive emotions, and negative predictor of negative emotions. In addition, poor relationships with teachers or peers, controlling environments, and academic pressure to achieve are all associated with negative emotions toward mathematics (Sun et al., 2022; Goetz et al., 2006).

To connect these areas of research, we review the literature on prior motivations, task-level emotions, task-level motivations, as well as the academic and social support afforded by teachers and peers. We then summarize and synthesize these relationships and identify some gaps in the literature. Finally, we introduce and assess a comprehensive framework, investigating in greater detail the interrelations between these concepts, and adding further differentiation in terms of affective experiences.

1.1 Prior motivation and appraisals

Prior motivations and appraisals can influence in-the-moment emotions and motivations. Among the most important are interest, self-efficacy, and self-regulated learning (SRL).

1.1.1 Personal and situational interest

Interest is an appraisal of the value of a domain, thus linking it with intrinsic value appraisals in CVT. The work on interest typically distinguishes between personal interest (one's longer-term interest in mathematics) and situational interest (the "interestingness" of an activity in the moment; Ainley & Hidi 2014). Situational interest, in particular, is related to other task-level affective and motivational processes. Greater situational interest increases effort expended in mathematical tasks, assists in goal coordination (especially of mastery goals), influences the development of positive self-efficacy, and encourages more effective SRL strategies in learners (see Renninger & Hidi 2019 for a comprehensive review). Notably, personal interest and situational interest show reciprocal relationships; continued situational interest leads to the development of personal interest, and personal interest helps learners evaluate the value of engagement in, and the degree of effortful processing needed for, tasks that are like previous experiences (Hidi & Renninger, 2006).

1.1.2 Efficacy beliefs

CVT research has shown that learners who believe they will be efficacious tend to show more positive task-level emotions, fewer negative task-level emotions, and more productive self-regulatory strategies (Muis et al., 2018). Similarly, mathematical self-efficacy has been found to be a strong predictor of enjoyment, effort, and perseverance, and a strong negative predictor of anxiety (Van der Beek et al., 2017; Mega et al., 2014).

Efficacy beliefs can also be thought to occur at both trait- and state-levels. At the state level, task-efficacy helps learners adapt to task requirements and engage appropriate SRL strategies. In the long term, it helps learners assess the worthiness of engagement and call up strategies likely for success.

1.1.3 Self-regulated learning

Self-regulated learning (SRL) describes how the learner coordinates their behaviors to initiate, monitor, and adapt to task requirements (Musso et al., 2019). SRL is elicited by different task-level achievement emotions. For example, positive activating emotions foster planning and more complex SRL strategies (Di Leo et al., 2019; Pekrun & Perry, 2014), whereas negative activating emotions encourage students to seek out external resources for control and inhibit SRL strategies. However, the relationship between SRL and achievement emotions is not always straightforward. For example, Ben-Eliyahu & Linnenbrink-Garcia (2015) found that students who are extremely excited tend to lack planning capabilities and struggle to focus, inhibiting SRL.

SRL is also impacted by patterns of social and cognitive engagement in the classroom. In the context of teacher-led collaborative group work, students' enactment of problem-solving plans aligns with cognitive SRL strategies, while students' use of forethought and planning is associated with their social and emotional engagement (Järvelä et al., 2016).

In student-led sessions, students' social and emotional engagement to maintains group functioning to facilitate problem-solving. Thus, characteristics of the task, and the social interactions involved, may be associated with different SRL strategies.

1.2 Task-level emotions

Emotions are cognitively useful for behavior regulation and task-level motivation. Research in the CVT tradition has shown that positive emotions tend to support continued cognitive engagement (more effective SRL strategies), interest, and feelings of efficacy (e.g., Goetz et al., 2020); whereas negative emotions are associated with less effort, poorer application of SRL strategies, reduced interest, reduced efficacy, and poorer academic and social performance.

Some evidence suggests that task-level emotions are directed toward different objects, enabling students to hold negative and positive emotions simultaneously (Russell, 2003; Wiezel et al., 2019), for example, studied patterns of task-level emotions in high school students in over a dozen math classrooms. They found that students' emotions could be directed toward several objects including the math task, their teachers and peers, and themselves, and that emotional responses to these objects (e.g., being happy with one's teacher/class while being ashamed of oneself) may help explain why students often report both positive and negative feelings simultaneously (Di Leo et al., 2019). Task-level emotions also help modulate students' long-term self-regulation during, and self-efficacy following, a task, and their future willingness to engage in the subject (Netzer et al., 2018; Hanin & Van Nieuwenhoven, 2016).

1.3 Task-level motivations

There are a variety of outcomes to consider in terms of motivation in the moment. Two of these—interest and efficacy—were discussed in the prior motivation sections above as having task-level instantiations. Below, we also address instrumentality, effort, and social engagement.

1.3.1 Instrumentality

Learners perceive tasks to be useful, or instrumental, when they are thought to help facilitate achieving a future goal (Husman et al., 2004). Feelings of instrumentality have been shown to promote the use of deeper and more focused SRL strategies, situational interest, better effort and performance, and persistence over time (Hilpert et al., 2012).

1.3.2 Effort

The effort a student expends in mathematics directly impacts their achievement. Effort has been shown to be influenced by each of the task-level motivation and affect variables reviewed so far. In addition, students' task effort is influenced by their longer-term interest and efficacy (Pinxten et al., 2014). At the task-level, effort seems to be increased by in-the-moment enjoyment, but *decreased* by in-the-moment competence beliefs: if one is competent and knows it, task goals can be accomplished with less effort. This implies that effort is most useful when people feel less competent (Schunk, 1983), suggesting that effort may be a task-level manifestation of SRL strategies (Mrazek et al., 2018).

1.3.3 Social engagement

Educational transition periods are important points in students' social lives that impact their mathematics engagement (Madjar et al., 2018). For example, as students transition to high school, their peers become increasingly important models for adjusting academic and social behavior (Ryan, 2000). Similarly, the first two years of high school are especially volatile in terms of both positive and negative changes in motivation (Middleton et al., 2019). Despite the growing importance of students' peers, teachers remain important engineers of classroom social norms (Middleton et al., 2022). Teachers support positive SRL, interest, and efficacy when they choose tasks that are challenging, interesting, and personally relevant (to the students), and when they have high expectations, provide clear feedback, and verbally support mathematical efficacy (Fredricks, 2011).

1.4 Teacher and peer support

Teachers and peers are one of the primary levers of change for students' classroom motivation and achievement. Teachers can influence students' sense of belonging and cognitive and affective engagement through the selection and orchestration of mathematics tasks, scaffolding discussions, and assistance and feedback (Strati et al., 2017). Although teacher support tends to focus on academic support more than social support, both are common (Mohammad Mirzaei et al., 2021). When students perceive their teacher as supportive, they tend to report more positive emotions, such as greater satisfaction and lower anxiety towards math tasks, and more self-regulation and situational interest (Federici & Skaalvik, 2014).

Peer support also impacts students' beliefs about, and patterns of engagement in, mathematics. Peer support is positively associated with students' perceived competence, interest, and enjoyment in mathematics, as well as perceived

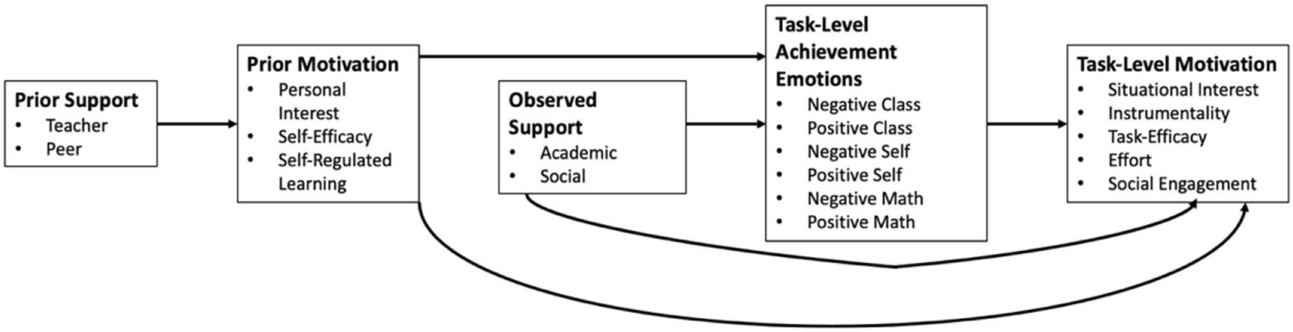

Fig. 1 Flow of hypothesized effects from students' perceptions of their prior mathematics experiences through observed classroom support, task-level achievement emotions, and motivational and behavioral outcomes

teacher support (Mata et al., 2012). Peer perceptions can also impact students' task-level regulation and mathematics achievement, and mediate students' interest and enjoyment of the subject (Reindl et al., 2015).

1.4.1 Academic and social support

Teachers and peers are classroom agents that provide academic support in the form of cognitive and regulatory help with learning the content, and social support in terms of belonging and identification (Sakiz et al., 2012). Research shows that for both academic and social features, students can internalize the norms and behaviors of their teacher and peers, and use these norms to inform their academic emotions, SRL, self-efficacy, and personal interest in mathematics (Yu & Singh, 2018).

1.5 Summary

Bringing this previous work together, students' perceptions of prior teacher and peer support should directl influence students' prior long-term motivation (personal interest, mathematical self-efficacy, and SRL strategies). Within a task, the classroom culture also provides varying degrees of academic and social support for students' engagement in mathematics. Consistent with the CVT, these support systems are then interpreted, along with the student's prior motivation, to inform their task-level control and value appraisals, and thus affective engagement. This affective engagement, in turn, can influence task-level motivation (situational interest, task-efficacy, instrumentality), self-regulation and effort, and social engagement displayed in the completion of the task.

However, much is not known about the relationships among these variables. Studies typically have modeled emotions by positive or negative valence, or separately, as in the case of enjoyment or boredom. Given the evidence that emotions co-occur and interact in mathematics learning, it is not evident how control attributions like math self-efficacy, and value attributions like personal interest predict both positively and negatively-valenced emotions directed at different emotional objects (Putwain et al., 2021). Moreover, because emotions, as intermediary effects on task-level motivation and subsequent achievement, have not typically been modeled as co-occurring, nor as distinguished by object, it is unclear how patterns of task-level emotions influence situational motivation in the learning task. We address this by explicitly modeling task-level achievement emotions distinguished by both valence and object in this study, examining their relationship with antecedent motivational variables, as well as concurrent observed support and task-level motivation variables.

1.6 The present work

The present work aims to clarify the relationships between the network of variables highlighted in the CVT literature, along with academic and peer support (see framework in Fig. 1). Prior Support in this model corresponds to antecedent, self-reported environmental factors assumed in CVT. Prior Motivation variables correspond with self-reported value-appraisals (Personal Interest), and control appraisals (Self-efficacy and Self-Regulated Learning). Observed support includes in-the-moment academic and social support observed by the researchers. Task-Level achievement emotions contain further complexity, dividing students' self-reported in-the-moment emotions by valence as well as object (Negative/Positive feelings about the Class [Teachers/Peers], Self, and Math). Finally, Task-level Motivation variables include students' self-reported task-level value appraisals (Situational Interest, Instrumentality), and task-level control variables (Task Efficacy, Effort, and Social Engagement).

In general, the paths indicated in Fig. 1 flow from left to right with students' beliefs about their prior support hypothesized to influence their prior motivation. Prior motivation, in turn, is hypothesized to impact students' perceptions of the task both emotionally and motivationally. Supportiveness of the classroom climate in terms of academic and social dimensions, is hypothesized to influence task-level emotions and motivation. And, finally, reflecting CVT, task level emotions are hypothesized to impact task-level motivation.

The specific hypothesized relationships between predictor and outcome variables are shown in Table 1. In general, the literature shows that positive beliefs about mathematics and one's prior experiences tend to be associated with positive task-level emotions and motivation. By contrast, negative prior beliefs tend to be associated with negative task-level emotions and motivation, though there are some exceptions. For example, a learner may expend more effort in a task to make up for perceived lack of efficacy, if the intrinsic or extrinsic value of the task is high (Villavicencio & Bernardo, 2013). In general, we hypothesize that the relationship between effort in a task is positively related to prior self-efficacy and positive emotions, but the specific dynamics of this relationship are somewhat more exploratory, as they are not well established in the literature, particularly when emotions are broken down by object.

The remainder of this manuscript presents a study of 9th grade high school mathematics classrooms from a longitudinal study on the development of adolescents' mathematics engagement, and the academic and social support practices that can support productive engagement. Path analyses were used to model the strength and direction of these hypothesized relationships for students' first year of high school mathematics.

2 Method

2.1 Participants

Students (n = 285) were sampled from schools in one large urban school district in the Southwest U.S. and two moderate-sized districts in the Mid-Atlantic U.S. Classes for this study were selected by soliciting teacher nominations from district curriculum supervisors. Sixteen teachers participated (11 female, 5 male; 14 white, one Asian-American, and one Hispanic/Latinx), with an average of 10.8 years' teaching experience.

Two first-year high school mathematics classes were selected for each teacher. These classes focused on traditional Algebra content. Of the total sample, 48% of students identified as male, 49% identified as female, and 1% identified as neither or both. Student demographics for the schools in the Southwest were: 85–94% low income, 2–5% White, 1–15% Black, 74–96% Latinx, and 0–5% Asian,

Table 1 Hypothesized Relationships Among Variables Reflecting Prior Support, Prior Motivation, Observed Support, and Task-level Emotions and Motivation

		Outcome Variables														
Predictor Variables		Prior Motivation			Task-level Achievement Emotions						Task-Level Motivation					
		Int.	SRL	Eff.	Neg. Class	Pos. Class	Neg. Self	Pos. Self	Neg. Math	Pos. Math	Task Effic.	Effort	Soc. Eng.	Instrumentality	Sit. Interest
Prior Supp.	Teach Supp.	+	+	+											
	Peer Supp.	+	+	+											
Prior Mot.	Math Interest				-	+	-	+	-	+	+	+	+	+	+
	SRL				-	+	-	+	-	+	+	+	+	+	+
	Math Effic.				-	+	-	+	-	+	+	+	+	+	+
Obs. Supp.	Acad. Supp.				-	+	-	+	-	+	+	+	+	+	+
	Soc. Supp.				-	+	-	+	-	+	+	+	+	+	+
Task Level Mot.	Neg. Class										-	-	-	-	-
	Pos. Class										+	+	+	+	+
	Neg. Self										-	-	-	-	-
	Pos. Self										+	+	+	+	+
	Neg. Math										-	-	-	-	-
	Pos. Math										+	+	+	+	+

Note. For clarity of the specific hypotheses tested in this research, Table 1 does not show all potential inter-variable correlations, but these are reported in the results in Table 2

Native American, or Multi-Racial; student demographics for the schools in the Mid-Atlantic were: 9–30% low income, 24–57% White, 27–46% Black, 7–24% Latinx, and 0–5% Asian, Native American, or Multi-Racial.

Student participation rates varied within classes, from very low (4/28) to moderately high (40/48). Since measures were administered at the beginning and in the middle of the school year, we were unable to obtain full records for many participants due to absenteeism and transfers during the middle of the school year. The data reported represent an average of 9 full records per class, and thus has some non-random sampling bias for each class. Patterns of absenteeism did not appear to be unusual within the districts, therefore we report results for the full sample rather breaking down results by class.

2.2 Instruments and procedure

2.2.1 Overview of procedure

The temporal flow of data collection followed the flow in Fig. 1. Instruments measuring perceived prior support and prior motivation were administered near the beginning of participants' first year of high school (grade 9 in the US) using a Long-term Engagement Survey. Observed support variables were measured via coded, video-recorded segments of mathematics activities that teachers nominated as likely to be engaging for students. Task-level emotion and motivation were assessed immediately following the video-recorded segments using a short survey.

We present our instruments and procedure starting with the task-level motivations and emotions, then prior motivation and support, and finally, observed academic and social support.

2.2.2 Task-level motivation and emotional appraisal

To assess learners' task-level emotion and motivation, a survey was administered immediately following a focal class activity during the middle of the first semester of students' 9th grade mathematics classes. We targeted specific experiences that the teachers nominated as being likely to be engage (e.g., Shernoff & Vandell 2007). We video recorded the entire class period in which the identified activity took place, with special focus on the pre-identified activities, which lasted an average of 30 min. Surveys were then administered online (with students responding via cellphone or laptop computer) after the focal activity via the survey platform Qualtrics.

The survey took approximately 2 to 5 min to complete and featured two sets of items: a checklist of situational emotions and a set of items on task-level efficacy, effort, interest, perceived instrumentality, and social engagement. Complete item text, sources, research backing, and psychometric properties can be found in Wiezel et al., (2020) also included in the online supplement to this article.

Task-Level Motivation. Three of the task-level scales, *Task Efficacy*, *Task Effort*, and *Situational Interest* paralleled variables in the literature on Prior Motivation: Math Self-Efficacy, Math Self-Regulated Learning, and Math Personal Interest. Two additional task-level scales measured task-level Perceived Instrumentality and Social Engagement. For each scale, students were asked to answer prompts related to their impressions about the math activity they were working on right before they started the survey, using 5-point Likert responses.

Task Efficacy. This scale had two items ($\alpha = 0.80$): "Rate how much you understand the math covered in the activity you were working on," and "I felt successful in the activity I was just working on."

Task Effort. This scale had three items ($\alpha = 0.77$) : "How hard were you concentrating on the activity you were just working on," "How hard were you trying during the activity you were just working on?", and "I was on task during the activity I was just working on."

Situational Math Interest. This scale had two items ($\alpha = 0.86$): "I enjoyed the activity I was just working on," and "I think the topic covered in the activity I was just working on is interesting."

Perceived Instrumentality. Items measuring both endogenous and exogenous instrumentality were included in this scale. It had four items ($\alpha = 0.80$): "I will use what I learned from the activity I was just working on in future courses," "I will use what I learned from the activity I was just working on when I grow up," "The activity I was just working on was personally relevant to me," and "How I performed on the activity I was just working on will affect my future success."

Social Engagement in Learning. This scale had four items ($\alpha = 0.76$): "I had the opportunity to ask questions during the activity I was just working on," "I felt supported by my teacher in the activity I was just working on," "I felt like my contribution was respected during this activity I was just working on," and "I built on others' ideas during the activity I was just working on."

Academic Emotions. Task-level emotions were assessed using 16 emotions drawn from the literature on academic emotions (*angry, anxious, ashamed, bored, confident, embarrassed, excited, frustrated, happy, hopeful, hopeless, interested, proud, relieved, satisfied*, and *worried*). Students were asked to indicate whether they had felt (yes/no) each of the emotions during the math activity they were just working on. Each emotion could be directed toward four possible objects in the students' math class: the math activity, themselves, their classmates, and their teachers. Prior factor analyses of the students' responses showed that emotions fell into six categories depending on the object to which the emotion was directed –negative/positive emotions about the class (teacher/classmates), self, and the math (Wiezel et al., 2020).

Negative Emotions about Teacher/Classmates. This scale had nine items ($\alpha = 0.66$), including "Angry about my classmate(s)" and "Frustrated about/by my teacher(s)".

Positive Emotions about Teacher/Classmates. This scale had 15 items ($\alpha = 0.82$), including "Happy about/by my classmate(s)" and "Excited about/by my teacher(s)".

Negative Emotions about the Self. This scale had eight items ($\alpha = 0.81$), including "Ashamed about/by myself" and "Hopeless about/by myself."

Positive Emotions about the Self. This scale had eight items ($\alpha = 0.81$), including "Relieved about/by myself" and "Proud about/by myself."

Positive Emotions about the Math Activity. This scale had eight items ($\alpha = 0.75$), including "Happy about the math activity" and "Excited about the math activity."

Negative Emotions about the Math Activity. This scale had five items ($\alpha = 0.70$), including "Frustrated about the math activity" and "Anxious about the math activity."

2.2.3 Prior motivation and support: long-term engagement survey

Early in the first semester of their 9th grade mathematics classes (prior to the observed activities), students were given a survey on their perceptions of Teacher and Peer support, and their longer-term mathematics motivation. All items were measured on a 7-point Likert scale. Surveys took about 25 min to complete and were administered online (with students responding via cellphone or laptop computer) on Qualtrics. Complete item text, sources, research backing, and psychometric properties can be found in Zhang et al., (2020), included in the online supplement for this article.

Measures of Perceived Teacher and Peer Support. This involved two scales.

Teacher Support. This scale had 12 items assessing instrumental and emotional support ($\alpha = 0.95$), including "My math teacher tries to understand how I see things before suggesting a new strategy."

Peer Support. This scale had seven items assessing belonging and classmates' interest and caring ($\alpha = 0.84$), including "My classmates in my math class care about how well I learn."

Measures of Prior Engagement. These used three scales, focusing on affective and cognitive engagement:

Math Personal Interest. This scale had nine items assessing students' longer term mathematics interest ($\alpha = 0.91$), including "I find math to be enjoyable."

Mathematics Self-Regulation. This scale had eight items assessing students' effort and strategies used and mastery goal orientation ($\alpha = 0.84$). An item was: "When I study math, I try to put together the information we discussed in class, from the textbook, or other materials."

Mathematics Self-Efficacy. This scale had 11 items assessing the how capable students feel doing math ($\alpha = 0.87$), including "I am confident that I can do an excellent job on math assignments."

Mathematics Self-Efficacy. This scale had 11 items assessing the how capable students feel doing math ($\alpha = 0.87$), including "I am confident that I can do an excellent job on math assignments."

2.2.4 Measures of observed academic and social support: Observation Rubrics

Researchers also observed, the following aspects of Academic Support: (1) *Students' Opportunities for Sense Making and Reasoning*; (2) *Connections Between Representations or Strategies*, (3) *Pressing Students to Explain*, (4) *Mathematics Language Use*, (5) *Feedback*, and (6) *Students' Opportunities for Agency and Autonomy*. Social Support rubrics assessed (1) *Small Group Discourse*, (2) *Teachers' Attempts at Status Raising*, (3) *Motivational Discourse*, and (4) *Accountability and High Expectations*.

Each dimension was scored on a four-point rubric: absent (0), weak enactment (1), moderate enactment (2), and strong enactment (3). For example, the definition of a strong level of enactment of *Teachers' Attempts at Status Raising* was, "The teacher and students **often** use language that magnifies specific student's strengths with respect to knowing and doing mathematics and assumes capability instead of shortcomings (assigns competence)" (Jansen et al., 2021).

We applied the observation rubrics to the video-recorded activities in 10-minute segments. Each 10-minute segment was independently rated by two coders who then met to resolve any disagreements in scoring. The average intraclass correlation (ICC) between raters ranged from 0.38 to 0.88 for each rubric. The mean ICC for the Academic Support Scale was 0.60 indicating moderate agreement, and that for Social Support was 0.62 indicating moderate-to-good agreement. To resolve rating discrepancies, the two independent ratings were averaged to create mean ratings for each rubric. The relevant mean scores for each Academic Support rubric, and the relevant mean scores for each Social Support Rubric, were then summed to form the Academic Support and Social Support scores, respectively.

3 Results

We modeled all variables as measured variables. No intravariable correlations were greater than 0.60, indicating that no pairwise set of variables shared more than 36% of their variance, and most shared less than 10% variation. Variance Inflation Factors ranged from 1.01 (Positive Self Emotions) to 1.84 (Task Efficacy). Tolerance statistics ranged from 0.544 for Task Efficacy to 0.993 for Positive Self Emotions. Together these values suggest that there was little collinearity in the model (O'brien, 2007). Table 2 presents all intervariable correlations.

3.1 Testing the hypothesized model

The hypothesized model was assessed using Path Analysis using a full information Maximum Likelihood estimator (Mplus, version 8; Muthén & Muthén 2017). Though there was missing data across several variables, the minimum covariance coverage was 0.94 with a median coverage of 0.98, indicating that at least 94% of participants were included in all covariance computations. Table 3 presents standardized regression coefficients for all hypothesized paths in the model, and Table 4 shows the fit statistics.

Recent work using Monte-Carlo simulations of SEM analyses suggests that for smaller sample sizes (less than 500 records), CFI and TLI are negatively biased, while RMSEA is positively biased (Shi et al., 2019). As the number of free parameters increases, the relative bias in these estimates becomes more pronounced. For models like ours, with approximately 285 subjects and 147 free parameters, the estimated CLI/TLI can average as much as -0.40 less, and RMSEA as much as + 0.04 more, than population values. Given that the results show a $\frac{\chi^2}{df}$ ratio of 2.32, (well under the recommended ratio of 3), SRMR of 0.04 (under the recommended value of 0.05), and a CLI of 0.97 (well over the recommended value of 0.95), we judge this model to show relatively good fit despite lower estimated values of TLI and RMSEA (Hu & Bentler, 1999).

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We now work through the hypothesized paths in the model, starting with outcome variables and their relationships to proximal predictor variables as predicted by CVT, and then working backwards through the model to prior motivation and prior support. The full path model is presented in Fig. 2 and broken down in subsequent figures. We have used color coding to indicate the specific hypotheses in this complex model. The results are presented *right* to *left*, from outcome variables, through successive levels of predictors.

3.2 Relations between task-level emotions and task-level motivation

A fundamental tenet of CVT is that task-level achievement emotions contribute to students' motivation. Working backwards from motivation outcomes as outcome variables in Fig. 2, we can see that negative emotions tend to be *negatively* associated with task-level motivation (see Fig. 3). Negative Class (Teacher and Classmates) emotions were negatively associated with Effort, Social Engagement, Task-Efficacy, and Situational Interest. Negative Math emotions were negatively associated with Social Engagement, Task Efficacy, Instrumentality and Situational Interest. Negative Self emotions were negatively associated with Task Efficacy.

By contrast, *positive* emotions tended to positively predict Task-Level motivation. Positive class emotions were positively associated with Social Engagement (See Fig. 4). Positive math emotions were positively associated with Task Efficacy, Task-level Social Engagement, and Situational Interest. Finally, Positive Self emotions were positively associated with each of the Task-level motivation outcomes.

Standardized coefficients for negative emotions tended to be greater in magnitude than for positive emotions. Specifically, the relationship between Negative Math emotions and feelings of Social Engagement, Task Efficacy, and Situational Interest were much stronger than other paths. Positive Math emotions showed the strongest predictors among the positive emotions, showing moderately large positive relationships with Social Engagement and Situated Interest. These findings highlight the important role negative

Table 2 Correlation Matrix for All Measured Variables

	Teach Supp.	Math Interest	SRL	Math Effic.	Peer Supp	Acad. Supp	Soc. Supp	Neg. Class	Pos. Class	Neg. Self	Pos. Self	Neg. Math	Pos. Math	Task Effic.	Effort	Soc. Eng	Instrumentality	Sit. Interest
Teacher Support	1.00																	
Math Interest	**0.37**	1.00																
SRL	**0.42**	**0.43**	1.00															
Math Efficacy	**0.39**	**0.49**	**0.24**	1.00														
Peer Support	**0.59**	**0.43**	**0.41**	**0.34**	1.00													
Acad. Support	-0.10	-0.08	-0.02	-0.10	-0.09	1.00												
Social Support	**0.12**	0.00	0.07	0.04	-0.03	**0.60**	1.00											
Neg. Class	**-0.32**	**-0.24**	**-0.18**	**-0.16**	-0.32	0.00	-0.07	1.00										
Pos. Class	0.08	**0.17**	**0.13**	0.02	0.07	0.09	**0.12**	**0.18**	1.00									
Neg. Self	-0.10	-0.04	0.03	**-0.27**	-0.06	-0.07	**-0.12**	**0.33**	**0.20**	1.00								
Pos. Self	0.10	0.07	0.07	0.05	0.09	-0.02	0.01	**0.18**	**0.37**	0.10	1.00							
Neg. Math	-0.11	-0.05	0.07	**-0.30**	-0.07	0.06	-0.09	**0.30**	**0.17**	**0.30**	0.07	1.00						
Pos. Math	**0.17**	0.22	0.08	**0.14**	0.06	0.06	0.05	0.07	**0.30**	0.01	**0.39**	0.09	1.00					
Task Efficacy	**0.41**	0.22	**0.17**	**0.42**	**0.27**	-0.07	**0.18**	**-0.26**	0.07	**-0.30**	**0.21**	**-0.45**	0.32	1.00				
Effort	**0.31**	0.18	**0.51**	**0.12**	**0.27**	-0.06	0.00	**-0.16**	0.10	-0.01	**0.26**	0.07	0.10	0.10	1.00			
Social Engage	**0.53**	0.26	**0.26**	**0.25**	**0.43**	0.00	**0.15**	**-0.31**	**0.14**	**-0.18**	**0.18**	**-0.34**	**0.19**	0.54	0.29	1.00		
Instrumentality	**0.35**	0.49	**0.33**	**0.23**	**0.35**	-0.03	0.04	**-0.18**	**0.17**	-0.03	**0.24**	**-0.18**	**0.24**	0.32	0.22	0.51	1.00	
Sit. Interest	**0.32**	0.45	**0.21**	**0.24**	**0.26**	-0.03	**0.18**	**-0.24**	**0.17**	**-0.12**	**0.24**	**-0.32**	**0.37**	0.54	0.17	0.57	0.55	1.00

Note. Bold correlations significant, $p < 0.05$

Table 3 Standardized Regression Coefficients for Each Hypothesized Path

	Prior Supp	Prior Motivation			Obs. Supp	Task-Level Achievement Emotions						Task-Level Motivation			
	Peer Supp	Pers. Interest	Math SRL	Math Self Effic	Soc Supp	Neg. Class	Pos. Class	Neg. Math	Pos. Math	Neg. Self	Pos. Self	Task Effort	Social Engage	Instrumentality	Sit. Interest
Teach. Supp	**0.75**	0.14	**0.24**	**0.25**											
Peer Supp		**0.26**	**0.18**	0.05											
Pers. Interest						**-0.17**	**0.19**	0.05	**0.22**	0.07	0.08	-0.10	0.05	**0.44**	**0.36**
Math SRL		**0.34**				−0.10	0.06	**0.15**	-0.02	0.08	0.03	**0.50**	**0.19**	**0.14**	0.04
Math Self-Effic.		**0.44**	**0.17**			−0.06	-0.08	**-0.33**	0.04	**-0.32**	0.00	0.03	0.00	-0.10	**-0.14**
Neg. Class					-0.02							**-0.15**	**-0.20**	-0.05	-0.10
Pos. Class					0.02							-0.01	**0.12**	0.04	0.04
Neg. Math					**-0.11**					**0.21**	0.08	-0.08	**-0.30**	**-0.21**	**-0.30**
Pos. Math					0.01		**0.28**	**0.12**		0.04	**0.38**	0.00	**0.12**	0.10	**0.27**
Neg. Self					-0.06		**0.21**					-0.02	-0.05	0.01	-0.03
Pos. Self					0.03		**0.37**					**0.26**	**0.13**	**0.16**	0.13
Task Efficacy										**0.11**		-0.06	**0.32**	**0.13**	**0.32**
Effort													**0.16**	0.05	0.04
Social Eng.														**0.38**	**0.39**
Instrumentality															**0.33**
Sit. Interest															
Acad. Supp.					**0.60**	0.06	0.06	0.11	0.06	-0.02	0.00	-0.04	-0.06	0.01	**-0.13**

Note. Bold coefficients significant. $p < 0.05$ (two-tailed)

Table 4 Fit Indices for Hypothesized Path Model

χ^2	df	$\frac{\chi^2}{df}$	RMSEA	RMSEA 90% CI	SRMR	CFI	TLI
65.09	28	2.32	0.069	[0.047, 0.091]	0.039	0.97	0.84

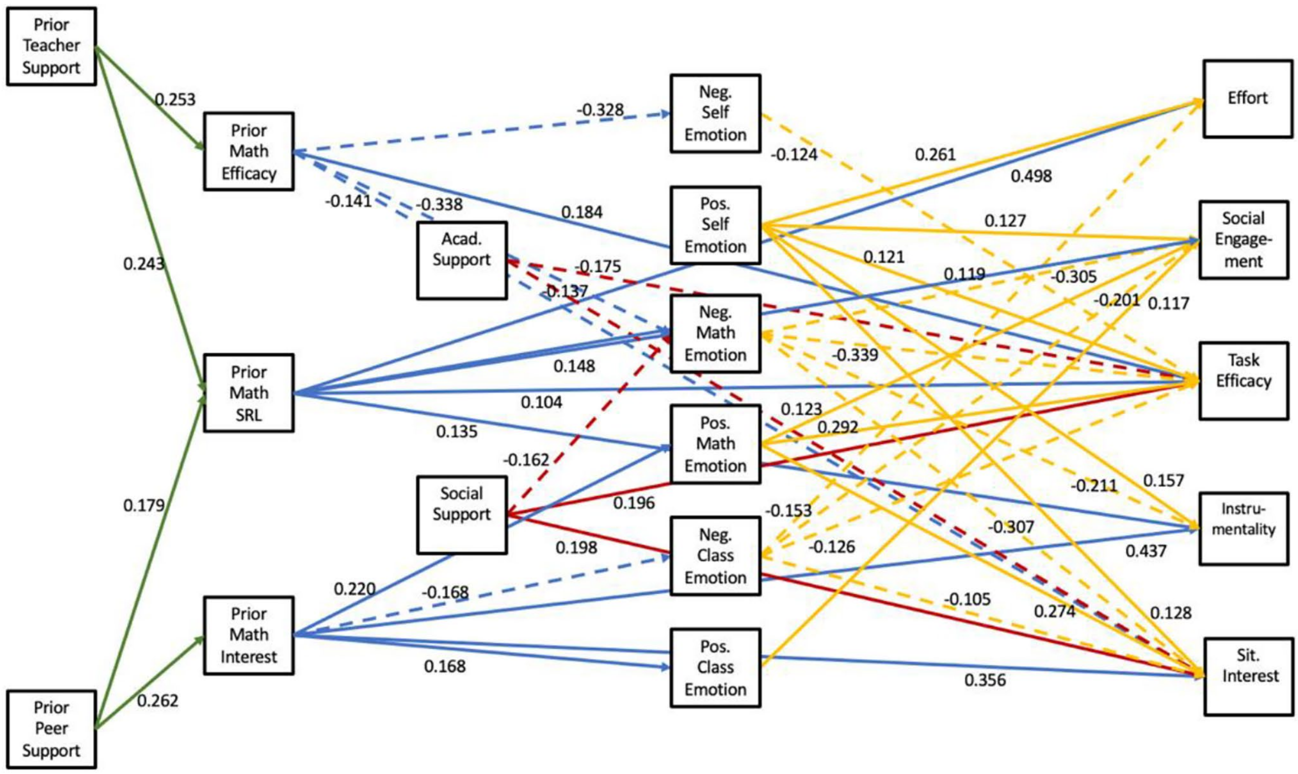

Fig. 2 Full Path Model Showing Significant Relationships Between Support and Motivation Variables from Prior Support (Green Arrows) Through Prior Motivation (Blue Arrows) and Observed Support (Red Arrows), to Task-Level Emotions and Motivation (Yellow Arrows). Dashed Lines Reflect Negative Regression Coefficients

emotions, such as anxiety and frustration, may have in inhibiting math-related motivation.

3.3 Relations between observed academic and social support and task-level emotions and motivation

Looking at the behaviors of the class during the video-recorded lesson, Observed Academic and Social Support showed few relationships with task-level emotions (see red arrows in Fig. 5). Only Social Support showed a significant negative association with Negative Math emotions.

More relationships emerged between Observed Support variables and Task-level motivations. Specifically, Observed Social Support was positively associated with Situational Interest and Task Efficacy in students. By contrast, Academic Support was moderately *negatively* associated with Situational Interest and Task Efficacy. These negative relationships for Academic Support were unexpected, and we speculate about the reasons for these findings in the discussion. In general, though, results show that the relationship between classroom support variables is complex, with attempts to make mathematics rigorous, versus a nurturing classroom social environment, predicting different outcomes (Mata et al., 2012).

3.4 Relations between prior motivation factors and task-level motivation

Prior motivations, because they are longer-term belief systems, should have some direct impact on their counterparts at the task-level (see blue arrows in Fig. 6). Indeed, Prior Math Self-Efficacy was positively associated with Task Efficacy; SRL was positively associated with Task Effort; and Personal Interest in mathematics was (only) positively associated with Situational Interest.

However, these prior motivation factors show differential relationships with the other task motivation outcomes. Prior Math Efficacy was negatively associated with Situated Interest, but positively associated with Perceived

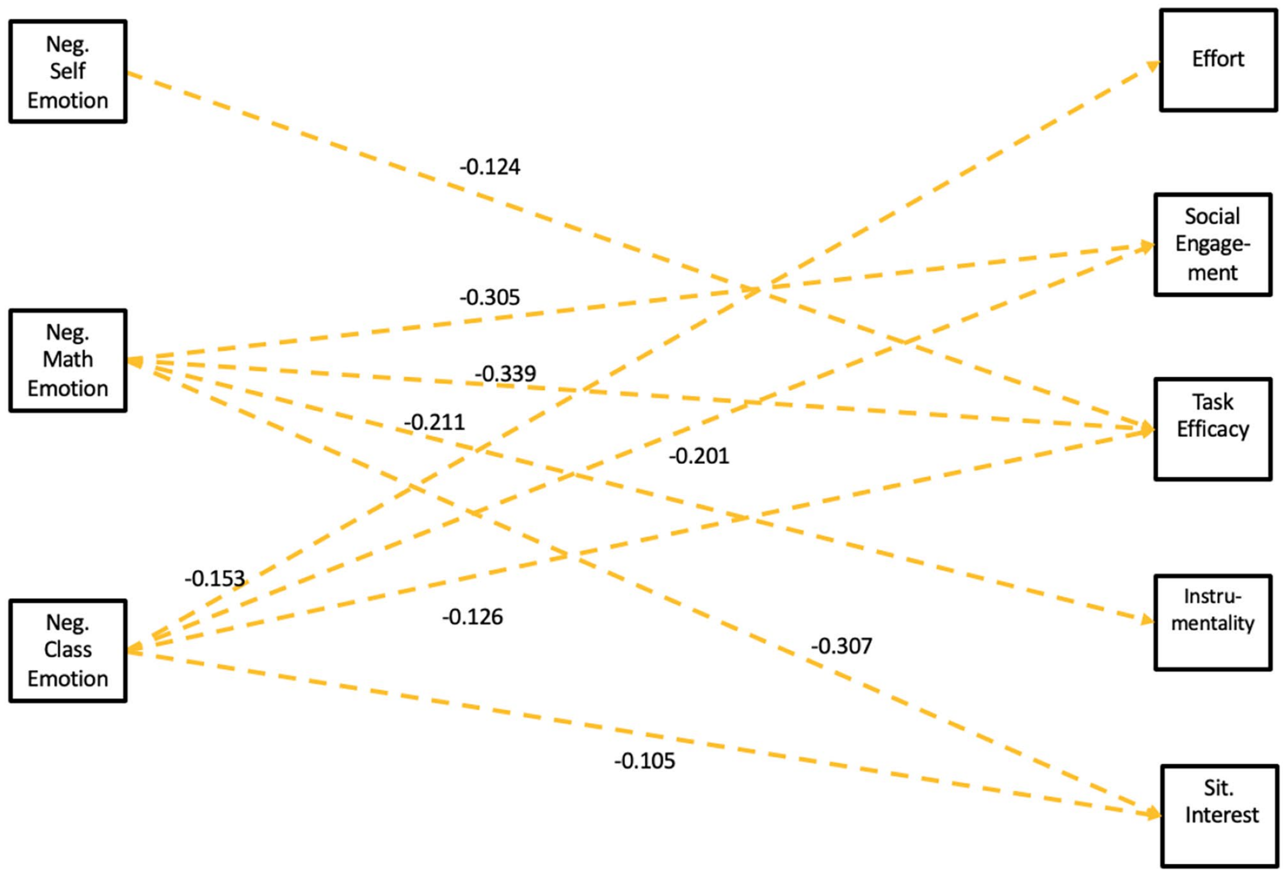

Fig. 3 Significant Relationships Between Task-Level Negative Emotions and Task-Level Motivation (Negative Paths Indicated with Dashed Arrows)

Instrumentality. SRL was positively related to Effort, Social Engagement, Task Efficacy, and Perceived Instrumentality, and the path coefficients between SRL and Effort and Instrumentality were among the highest in the model.

3.5 Relations between prior motivation factors and task-level emotions

As predicted by CVT, prior motivation variables associated with control (Math Self-efficacy, SRL) and value (Math Interest) were generally associated with students' self-reported task-level emotions (see Fig. 6, blue arrows with negative paths dashed), and varied in their prediction of task-level emotions based on the objects toward which they were directed (e.g., Wiezel et al., 2019). Prior Math Self-efficacy was strongly *negatively* associated with Negative Self and Math emotions; Prior Math SRL was positively associated with Negative Math emotions; and Math Personal Interest was positively associated with Positive Math and Class emotions, and *negatively* associated with Negative Math emotions.

3.6 Relations between prior support and prior motivation factors

Both Teacher and Peer support factors at the beginning of the semester displayed significant positive relationships with prior motivation variables (see Fig. 7). Perceived Teacher Support showed positive associations with Self-Efficacy and SRL, and Perceived Peer Support showed positive associations with Personal Interest and SRL. The relationship between Peer Support and Math Personal Interest was the strongest coefficient in this portion of the model. Consistent with the Observed Support variables reported earlier, this pattern suggests that at this stage in adolescence, students look to teachers more for academic support, and to peers more for social support. Students may look to peers to maintain positive relationships, and help each other seek solution strategies (Järvelä et al., 2016), whereas they may attend to the teacher for vicarious modeling, or verbal encouragement (Regier & Savic, 2020).

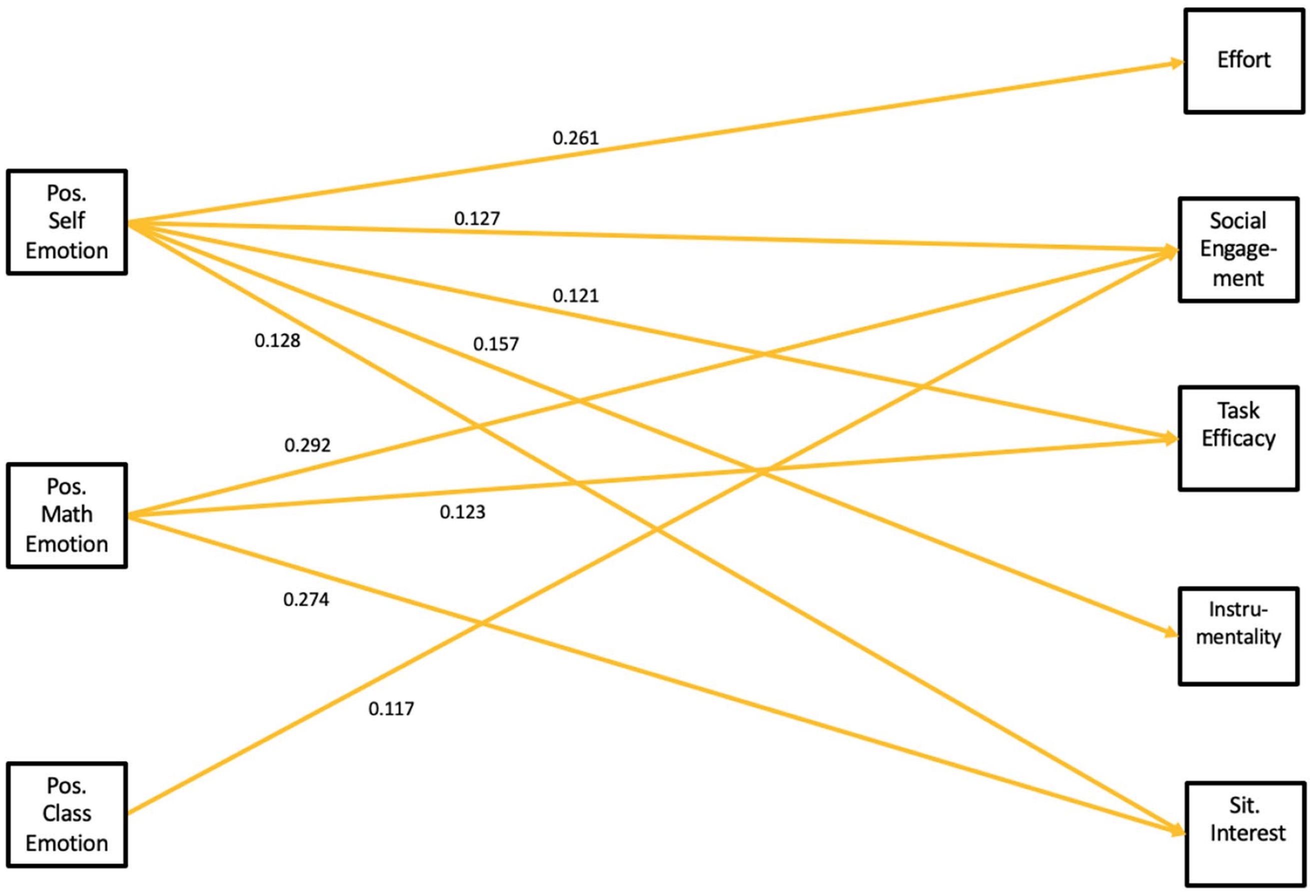

Fig. 4 Significant Relationships Between Task-Level Positive Emotions and Task-Level Motivation

4 Discussion

4.1 Overviewing the Relationships between support, motivation, and emotions

When we consider these results together under the CVT framework, a pattern emerges, suggesting that Task-level achievement emotions flow *from* prior control and value appraisals (Math Self-Efficacy, SRL, and Math Personal Interest), *towards* task-level control and value appraisals (Task-level Effort, Social Engagement, Task-Efficacy, Instrumentality and Situational Interest). In addition, the classroom culture provides varying degrees of Academic and Social Support, informing the control and value aspects of students' task-level affective engagement. Beliefs about prior teacher and peer support may be mediated by prior control and value appraisals, and through task-level emotions, influencing task-level motivations, closely following the predictions of CVT. Note that we did not perform mediation analyses in this study, so this latter speculation needs to be taken up in future research.

4.2 Relations between task-level emotions and task-level motivation

As predicted by CVT, task-level achievement emotions appeared to influence students' cognitive appraisals of the situation. But differential patterns among the emotional objects show that students look to different cues to interpret their experiences.

In general, positive math emotions appear to increase task-level interest and efficacy beliefs, while negative emotions appear to decrease task-level interest and efficacy. Negative emotions about the math also appear to be negatively associated with social engagement and feelings of instrumentality. This suggests that when students experience frustration and anxiety, anger, or disappointment during math tasks, they may be less inclined to participate in collaborative groupwork, and they may find the math less personally useful or relevant.

The positive association between positive class-focused emotions and social engagement suggests that when a person has positive in-the-moment feelings about their relationships with teachers and peers, they engage more with

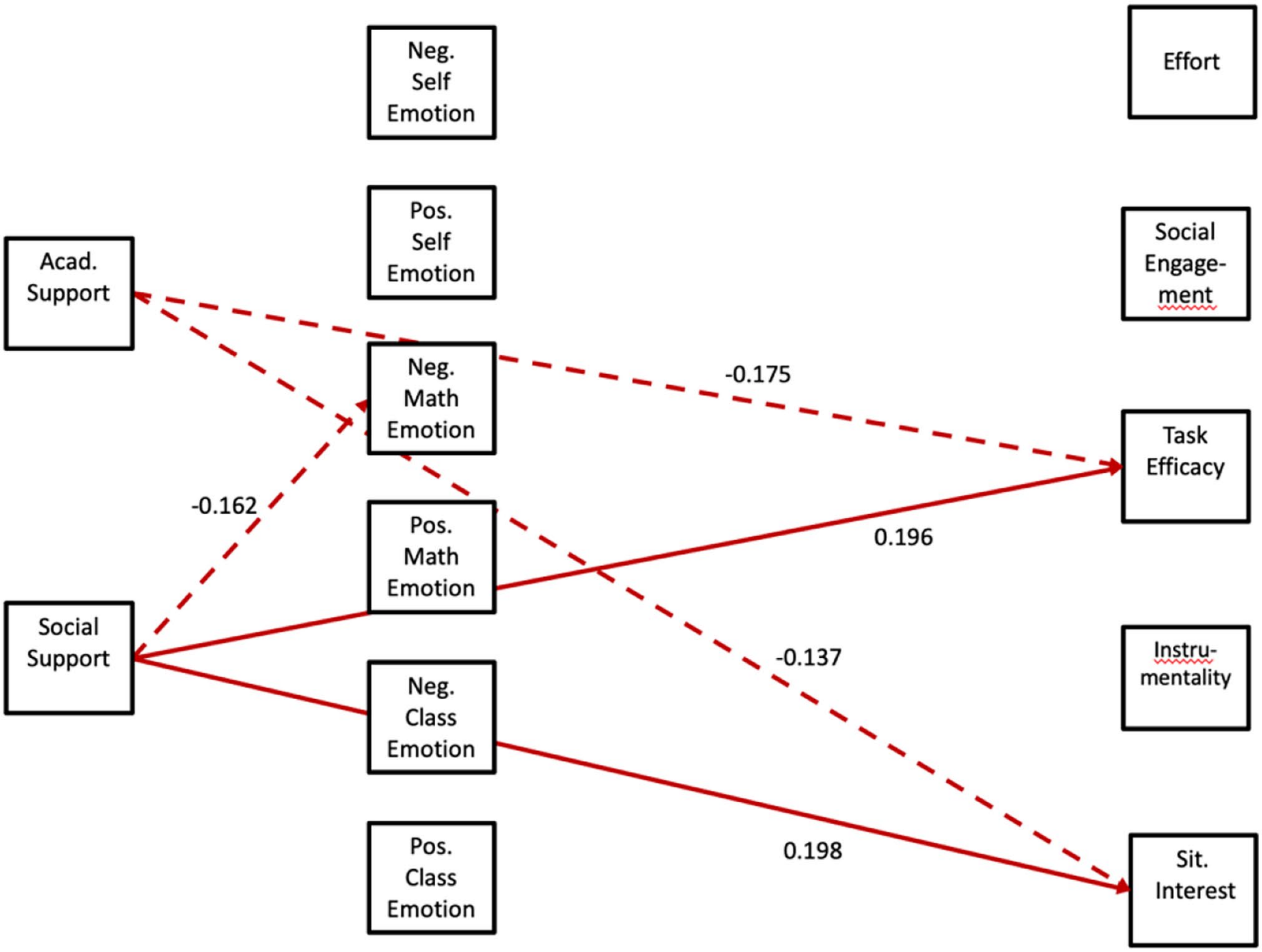

Fig. 5 Significant Relationships Between Observed Support Variables with Task-Level Emotions and Motivation (Negative Paths Indicated with Dashed Arrows)

those teachers and peers. Additionally, because negative class emotions were strongly negatively related to students' task-level effort, social engagement, efficacy and situational interest, results suggest that students use social cues to inform their control attributions.

Finally, Positive Self-emotions appeared to be associated with a variety of motivational outcomes, including greater Effort, Social Engagement, Task Efficacy, Instrumentality and Situational Interest. By contrast, Negative Self-emotions were only significantly related to feelings of Task efficacy. This suggests that fostering position emotions about the self may be more important than reducing negative self-emotions in the classroom.

4.3 Relations between observed academic and social support and task-level emotions and motivation

In our classroom observations, academic support was negatively related to situational interest and task efficacy, whereas social support showed a positive relationship with these two outcomes, with lessening of negative math emotions.

Why the negative impact of observed academic support on task-level interest and efficacy? We speculate that these relationships may stem from feelings of challenge, as students' perceptions of challenge can be negatively associated with academic support when students feel too challenged or insufficiently emotionally nurtured (Turner & Meyer, 2004). Although the Academic Support rubrics we employed focused on challenge as a positive aspect of the classroom environment—including conceptual depth, mathematical precision, and pressing students to explain— it may be that

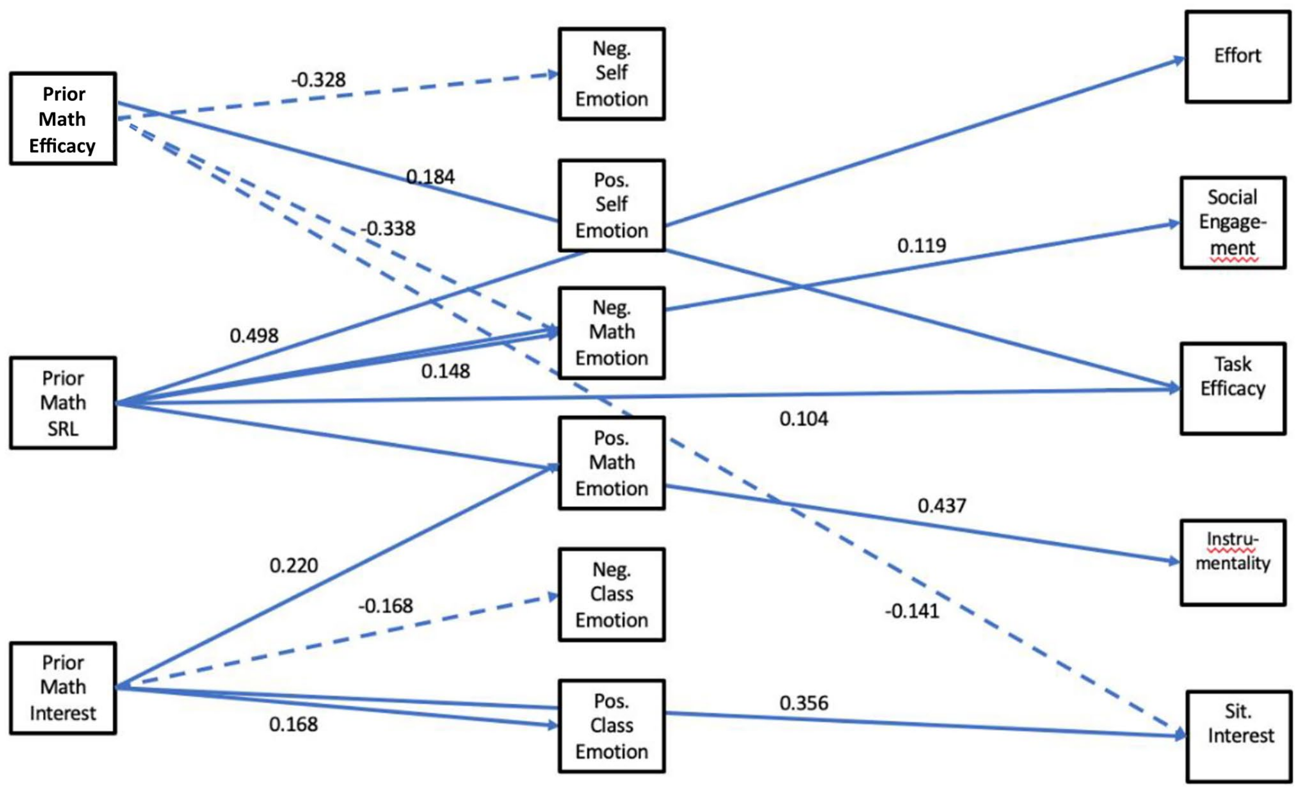

Fig. 6 Significant Relationships Between Prior Motivation Variables and Task-Level Emotions and Motivation (Negative Path Indicated with Dashed Arrows)

such "challenge" is perceived as negative by students at this age.

Turning to observed Social Support, its positive association with task-level interest and efficacy highlight the increasing significance of students' relationships with their peers in this developmental period (Juvonen, 2007). Social support appears to reduce task-level, negative feelings about math, and increases students' situational interest. This echoes prior work by Kilday & Ryan (2019) suggesting that Teacher and Peer Support show longer-term positive associations with affective engagement.

4.4 Relations between prior motivation factors and task-level motivation

Results suggest that Personal Interest in Mathematics, SRL, and Math Self-Efficacy may be positively related to their counterparts at the task-level, but that the prior motivation factors vary in terms of impact on other task-level motivations. The relationships between prior efficacy beliefs and task-level interest are particularly intriguing. Why would a person who feels capable, generally, in mathematics, show less situational interest on average? Some of this, we believe, may be explained by potential mediation via task-level object-focused emotions, but merits further investigation in future work.

4.5 Relations between prior motivation factors and task-level emotions

The motivational characteristics students bring with them have long been associated with task-level emotions and task performance (Kiuru et al., 2020). Our results add further nuance to these findings in terms of emotion-objects. While prior SRL, self-efficacy, and interest were each associated with task-emotions related to the math, only efficacy also showed associations with task-emotions about the self, and only interest with task-emotions about the class.

4.6 Relations between prior support and prior motivation factors

Prior work has suggested that perceived peer and teacher support predict SRL and achievement via students' math self-efficacy, interest, and perceived instrumentality (Reindl et al., 2015, Yildirim, 2012). However, we found that teachers and peers are perceived differently in terms of support they provide, and in the resulting long-term motivation they impact: whereas teachers may impact SRL and efficacy

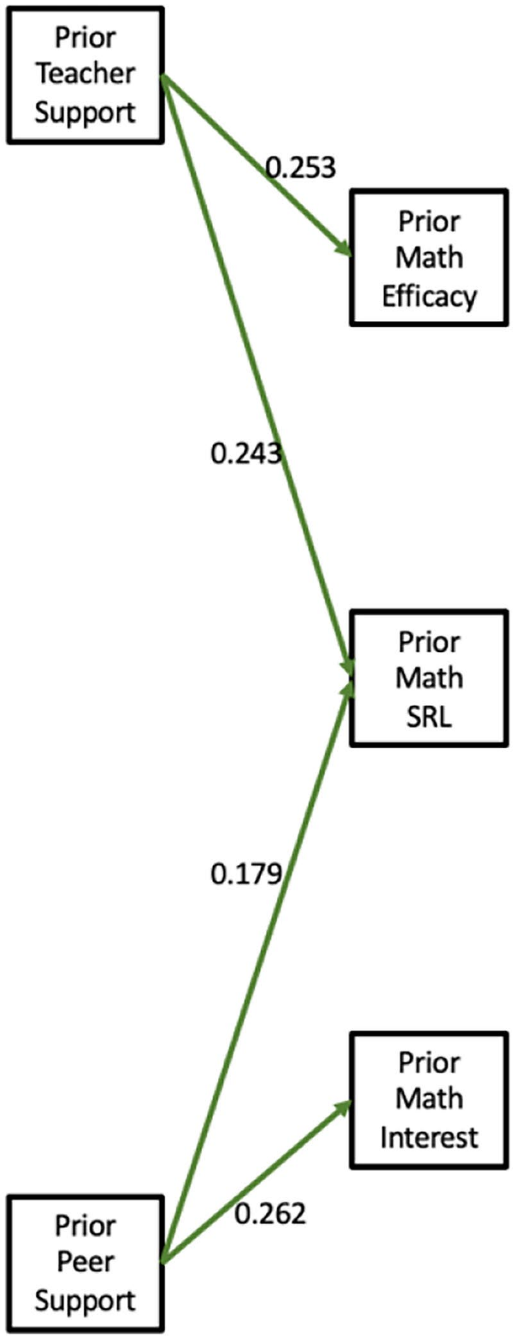

Fig. 7 Significant Relationships Between Prior Support and Prior Motivation Variables and Task-Level Emotions and Motivation

beliefs, peers may influence SRL and personal interest. In high school mathematics, students look to both their teachers and their peers for intellectual and strategic assistance in solving problems (Lawson et al., 2019); peers, however, seem to be more integral to their interest in mathematics as a subject (Latipah et al., 2021).

It appears that in the important transitional period between middle and high school, teachers have a more direct influence on students' engagement than they do when the first year of high school is nearly over. However, Yu & Singh (2018) suggest that positive interactions between teachers and students encourage stronger self-efficacy and personal interest in the subject matter, thus supporting achievement, as well. Similarly, our finding may imply a mediating role of peer support. Combining these perceived support results with the observed support results suggests that teachers' best opportunity to influence their students' long-term motivation and affective beliefs may be by creating a classroom peer culture that is welcoming, supportive, and focused on the improvement of one another's learning.

4.7 Limitations

Several limitations must be noted when interpreting this study with respect to CVT and the broader literature on mathematics affect, motivation, and engagement. First, with 285 participants and 147 parameters, our power is low. There are undoubtedly relationships among variables in the model which we had too little power to detect. Moreover, though we speculate that emotions serve as mediating factors between observed support and task-level motivation we did not perform mediation analyses due to concerns about power, leaving this a topic for future research.

Although the model benefits from comprehensiveness in terms of its educational implications, it does stretch the boundaries of CVT theoretically. We have been explicit with our hypotheses drawn from CVT, but there may be more direct ways to test those relationships.

Lastly, while we believe the findings are largely generalizable at least within the U.S., some of the specific relationships uncovered may differ in magnitude and in direction for subpopulations corresponding to culture, language, and economic differences across communities.

4.8 Conclusion

These results provide three important contributions to the study of affect, motivation, and engagement in mathematics. First, the tested model extends the utility and explanatory power of CVT across a particularly wide set of variables measured over the span of a school year. It has long been known that interest (personal and situational), efficacy (task- and subject-specific self-efficacy), and SRL (effort and applied strategies) are related, and that each is implicated in the interpretation of one's experience and the decisions made in challenging content like mathematics (Middleton et al., 2017). However, this study has extended the understanding of the role of task-level academic emotions as contributors to task-level motivation and regulation (Parker et al., 2021) in combination with other variables such as perceived and observed support.

Second, adding objects in addition to valence to the analysis of in-the-moment emotions suggests important new directions for how emotional experiences are interpreted during academic tasks, and how these interpretations differentially impact task-level motivation and behavior. For example, Negative Math emotions showed significant negative relationships with social engagement, task efficacy, instrumentality, and situational interest (but not effort), whereas Negative Self emotions showed only a negative relationship with task efficacy. By contrast, *Positive* Self emotions showed significant positive relationships with all the aspects of Task-level motivation considered here. Paying attention to how—and toward what— students attribute their task-level emotions may be fruitful for the design of classroom practices that capitalize on emotion regulation in students.

Finally, this study examined a robust set of support variables: from perceived teacher and peer support, to researcher-observed academic and social support. Across these results, it appears that social support provided by a classroom culture that respects individual contributions to learning and positions students as competent reduces students' negative mathematics emotions, and improves both students' situational interest and feelings of efficacy. This, in turn, should support achievement. Future research should investigate how to best instantiate this in the classroom, as well as what moderators may increase or decrease its effectiveness.

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