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Associations Between Teacher and Student Mathematics, Science, and Literacy Anxiety in Fourth Grade

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The present study explored associations among teachers' anxiety for teaching mathematics, science, and English language arts and their students' own anxiety in each content area, and how these associations varied depending on student sex and socioeconomic status (SES). Participants included 33 fourth-grade teachers and 463 students from 14 schools in the Southwestern United States. Multiple regression models with cluster-robust standard errors were run regressing students' mid-year, self-reported content-area anxiety on teachers' self-reported content-area anxiety at the beginning of the year and controlling for students' beginning-of-year anxiety in that content area. Two interaction effects were detected whereby teachers' mathematics and science anxiety were each positively associated with the mathematics and science anxiety of their low-SES students. Findings provide additional evidence for processes of emotional transmission between teachers and students in the classroom and provide additional information about the learning contexts and student groups for whom these processes may be particularly relevant.

Educational Impact and Implications Statement

We investigated associations among teachers' and students' anxiety in mathematics, science, and literacy. We found that teachers' anxiety in mathematics and science was associated with the mathematics and science anxiety of their low-SES students. Results highlight STEM content areas as contexts in which transmission of negative emotions between teachers and students may take place, as well as highlight the particular impacts these processes might have on students from underserved socioeconomic backgrounds.

Keywords: teacher anxiety, student anxiety, teacher emotions, content areas, elementary education

The recent Nation's Report Card of U.S. students' academic achievement demonstrated that the majority of middle elementary students are below proficiency in mathematics, reading, and science, with proportions of proficient students lowest among underserved groups (National Center for Education Statistics, 2020). This highlights the need for rigorous research into factors that contribute to elementary students' achievement and persistence in mathematics, science, and literacy, including investigations into how teaching and learning processes might operate differently for students from traditionally underserved and underrepresented groups. Teachers have a strong impact on their students' educational development (Chetty et al., 2011; Nye et al., 2004) and as such are high-leverage targets for investigation and intervention. It is not surprising, then, that a long history of research exists identifying factors that contribute to teacher effectiveness, with the majority of focus given to teachers' technical skills and knowledge (Loewenberg-Ball et al., 2008; Mishra & Koehler, 2006; Van Driel & Berry, 2012). However, seminal work has revealed that while knowledge-focused interventions can indeed improve teachers' knowledge, this does not often translate to improved student outcomes (Garet et al., 2016; Gersten et al, 2017). This suggests that such efforts are missing consideration of other important elements of teaching and learning.

Teachers are not only responsible for applying instruction and structuring learning opportunities in the classroom, but also for setting the emotional tone, providing emotional support, and serving as a key point of social reference for students. Thus, efforts to study and improve teacher effectiveness should include consideration of affective elements of teaching and learning such as teachers' and

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students' emotions and beliefs. Recent work along this vein has identified important connections among teachers' emotions and their students' emotions, classroom experiences, and outcomes (Frenzel et al., 2021), illustrating that this is a promising direction for teacher effectiveness research. However, there is still much to be learned as most studies of teacher and student emotions do not consider specific content areas and those that do typically focus on a single content area rather than comparing across multiple (e.g., Pendergast et al., 2015; Ramirez et al., 2018; Wilkins, 2008). This is a critical gap as evidence supports that teachers' emotions and their impacts on students are content-area dependent (McLean & Connor, 2015, 2018). In addition, some preliminary work has suggested that teachers' emotions might impact students differently depending on student characteristics (Beilock et al., 2010; Schaeffer et al., 2021), yet these types of effects are yet to be fully substantiated and described.

In the present study, we explored associations among teachers' mathematics, science, and ELA anxiety and their students' own anxiety in each content area, and how these relationships varied depending on student sex and SES. Our goal was to extend the current knowledge of direct emotional transmission (Frenzel et al., 2021) between teachers and their students, to describe how this transmission might operate differently across content areas, and to inform how students from traditionally underrepresented (females in STEM) and underserved (low SES) groups might experience this transmission differently. Through this investigation, we aim to provide further evidence that teachers' and students' emotions (and related affective experiences) are important to consider in research and intervention targeting teacher effectiveness, as well as to provide more nuanced information about in which contexts, and among which groups, these processes are most relevant. This information could inform novel approaches to teacher preparation and professional learning that explicitly center training on managing negative, and leveraging positive, emotions in teaching.

Theoretical Framework

We rely on Sociocultural Theory (John-Steiner & Mahn, 1996; Vygotsky & Cole, 1978), Appraisal Theory (Scherer, 1999), and Control Value Theory (Pekrun, 2006; Pekrun et al., 2007) to provide a framework for the roles of emotions in teaching and learning. Sociocultural Theory describes developmental processes as occurring through children's observations and interactions with "more knowledgeable others" in their environment. Teachers hold the role of the "more knowledgeable other" in the classroom, and as such students' classroom experiences and outcomes are influenced by both the explicit instruction and learning opportunities teachers provide as well as by teachers' emotional, behavioral, and affective cues. Appraisal Theory further illustrates that individuals use emotional, behavioral, and affective cues from others in their environment to interpret and respond to what is happening in a given moment (Parkinson & Manstead, 2015).

Applying the above tenets to teaching and learning processes in the classroom, Control-Value Theory describes how students' achievement emotions are influenced by appraisals of their environment. This theory highlights the central roles of social antecedents, or environmental features, in determining achievement emotions and cognitive, motivational, and regulatory processes. In elementary classrooms, the teacher is the prime initiator of these social antecedents, including instruction, classroom values, support for student autonomy, goals and expectations, feedback, and consequences (Pekrun, 2000). All of these teacher-initiated social antecedents have previously been found to be impacted by teachers' emotions, beliefs, well-being, and other affective experiences (Hagenauer et al., 2015, Hamre & Pianta, 2004; McLean & Connor, 2015, 2018; McLean et al., 2018; Roberts et al., 2016; Sandilos et al., 2015), illustrating the likely pathways through which teachers' emotions might influence students.

Related research provides evidence for these processes unfolding in the classroom; Frenzel et al. (2021) describe the processes of emotional transmission whereby an emotion expressed by one participant in an interaction is induced in their interaction partner(s), either directly or indirectly. This might unfold in the classroom the following way: a teacher who experiences mathematics anxiety might display negative affective cues during mathematics lessons including rushed/nervous speech patterns, posturing that turns them away from students and limits gesturing, and concerned/nervous facial expressions. Students may notice these cues and then appraise that mathematics is a threatening and/or intimidating content area and may themselves develop higher mathematics anxiety. Importantly, Frenzel et al. (2021) note that teachers' and students' emotions likely influence each other bi-directionally and/or reciprocally, for instance, expanding on the example above, students might internalize their teachers' mathematics anxiety and begin to react negatively to mathematics lessons via increased problematic behaviors and/or decreased engagement, and the teacher may then notice this and experience further heightened mathematics anxiety themselves. Such a process could continue across the year, creating a "snowball effect" of mathematics anxiety between teachers and students. While we acknowledge that such bi-directional/reciprocal relations are plausible, we use information gleaned in the present study to speak most directly to the influence of teachers' emotions on their students. Given the teacher's clear role as the leader of the classroom (and thus the main point of social reference/appraisals among students), as well as the fact that the teacher is the most accessible target for intervention, we assert that speaking most directly to the implications of teachers' emotions for students will yield the most actionable information.

The Role of Emotions in Teaching and Learning

Most U.S. elementary teachers are responsible for providing primary, daily instruction in multiple content areas to a single group of students as opposed to middle or high school teachers who specialize in one or two content areas and work with rotating groups of students throughout the day/week. Importantly, teachers can and do experience certain emotions regarding the content they teach; studies have revealed that teachers report more discomfort when instructing in mathematics and science, with this discomfort highest among teachers of younger students (Bates et al., 2013; Wilkins, 2008, 2009). It would stand to reason, then, that the impacts of teachers' emotions on classroom processes and student outcomes might look different across different content areas and may be most relevant in elementary and/or early childhood settings when students are first forming their impressions of each primary content area. However, most studies of teachers' emotions typically consider a single content area or investigate teachers' emotions in general without regard for the content area(s). While such investigations have

added valuable insight into how teachers' emotions and related experiences might operate in the classroom, there is still little understanding of how elementary teachers' emotions shift as they provide instruction across multiple content areas, and in which contexts (content areas) and for which students these emotions might be most impactful. Further still, most studies describing the connections between teacher and student emotions rely solely on teacher-reported data which can introduce reporter bias as well as inflate effect sizes (Frenzel et al., 2021). Thus, our investigation of these relations using data collected from both teachers and students, and our illustrations of how these relations vary across content areas, represent important elaborations on existing literature.

The field of psychology has broadly established that individuals' emotions impact their functioning (Fisher et al., 2013). Emotions predict problem-solving and cooperative skills among employees, and emotional intelligence predicts high-impact professional outcomes including employee turnover, performance, and job satisfaction (Jordan & Troth, 2011; Troth et al., 2012). Research has illustrated that teachers' emotions and related factors are associated with a range of teacher outcomes including job satisfaction and burnout (Ferguson et al., 2012; Jones & Youngs, 2012), classroom quality (McLean & Connor, 2015; Sandilos et al., 2015), classroom relationships (Hamre & Pianta, 2004), instruction (McLean et al., 2017, 2018), discipline (Hagenauer et al., 2015), and classroom social/emotional climate (Roberts et al., 2016). Efforts to describe more specific connections between teachers' and students' emotions have been fruitful: Prior work has found that teachers' enjoyment, anger, anxiety, and boredom all relate to the corresponding emotion in students (Becker et al., 2014; Frenzel et al., 2009; Tam et al., 2020). As well, connections have been made between teachers' emotions and students' achievement and related learning behaviors. For example, Hagenauer et al. (2015) reported associations between teachers' self-reported anger and anxiety and teacher-reported student engagement. Studies conducted among elementary and secondary samples have shown that teachers' reports of their teaching enjoyment are positively correlated with their ratings of students' attention (de Ruiter et al., 2019, 2020; Frenzel et al., 2018, 2020) and ratings of aggregate, classroom-level student behavior (Aldrup et al., 2018; Kunter et al., 2011). Frenzel et al. (2020) reported positive associations between teacher enjoyment and their ratings of students' academic competence. Lastly, McLean et al. (2022) found that teachers' content-area teaching enjoyment was related to their students' engagement in ELA and mathematics, and that in mathematics this relationship was particularly strong among low-SES students.

Teachers' and Students' Anxiety for Content Areas

We define content area anxiety as the discomfort that arises in teachers and/or students from doubts about their abilities to understand and utilize mathematics, science, or ELA concepts. While research on teacher anxiety has been gaining momentum in recent years, it is still a largely understudied topic when compared with other teacher emotional experiences such as stress or burnout. Further, within the teacher anxiety literature, much of the existing work focuses on teachers' general anxiety (i.e., not content-area specific, e.g., see Ferguson et al., 2012; Frenzel et al., 2016; McLean et al., 2017; Sinclair & Ryan, 1987) and relies on narrative or single-case data (Frenzel, 2014) or, again, includes solely self-report data from teachers for both independent and dependent variables (Frenzel et al., 2021).

Some descriptive work has suggested that teachers experience increased anxiety for mathematics and science (Bates et al., 2013; Wilkins, 2008, 2009), and within this teachers' (and more broadly, adults') anxiety for mathematics has been studied, measured, and intervened upon the most (e.g., see Barroso et al., 2021; Beilock et al., 2010; Ganley, et al., 2019; Hart & Ganley, 2019; Ramirez et al., 2018). First, foundational work has established that teachers can experience a notable degree of mathematics anxiety and that this impacts their functioning in the classroom (Loewenberg-Ball, 1990; Rech et al., 1993; Schmidt & Buchmann, 1983). There is evidence indicating that teachers' mathematics anxiety also impacts student outcomes including students' own mathematics anxiety and achievement (Beilock et al., 2010; Hadley & Dorward, 2011; Ramirez et al., 2018; Schaeffer et al., 2021). Further, there is evidence that these processes can unfold differently for different student groups and are mediated and/or moderated by factors such as students' perceptions and appraisals of their teacher. For example, studies have found female students are especially impacted by their teachers' mathematics anxiety (Beilock et al., 2010; Schaeffer et al., 2021), and that students' perceptions of their teacher play a role in how teachers' mathematics anxiety impacts students' achievement (Ramirez et al., 2018). Teachers' science anxiety has been studied less, however recent work suggests that teachers do report anxiety about their ability to support young students' scientific learning (Pendergast et al., 2015). In fact, it has been reported that as few as 28% of elementary teachers feel qualified to teach science (Weiss, 1994). Almost no work exists that examines teachers' anxiety about ELA, with the exception of studies describing the anxiety of teachers providing ELA instruction to students who are English language learners (ELLs; e.g., Machida, 2016; Merç, 2015), which is not the case in the present study. Given the notable lack of empirical work describing elementary teachers' science and ELA anxiety, and no work comparing how the influence of these factors might differ across content areas and student groups, the present study offers some notable elaborations.

Past work has shown that the anxiety of key adult socializers in children's lives (i.e., parents, teachers) does indeed influence children's outcomes: children whose parents have high mathematics anxiety show more mathematics anxiety themselves, which in turn relates to lower mathematics performance when compared with peers whose parents have low mathematics anxiety (Foley et al., 2017). As well, having more science-anxious teachers, experiencing science-centric gender and racial stereotyping, and observing stereotypes of scientists in popular media have all been shown to shape children's developing perceptions of and emotions surrounding science as a content area (Udo et al., 2004). Notably, anxiety does not appear to impact all students in the same ways: studies have shown that females have significantly higher rates of mathematics anxiety than their male peers in both primary and secondary school, with this discrepancy continuing through adulthood (Hill et al., 2010, 2016). Differences among students based on SES have also been detected: Yildirim (2012) reported that students in higher SES schools experienced lower mathematics anxiety and higher mathematics self-efficacy compared with students from lower SES schools.

Similar to teachers, students' mathematics anxiety has been most thoroughly described in the literature compared with anxiety in other

content areas. Previously, it was believed that mathematics anxiety did not emerge among students until encountering more advanced mathematics such as algebra, but recent research has demonstrated that mathematics anxiety can emerge as early as first grade (Barroso et al., 2021; Foley et al., 2017; Lauer et al., 2018; Maloney et al., 2015). Mathematics anxiety creates barriers to success for student learning; analysis of data from the Program for International Student Assessment (PISA) has found that mathematics anxiety relates negatively to mathematics performance among students in 63 out of 64 involved countries (Sälzer & Roczen, 2018). Most recently, Barroso et al. (2021) conducted a meta-analysis illustrating the relationship between students' mathematics anxiety and their mathematics performance across a variety of ages, solidly illustrating the importance of this emotion to learning processes and resulting achievement. Students' science anxiety, while studied comparatively less, has been shown to impact students' science learning behaviors, with increased anxiety leading to students' avoidance of science as well as a reduced capacity for scientific decision-making (Cumming & Harris, 2001; Daker et al., 2021). Investigations regarding ELA anxiety among students are again relegated to anxiety among students with specific reading/language disorders or to ELL students (e.g., see Hashemi, 2011; Pappamihiel, 2002; Woodrow, 2006).

Research Questions and Hypotheses

Guided by the above literature, we sought to address the following research questions: First, how does teachers' anxiety about about teaching mathematics, science, and ELA directly relate to their students' anxiety for learning in each content area? Given past findings that the anxiety of key adult socializers in children's lives can and does impact children's emotions (Foley et al., 2017; Udo et al., 2004), we anticipated that teachers' anxiety would be negatively associated with students' anxiety in each content area. Second, in which content areas, and for which students are the above relations most profound? Given past findings that teachers report more negative emotions for mathematics and science (Bates et al., 2013; Wilkins, 2008, 2009) and that female students and low-SES students experience more mathematics anxiety and are more influenced by the emotions of their teachers (Beilock et al., 2010), we anticipated that teachers' anxiety would be most impactful in mathematics and science, and would have the strongest effects on female students and low-SES students in these content areas.

Method

Procedures

Data were collected as part of a federally funded study investigating teaching and learning processes across core content areas in U.S. elementary classrooms. Data were collected across multiple cohorts of fourth-grade teachers and their students, with each cohort participating for one academic year. Pooled data from the first two cohorts of participants are used to address the research questions in the present study. Both cohorts underwent the same data collection procedures according to the same timeline (described below), with Cohort 1 undergoing data collection in the 2018/2019 academic year, and Cohort 2 in the 2019/2020 year. Each cohort was comprised of a unique group of teachers and students; participants were not able to participate for multiple years. Teachers were invited to enroll in the project during the summer prior to their participating year and provided informed consent and reported on their demographics prior to the start of the school year. In the first weeks of the school year, parents/guardians of students in classrooms of participating teachers were invited to enroll their child to participate in the study via enrollment packets sent home by teachers on behalf of study investigators. Enrollment packets contained information about the study, consent documents, and a short family demographics survey.

Teachers and students completed two surveys each throughout their participating year in which they reported on their feelings, beliefs, and behaviors in mathematics, science, and ELA. Survey administrations took place in the fall (Time 1) and Winter (Time 2). In the fall, teachers completed initial surveys in the first weeks of the school year (August), with the goal of capturing their feelings and beliefs for content areas before spending a significant amount of time with their current group of students. Teachers received electronic links to surveys housed in the platform Qualtrics and were given a 2-week window to complete the survey during which they were sent two reminders. Students completed fall surveys in October, after all teacher surveys had been completed. Teachers were asked to schedule a time within a 4-week window for a project member to administer paper-and-pencil surveys to all enrolled students in their classroom. The same approach was taken in the winter, with teachers completing surveys in January and students completing surveys in late February and early March. All teacher surveys were taken in English, and all students were given the option to take their survey in either English or Spanish, though the vast majority of students elected to take surveys in English. In the case that enrolled students were absent on the scheduled day of student survey administration, project staff worked with teachers to arrange a follow-up visit within 1 week of the initial administration for these students to complete the survey. Teachers were provided monetary compensation for their completion of surveys, and students were provided a small gift. All winter survey data from Cohort 2 (2019/2020) was collected prior to schools closing in response to the COVID-19 pandemic.

Participants

Teacher and student participants were recruited from 14 public elementary schools in six school districts in a single state in the Southwestern United States. All districts were located within the same 50-mile area but within this spanned rural, urban, and suburban settings. A wide range of school SES was observed, indicated by the school-wide percentage of students enrolled in a Free and Reduced Price Meals (FARM) program, with schoolwide FARM enrollment ranging from 6% (high-SES) to 94% (low-SES). The racial/ethnic makeup of schools also varied greatly, with school-wide percentages of students of color ranging from 96% (majority students of color) to 17% (majority Caucasian). Eight of the 14 schools had over 50% enrollment of Hispanic/Latino/a students, and five of these schools reported 80% or higher enrollment of Hispanic/Latino/a students.

Fifteen teachers and 199 students participated in Cohort 1, and 18 teachers and 264 students participated in Cohort 2, for a total combined sample analytic sample of 33 teachers and 463 students. The majority of teachers were female (88%). Sixty-seven percent of teachers were White, 24% were Latino/a, 3% African American, and 6% multiracial. Teachers ranged in years of

experience from 0 to 38 years ($M = 10.33$ years, $SD = 8.68$ years). All teachers held at least a bachelor's degree in Education and 39% held a master's degree or higher (2% held doctoral degrees). Fifty-three percent of students were female. Forty-four percent were Latino/a, 19% White, 12% multiracial, 5% African American, 3% Native American/American Indian/Alaskan Native, 2% Eastern Asian/Pacific Islander, and the parents/guardians of the remaining 10% either reported "other" or opted not to report their child's race. Fifty-six percent of students were enrolled in FARM.

Measures

Teacher and Student Demographics

Teachers and parents/guardians of students reported demographics at their respective time of enrollment (Summer for teachers, early Fall for students). Pertaining to the present study, teachers reported their years of teaching experience not including the participating year and parents/guardians reported on their child's sex (coded in the data as 0 = *boys* and 1 = *girls*) and FARM status (coded as 0 = *not enrolled in FARM* and 1 = *enrolled in FARM*). In addition, each participant was designated in the data as participating in either Cohort 1 or Cohort 2. Again, teachers participated in only one cohort; there was no overlap in teacher or student participants between cohorts. Across both cohorts, 100% of teachers and 99% of students provided demographic data (via parent report). All participants were assigned variables designating cohort membership.

Teachers' Anxiety About Teaching Mathematics, Science, and ELA

Teachers' anxiety about teaching mathematics, science and ELA was assessed at T1 using the Anxiety subscale of the Teacher Emotions Scale (TES; Frenzel et al., 2016). The overall TES is an 11-item scale which assesses teachers' enjoyment, anxiety, and anger during teaching by asking users to respond to a set of statements on a 4-point Likert scale, with 0 indicating that the statement is not true for them and 3 indicating that the statement is completely true. This measure was initially created to capture teachers' feelings about teaching in general, without referencing a specific content area (Frenzel et al., 2016). In order to reliably capture variation in teachers' anxiety across content areas in the present study, the same measurement tool had to be applied in each content area. As such, we felt the best approach was to adapt a context-neutral scale to reflect our focal content areas (mathematics, science, ELA). This was more feasible than working with existing context-specific tools which present teachers with tasks or scenarios specific to the given content area and ask them to report their feelings about those tasks or scenarios, as measure equivalence would not be achieved without significant adaptation and psychometric analysis.

The TES Anxiety subscale includes four items, and these items were adapted to reflect each content area of interest in the present study (mathematics, science, and ELA), resulting in a total of 12 items. Example items include "I generally feel tense and nervous while teaching math/science/ELA" and "preparing to teach math/science/ELA causes me to worry." The TES subscales have shown high internal consistency in foundational studies, with alpha coefficients between 0.70 and 0.92 across subscales (Frenzel et al., 2016). The content-area-specific Anxiety scales applied in the present study showed high internal consistency as well, with alpha = 0.73 for mathematics, 0.85 for science and 0.86 for ELA. Across both cohorts, 94% of teachers provided data for the T1 measurements of content-area anxiety.

Students' Anxiety for Learning Mathematics, Science, and ELA

Students' anxiety about learning mathematics, science, and ELA was assessed at T1 and T2 using the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011) adapted for elementary students (Lichtenfeld et al., 2012). The overall AEQ assesses students' enjoyment, anxiety and boredom for focal content areas, including their feelings regarding classroom instruction, homework, and tests in a content area. The anxiety subscale of the AEQ asks students to respond to 12 statements on a 4-point Likert scale indicating how true each statement is for them, with 0 indicating *the statement is not at all true* and 3 indicating *the statement is very true*. Similar to our approach to measuring teacher anxiety, each item was phrased to reflect a certain content area, resulting in 36 items given to students: 12 for mathematics, 12 for science, and 12 for ELA. Example items include "During math/science/ELA class, I worry that everything is too difficult for me" and "math/science/ELA tests scare me so much that I would rather not take them." The AEQ has shown high internal consistency in foundational studies with alpha estimates ranging from 0.73 to 0.92 (Lichtenfeld et al., 2012), as well as in the present study, with alpha estimates above 0.75 for each focal content area. Across both cohorts, about 92% of students provided data for the T1 measurement of content-area anxiety and about 80% provided data for the T2 measurement.

Analytic Approach

Descriptive statistics and zero-order correlations were examined to confirm acceptable variable distributions and explore the nature of baseline relations among variables. Multiple regression models using cluster-robust standard errors were tto address each research questihen run in MPlus (Muthén, 2018) on. Cluster robust standard errors are an accepted approach for accounting for the nested nature of data in cases where nesting exists but the number of cluster units is small (Cameron & Miller, 2015), as was the case here with 463 students nested in 33 classrooms. All continuous predictor variables were centered prior to analysis, with teacher-level variables (teacher years of experience, enjoyment) grand-mean centered and the student-level variable (Time 1 engagement) group-mean centered to account for potential "frog pond effects" whereby an individual data point might be influenced in part by the nature of the larger context (Marsh et al., 2008). All models were run using the robust Full Information Maximum Likelihood estimator, which uses each case's available data to compute estimated values for missing data, thus retaining the analytic sample's full power (Hox, 1999).

A model-building approach was used that first introduced covariates as predictors of focal outcomes, and then subsequently introduced main effects and interaction effects as additional predictors. In total, nine models were run: three per content area. First, covariates-only models were run which regressed students' Time 2 anxiety in each content area on teacher years of experience, cohort membership, student sex, student FARM status, and students' Time 1 anxiety for that content area. Next, main effects models

were run that included teachers' Time 1 anxiety in each content area as a focal predictor of students' Time 2 anxiety in that content area. Last, interactions models were run that included teacher anxiety-by-student sex and teacher anxiety-by-student FARM status interaction terms as additional predictors of students' Time 2 anxiety in each content area. Consistently insignificant covariates were trimmed from the final models to preserve parsimony.

Transparency and Openness

This manuscript has been prepared according to the standards described in the Journal Article Reporting Standards (JARS; Kazak, 2018) for the American Psychological Association. We have reported all necessary study information, including participant recruitment methods; data exclusions and manipulations, and all approaches to the measurement of study variables. All participants were provided all relevant study information prior to consenting, and provided informed consent to participate. All study activities were approved and overseen by the IRB board of the awarded institution, and regular reports of study activities were provided to the sponsoring institution throughout active data collection.

This study's design and analysis were not pre-registered. Data for this study will be transferred to an online data-sharing repository approximately 1 year after the culmination of the federally funded study from which they come, in July 2025. Prior to that time, those interested in obtaining study data should contact the corresponding author at lmclean@udel.edu.

Results

Preliminary Analyses

Descriptive statistics (see Table 1) indicated that all variables were within acceptable ranges of skewness and kurtosis (skewness < 2, kurtosis < 7; Fidell & Tabachnick, 2003). Bivariate correlations (see Table 2) did not indicate any relationship between teachers' time 1 anxiety and students' time 2 anxiety. Students' anxiety for content areas were consistently significantly related both within and across time points in the expected directions. Interestingly, teachers' years of experience was negatively correlated with their ELA and mathematics anxiety but showed no association with their science anxiety. Teachers' years of experience were not correlated with students' anxiety in any content area.

Table 1
Descriptive Statistics

Variables	*n*	Min	Max	*M*	*SD*	Skewness	Kurtosis
1. T Yrs Exp	33	0	38	10.33	8.67	0.91	0.56
2. T T1 ELA Anx	31	1.00	4.00	1.95	0.82	0.54	−0.63
3. T T1 Math Anx	31	1.00	4.00	1.84	0.81	0.92	0.31
4. T T1 Sci Anx	31	1.00	3.33	2.12	0.75	−0.12	−1.18
5. S T1 ELA Anx	423	1.00	5.00	1.75	0.88	1.66	2.64
6. S T1 Math Anx	430	1.00	5.00	1.88	0.86	1.16	0.71
7. S T1 Sci Anx	427	1.00	5.00	1.66	0.77	1.73	3.29
8. S T2 ELA Anx	365	1.00	5.00	1.77	0.90	1.47	1.68
9. S T2 Math Anx	371	1.00	4.75	1.80	0.87	1.37	1.09
10. S T2 Sci Anx	366	1.00	5.00	1.66	0.79	1.69	2.92

Note. T = teacher; S = student; T1 = Time 1; T2 = Time 2; Sci = science; ELA = English language arts; Anx = anxiety; Yrs Exp = years of experience.

Aim-Specific Analyses

English Language Arts

The covariates-only model for ELA revealed no significant relations among cohort membership, teacher years of experience, student sex, or student FARM status on students' Time 2 ELA anxiety, though the effect of FARM status was approaching significance ($B = 0.16$, $p = .08$). Students' Time 1 ELA anxiety was positively related to their T2 ELA anxiety ($B = 0.38$, $p < .001$). Teacher years of experience and cohort membership were not significantly related to students' Time 2 ELA anxiety and were trimmed from subsequent models. See Table 3 for all main effects and interactions model estimates. The main effects model for ELA which introduced teachers' Time 1 ELA anxiety did not reveal any significant impact of this variable on students' Time 2 ELA anxiety. The interactions model which introduced teacher ELA anxiety-by-student sex and teacher ELA anxiety-by-student FARM interaction terms as additional predictors also did not reveal any significant interaction effects.

Mathematics

The covariates-only model for mathematics revealed significant relations among students' sex, FARM status and their Time 1 mathematics anxiety and their Time 2 mathematics anxiety such that girls and students enrolled in FARM had higher Time 2 mathematics anxiety ($B = 0.24$, $p < .01$ for sex; $B = 0.26$, $p < .01$ for FARM) and higher Time 1 mathematics anxiety was associated with higher Time 2 mathematics anxiety ($B = 0.61$, $p < .01$). Teacher years of experience and cohort membership were not significantly related to students' Time 2 mathematics anxiety and so were trimmed from subsequent models. The main effects model for mathematics did not reveal any significant relation between teachers' Time 1 mathematics anxiety and students' Time 2 mathematics anxiety. The interactions model revealed a significant teacher mathematics-anxiety-by-student FARM interaction effect ($B = 0.39$, $p < .01$) on students' Time 2 mathematics anxiety. This interaction effect (see Figure 1) indicated that in classrooms led by teachers with high (+1 *SD*) mathematics anxiety, low-SES students' mathematics anxiety was higher than their high-SES peers.

Science

The covariates-only model for science revealed significant relations among students' FARM status and their Time 1 science anxiety and their Time 2 science anxiety such that being enrolled in FARM was associated with higher science anxiety ($B = 0.18$, $p = .01$) and higher Time 1 science anxiety was associated with higher Time 2 science anxiety ($B = 0.42$, $p < .01$). Teacher years of experience and cohort membership were not significantly related to students' Time 2 science anxiety and so were trimmed from subsequent models. The main effects model revealed no significant effect of teachers' Time 1 science anxiety on students' Time 2 science anxiety. The interactions model revealed a significant teacher science anxiety-by-student FARM interaction effect ($B = 0.21$, $p = .05$) on students' Time 2 science anxiety. This interaction effect (see Figure 1) indicated that in classrooms led by teachers with high (+1 *SD*) science anxiety, low-SES students' science anxiety was higher than their high-SES peers (Figure 2).

Table 2
Correlations Among Primary Study Variables

Variables	1	2	3	4	5	6	7	8	9	10
1. T Yrs Exp	—									
2. T T1 ELA Anx	−.67**	—								
3. T T1 Math Anx	−.46**	.45**	—							
4. T T1 Sci Anx	.04	.11*	.33**	—						
5. S T1 ELA Anx	.01	.05	−.01	−.02	—					
6. S T1 Math Anx	−.10	.05	.16**	.03	.45**	—				
7. S T1 Sci Anx	−.01	.06	.06	−.01	.59**	.48**	—			
8. S T2 ELA Anx	−.04	.01	.08	−.02	.41**	.29**	.30**	—		
9. S T2 Math Anx	−.06	.04	.10	.02	.31**	.64**	.22**	.47**	—	
10. S T2 Sci Anx	.03	−.01	.02	−.01	.33**	.27**	.41**	.56**	.45**	—

Note. T = teacher; S = Student; T1 = Time 1; T2 = Time 2; Sci = science; ELA = English language arts; Anx = anxiety; Yrs Exp = years of experience.
*$p < .05$. **$p < .01$.

Discussion

In the present study, we explored associations among teachers' and students' content-area anxiety in mathematics, science, and ELA, and whether these associations differed for male versus female and low versus high-SES students. Our goal was to provide the field with additional, and more nuanced, evidence of the potential for direct transmission of emotions between teachers and students in elementary classrooms. Guided by prior studies suggesting that the impacts of teachers' negative emotions might be most pronounced in mathematics (Beilock et al., 2010; McLean & Connor, 2015; Ramirez et al., 2018; Wilkins, 2009), and might have specific implications for underrepresented and underserved students (Beilock et al., 2010; McLean & Connor, 2015; McLean et al., 2022), we predicted that teachers' anxiety would be positively associated with students' anxiety, that effects would surface most pointedly in mathematics and science, and that these processes were especially relevant for girls and low-SES students. While the anticipated direct associations between teacher and student anxiety were not detected in any content area, interaction effects indicated that when low-SES students were in a classroom with a teacher who reported higher mathematics and science anxiety, their anxiety for these content areas was higher than their higher-SES peers.

The present study elaborates on existing literature on teacher and student emotions in some notable ways. First, our comparison of these processes across content areas and among student groups provides more specific information about in which learning contexts and for which students' processes of direct emotional transmission between teachers and students might surface most pointedly. Second, our use of both teacher- and student-reported data to document the associations among teacher and student content area anxiety is a methodological approach that has recently been identified as lacking in the current body of work on teacher emotions (Frenzel et al., 2021). In addition, some elements of our methodological approach strengthen our ability to generalize findings to certain teacher and student populations. Our sample was diverse regarding

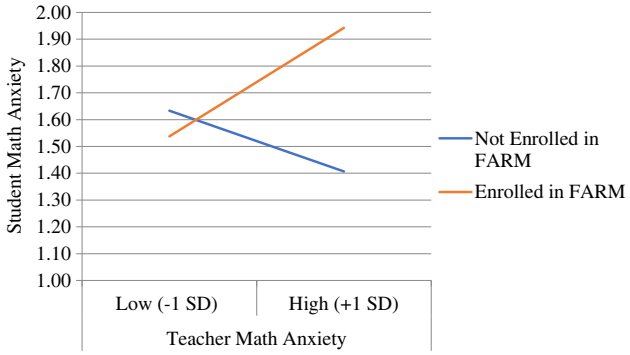
Table 3
Regression Model Estimates

Literacy main effects model				Mathematics main effects model				Science main effects model			
	Intercept				Intercept				Intercept		
S T2 ELA anxiety	1.67			S T2 math anxiety	1.55			S T2 sci anxiety	1.53		
	B	*SE*	*p*		*B*	*SE*	*p*		*B*	*SE*	*p*
S sex	−0.02	0.10	.81	S sex	0.25	0.07	<.01	S sex	0.07	0.09	.47
S FARM	0.19	0.11	.08	S FARM	0.20	0.08	.02	S FARM	0.15	0.08	.07
S T1 ELA anxiety	0.38	0.05	<.01	S T1 math anxiety	0.61	0.05	<.01	S T1 sci anxiety	0.41	0.05	<.01
T T1 ELA anxiety	0.02	0.08	.81	T T1 math anxiety	0.10	0.10	.33	T T1 sci anxiety	−0.01	0.06	.91
Literacy interactions model				**Mathematics interactions model**				**Science interactions model**			
	Intercept				Intercept				Intercept		
S T2 ELA anxiety	1.66			S T2 math anxiety	1.52			S T2 sci anxiety	1.55		
	B	*SE*	*p*		*B*	*SE*	*p*		*B*	*SE*	*p*
S sex	1.01	0.01	.91	S sex	0.25	0.07	<.01	S sex	0.06	0.09	.49
S FARM	0.20	0.10	.05	S FARM	0.22	0.08	<.01	S FARM	0.15	0.08	.08
S T1 ELA anxiety	0.38	0.05	<.01	S T1 math anxiety	0.62	0.05	<.01	S T1 sci anxiety	0.41	0.05	<.01
T T1 ELA anxiety	−0.16	0.12	.22	T T1 math anxiety	−0.14	0.09	.13	T T1 sci anxiety	−0.08	0.12	.51
ELA Anxiety × Sex	0.11	0.12	.37	Math Anxiety × Sex	−0.10	0.09	.25	Sci Anxiety × Sex	−0.08	0.13	.51
ELA Anxiety × FARM	0.20	0.14	.16	Math Anxiety × FARM	0.39	0.14	<.01	Sci Anxiety × FARM	0.21	0.11	.05

Note. FARM = Free and Reduced Price Meals; T = teacher; S = student; T1 = Time 1; T2 = Time 2; sci = science; ELA = English language arts.

Figure 1

Teacher Math Anxiety by Student FARM Interaction



Note. FARM = Free and Reduced Price Meals. See the online article for the color version of this figure.

race/ethnicity and socioeconomic status, and the demographic makeup of student participants in the present study aligns well with the current and future (expected) racial/ethnic and socioeconomic trends observed in the United States more broadly, with census data showing that the U.S. population of Hispanic/Latino/a school-aged children is rising and more U.S. families are fitting broad definitions of "low-SES" (Duffin, 2022).

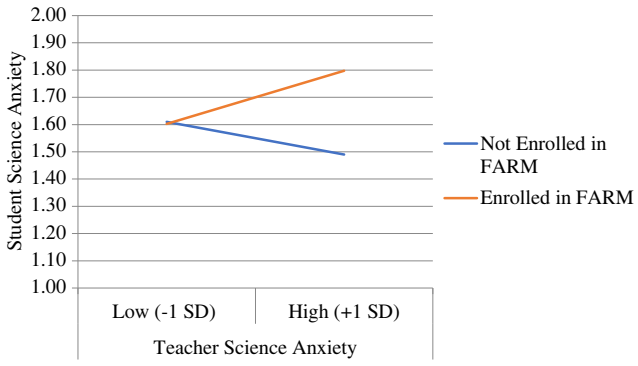
Below we discuss some immediate conclusions that can be drawn from our findings, as well as some broader implications for the field of education.

Conclusions

Before interpreting our main findings, we first discuss an interesting pattern of associations noted in correlation analyses: Teachers' years of experience were strongly, negatively correlated with their mathematics and ELA anxiety indicating that teachers with more experience reported lower levels of anxiety in these content areas. However, there was no significant correlation between teachers' years of experience and their science anxiety. In unpacking this finding, it could be that teachers who are the most uncomfortable with mathematics and ELA may attrit from the field before reaching veteran status, or alternately teachers who have been in the field for longer may have had more time to build and adapt their skills, knowledge, etc., in mathematics and ELA. However, these processes may not be as present in science, and the reasons why this might deserve careful study when considered along with the fact that historically, a large majority of teachers report feeling unprepared to support their students' learning in science (Weiss, 1994). We note that the role of teachers' years of experience and potentially associated patterns of teacher attrition as related to teachers' emotions and how they develop across the career could be fruitful avenues for future research.

Figure 2

Teacher Science Anxiety by Student FARM Interaction



Note. FARM = Free and Reduced Price Meals. See the online article for the color version of this figure.

Regarding our primary aims, some findings aligned with our predictions, and others were surprising. We did not detect the anticipated direct associations between teacher anxiety on student anxiety in any content area, nor did we detect any interaction effects based on student sex. However, we did detect interaction effects whereby teachers' mathematics and science anxiety were most strongly related to the mathematics and science anxiety of their low-SES students. Before interpreting these findings, we first want to note some methodological aspects of this study that may have contributed to where and how findings surfaced; First, our lack of direct effects could be an artifact of our underpowered teacher sample. Second, given that much of the past related work providing evidence for the connections between teacher and student emotions has relied on teachers to report both the teacher predictors and the student outcomes (e.g., de Ruiter et al., 2019, 2020; Frenzel et al., 2018, 2020), it may be that utilizing data from both teachers and students leads to associations among variables surfacing differently than they have in the past work or being more difficult to detect.

As we interpret findings, we first offer that the effects detected here serve as further evidence that processes of emotional transmission do indeed occur in elementary classrooms. This finding builds directly on past work that has described these processes more generally (Frenzel et al., 2021) and is supported by a number of theoretical frameworks describing how individuals (especially children) notice and internalize the affective cues of those around them (John-Steiner & Mahn, 1996; Pekrun, 2006; Pekrun et al., 2007; Scherer, 1999; Vygotsky & Cole, 1978). While a direct effect (i.e., teacher-to-student effects) was not shown in the present study, our timing of variables (teacher emotions collected before teachers spent significant amounts of time with their students) and our analytic approach (all models controlled for students' initial levels of anxiety) give us some preliminary insights into how teachers' emotions might impact students. From a theoretical standpoint and aligning with our framing of this study in Sociocultural, Appraisal, and Control-Value Theories, the teacher is the main point of social reference for students and is the initiator of many of the social antecedents that are known to influence students' learning-related emotions including structuring learning opportunities, providing instruction, and monitoring and responding to student behavior and engagement (Pekrun, 2000). The teacher is also the most accessible figure for intervention via structured professional learning opportunities. Thus, even in the likely case that bi-directional and/or reciprocal relations exist among teachers' and students' emotions, we view the teacher as the highest-leverage point of focus when attempting to study and intervene in these processes. Future research in this area could extend these findings further by substantiating the directionality of effects, and by identifying additional factors that might play indirect roles in how teacher and student emotions relate to each other. For example, future studies could employ observational methods to investigate if

teachers' emotions impact their instructional practices and/or observable effect in each content area, which might then have implications for students' emotions and other learning-related outcomes.

Results also indicated that emotional transmission may occur most pointedly in STEM contexts and among low-SES students. We offer a few considerations for this set of findings. First, it could be that low-SES children rely more on their teachers as STEM socializers than do other students. It is well-known that the home and other non-school environments that low-SES children experience are more limited in their resources to support early STEM learning (Milne & Plourde, 2006), and as such that low-SES may respond more strongly to the affective cues of their teacher as they develop their feelings and beliefs about STEM. Second, we offer that teacher STEM anxiety may be heightened when teaching low-SES students. The majority of U.S. teachers report feeling unprepared to facilitate their young students' STEM learning (Weiss, 1994), as well as feeling unprepared to support the learning and development of students from underserved communities (Johnston & Young, 2019). Further, the literature suggests that teachers at schools that serve higher populations of low-income students may not have access to hands-on and engaging STEM curriculum materials (Molina et al., 2016), which contribute to their anxiety. On a larger scale, teachers' anxiety for teaching STEM may be particularly heightened when instructing low-income students due to the United States disparate emphasis on student STEM achievement; Nationally and globally, STEM achievement has been deemed the gateway of the future and a primary mechanism by which to maintain or gain global power. Annually, reports are published comparing U.S. science and math placements with other developed nations (e.g., PISA, Nation's Report Card, etc.) and illustrating that the United States regularly falls behind many other countries. The national and global pressure to produce STEM-succeeding students may result in teachers feeling disproportionately intimidated by the tasks of providing adequate STEM education to their students.

Limitations

We note some limitations that are important to consider when interpreting study findings. First, while we had an adequate number of student participants, this study was underpowered at the teacher level, which increases the chance of type II error or failing to detect an existing effect. While it is encouraging that some effects were detected, future studies should replicate and expand on what was found here using larger samples. Second, this study is correlational in nature and analyses performed speak only to the associations among variables and not the directionality of effects. While we discuss the potential for teacher emotions to impact student emotions from theoretical and practical standpoints, future work should substantiate this by identifying a causal mechanism. Third, participants were recruited from a single state and voluntarily enrolled in the study after being invited, and thus this is a sample of convenience. There may be key differences between teachers and students (parents) who volunteered to participate in this project versus those who declined. Lastly, while nesting was accounted for in analyses via cluster-robust standard errors, other multileveled approaches such as hierarchical linear modeling could be considered more rigorous. The sample size was an important factor in our determination of the analytical approach. Still, future work should seek to replicate and expand upon these findings using more stringent multileveled analyses, again among larger samples. Considering these limitations, we frame the present study as an exploratory first step towards understanding the nature of associations among teachers' and students' content area anxiety, and the added impacts of context and student characteristics.

Broader Implications

Elementary teachers are some of the first to formally socialize young students to different content areas. Past work shows that students within the same classroom can have vastly different learning experiences depending on myriad factors including their and their teachers' characteristics, feelings, beliefs, etc. (Connor et al., 2009; McLean et al., 2020). The present study serves to highlight the potential role of the teacher in supporting their low-SES students' developing emotions, attitudes, and beliefs (and, likely, eventual achievement and persistence) for STEM content areas. Evidence from the present study suggests that elementary teachers may be uniquely situated to foster their low-SES students' interest and engagement in STEM. However, for these processes to unfold successfully, low-SES students (and more broadly, students from underrepresented communities) and the teachers who serve these students should be prioritized for added support to improve their STEM teaching and learning experiences. We note three contexts where we feel these supports could be most effectively provided: the schools and districts of practicing teachers; teacher preparation programs; and community settings via educational and social policy. First, school and district leaders could prioritize the targeted support of high-STEM-anxiety teachers via additional training and professional development that builds self-efficacy and positive emotions in these content areas. In addition, schools and districts could utilize mental health consultation and support services that address the emotional aspects of teaching, and most especially of educating low-income and other underrepresented students in STEM subjects.

We also highlight the role that systems of teacher preparation in the United States might play in contributing to teachers' feelings/beliefs about teaching STEM, and to the characteristics of the STEM teaching workforce at large. Due to high variability across U.S. teacher preparation programs (Schmidt et al., 2011), especially in the crucial supervised teaching experience (Clarke, 2001; Clarke et al., 2014), there is little guarantee that new teachers enter the field having been exposed to high-quality STEM instruction. As well, despite evidence that emotions and beliefs are important factors in teaching and learning (Schaeffer et al., 2021; Strati et al., 2017) training on promoting positive emotions and beliefs among new teachers is not widely incorporated into teacher preparation (Day, 2008; Newberry et al., 2013) and has never been aligned with teaching STEM specifically. The same is true for training on effectively centering justice and equity in teaching, with teacher preparation programs varying widely in their offerings on this topic and few programs aligning training with STEM content.

In terms of potential responses to the above barriers, increasing pre-service teachers' opportunities to learn and practice high-quality STEM instruction, as well as incorporating explicit training on the roles of emotions in teaching and learning and on culturally responsive pedagogy (Ladson-Billings, 1995, 2014) into teacher training, could be a promising approach to addressing the transmission of

negative STEM emotions before it occurs in the classroom. Along this vein, teacher preparation programs could intentionally monitor their pre-service teacher candidate's feelings and beliefs in each content area and could use these data to make more informed decisions about what types of preparation experiences might support their pre-service teachers' positive content-area emotions, and we offer that school systems, and most especially those that serve higher proportions of low-SES and racial/ethnic minority students, face consistent challenges in their ability to recruit and retain high-quality STEM teachers (Goldhaber, Lavery, et al., 2015; Goldhaber, Krieg, et al., 2015; Lankford et al., 2002), which lead to notable teacher quality gaps (Goldhaber et al., 2019) between more- and less- advantaged students. This latter workforce issue is likely further exacerbated by the more general fact that adults who are more STEM-anxious avoid careers in STEM (Ahmed, 2018; Cribbs et al., 2021; Levy et al., 2021), and thus may be attracted to teaching because it is not widely perceived as a "STEM career." In fact, as mentioned previously, there is evidence that teachers self-select into teaching younger students to avoid teaching STEM content (Wilkins, 2008, 2009). Educational and social policies to retain effective STEM teachers in high-needs contexts, raise the social prestige of the teaching career, and attract more members of the STEM community to teaching could lead to decreases in the STEM teacher quality gaps currently present in the STEM teaching workforce.

Outside of school settings, we also note that community-based efforts to promote STEM knowledge and engagement among low-income families are rare compared with those promoting literacy. Nationwide prioritization of literacy in educational and social policy has resulted in the development of many intervention programs that target low-income parents' and children's development of literacy skills (e.g., Let's Talk Dads, Raising a Reader, Reach out and Read, Unite for Literacy). Such programs provide ample messaging for parents to promote their child's literacy engagement and confidence, however there are comparatively few programs utilizing these strategies to promote early STEM. This heavier emphasis on supporting the literacy and reading development of U.S. children in the home and community environments via ad campaigns, programming, outreach, etc., may leave U.S. parents/guardians better equipped to positively socialize their children to ELA, but not STEM content. Increased availability of community-based science and math interventions for low-income families could provide more equitable STEM opportunities to all students, including students from low-income families.

While much more still needs to be clarified about how teachers' and students' emotions impact classroom processes and student outcomes, the present study underscores the importance of considering these factors along with more traditionally targeted classroom elements such as instruction, classroom quality, and teachers' pedagogical and content knowledge. By interrupting the negative, and leveraging the positive, transmission of emotions for STEM both in the classroom and outside of it, and by targeting these processes among underserved and underrepresented students, the field could move toward more effective and equitable learning experiences for all students.

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