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The Interpersonal Classroom:

Understanding Teacher Behavior and Math Anxiety in Teachers and Students Through the Interpersonal Circumplex

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Summary

Dyadic interactions between teachers and students are highly relevant for successful learning in schools. However, understanding how qualitative dyadic interpersonal behavior of teachers is shaped remains insufficiently understood. This dissertation utilizes the Interpersonal Circumplex within Interpersonal Theory (Kiesler, 1996; Leary, 1957) to describe behavior within a circumplex model along the dimensions of communion (e.g., warmth, affective involvement) and agency (e.g., direction, guidance), which allows for precise examination of behavioral configurations in teacher-student dyads.

This dissertation addresses two overarching research questions: (1) In what way is teachers' interpersonal behavior related to students' behaviors and scholastic competencies in dyadic interactions? and (2) In what way is dyadic teacher interpersonal behavior related to teachers' and students' emotions, particularly in the context of mathematics anxiety? To address these questions, this dissertation synthesizes the assumptions of the complementarity principle (Carson, 1969; Sadler et al., 2009), the adaptive teaching paradigm (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018), and research on teacher (Frenzel, 2014; Frenzel et al., 2021) and student emotions (Pekrun, 2006; Pekrun et al., 2023) through the theoretical lens of the Interpersonal Circumplex (Kiesler, 1996; Leary, 1957).

Study 1 examined interpersonal complementarity (Carson, 1969; Sadler et al., 2009) in relation to students' communal behaviors and scholastic competencies. Through observations of 78 teacher-student dyads across 39 primary and secondary schools, this study investigated the extent to which teachers' behavior was more communal in response to communal student behaviors, and less agentic when student competencies were higher. Results showed that high scholastic competencies were associated with teacher behavior characterized by the expected low agency but also moderately high communion ("participating-tolerating"). Further, in line with expectations, high communal student

behaviors were related to high communal teacher behaviors ("helping-guiding" and "understanding-interested"), while low communal student behaviors were associated with low communal teacher behaviors ("admonishing" and "ignoring-resigning").

Study 2 examined how primary school teachers' mathematics teaching anxiety related to their dyadic interpersonal behavior. The sample consisted of 161 primary school mathematics teachers who described their interpersonal behavior towards 2,235 students. Mathematics teaching anxiety was significantly associated with low teacher communion. Furthermore, substantial gender differences emerged in the association with agency: mathematics teaching anxiety in male teachers was associated with behavior low in both communion and agency ("ignoring-resigning" and "indeterminate-waiting"), while mathematics anxiety in female teachers was associated with low communion but moderate agency ("admonishing" and "ignoring-resigning").

Study 3 investigated how dyadic teacher interpersonal behavior relates to students' mathematics anxiety, with attention to mediating factors including student self-concept and perceived teacher expectations. The sample consisted of 42 primary school teachers and their 731 students. Results indicated that high teacher agency was associated with increased student mathematics anxiety. Furthermore, significant gender differences emerged: boys' mathematics anxiety was linked to high agency with moderate communion ("demanding-strict"), while girls' anxiety was associated with high agency and low communion ("admonishing"). For girls, both teacher agency and communion indirectly affected mathematics anxiety through perceived teacher expectations and self-concept, whereas for boys, only teacher agency showed these indirect associations.

This research advances the understanding of teacher-student interpersonal dynamics by describing dyadic behaviors on the dimensions of agency and communion and utilizing the propositions of the circumplex structure. Accordingly, it demonstrates that teachers'

dyadic interpersonal behavior (1) relates in complementary patterns in response to individual student characteristics and competencies, (2) substantially relates to teachers' mathematics teaching anxiety, and (3) relates to students' mathematics anxiety. Notably, the associations with both teachers' and students' emotions showed significant gender-specific patterns. These results contribute to current understanding of teacher-student interactions by emphasizing that the focus should lie on dyadic processes to illuminate mutual influences and emotional interplay within classrooms. This has critical implications for future research and educational practice to identify behaviors that are most beneficial for students and which processes hinder teachers from displaying optimal behavior.

Zusammenfassung

Dyadische Interaktionen zwischen Lehrkräften und Schüler:innen sind von großer Bedeutung für erfolgreiches Lernen in Schulen. Das Verständnis dafür, wie qualitatives dyadisches interpersonales Verhalten von Lehrkräften ausgestaltet ist, ist nach wie vor unzureichend erforscht. Diese Dissertation nutzt den Interpersonalen Zirkumplex innerhalb der Interpersonalen Theorie (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957), um Verhalten innerhalb eines Zirkumplex-Modells entlang der Dimensionen Communion (z.B. Wärme, affektive Einbindung) und Agency (z.B. Anleitung, Führung) zu beschreiben, was eine präzise Untersuchung von Verhaltenskonfigurationen in Lehrkraft-Schüler:innen-Dyaden ermöglicht.

Diese Dissertation adressiert zwei übergreifende Forschungsfragen: (1) Inwiefern steht das interpersonale Verhalten von Lehrkräften in Beziehung zu dem Verhalten der Schüler:innen und deren schulischen Kompetenzen in dyadischen Interaktionen? und (2) Inwiefern steht dyadisches interpersonales Lehrkraftverhalten in Beziehung zu Emotionen von Lehrkräften und Schüler:innen, insbesondere im Kontext von mathematikbezogener Angst? Um diese Fragen zu beantworten, synthetisiert diese Dissertation die Annahmen des Komplementaritätsprinzips (Carson, 1969; Sadler et al., 2009), des adaptiven Lehrparadigmas (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018) und der Forschung zu Lehrkraftemotionen (Frenzel, 2014; Frenzel et al., 2021) und Schüler:innenemotionen (Pekrun, 2006; Pekrun et al., 2023) durch die theoretische Brille des Interpersonalen Zirkumplexes (Kiesler, 1996; Leary, 1957).

Studie 1 untersuchte interpersonale Komplementarität (Carson, 1969; Sadler et al., 2009) in Bezug auf kommunales Schüler:innenverhalten und schulische Kompetenzen. Durch Beobachtungen von 78 Lehrkraft-Schüler:innen-Dyaden in 39 Grund- und weiterführenden Schulen untersuchte diese Studie, inwieweit das Verhalten von Lehrkräften kommunaler war,

je kommunaler das Verhalten der Schüler:innen und inwieweit das Verhalten von Lehrkräften weniger agentisch war, je höher die Kompetenzen der Schüler:innen. Die Ergebnisse zeigten, dass hohe schulische Kompetenzen mit Lehrkraftverhalten verbunden waren, das durch die erwartete niedrige Agency, aber auch durch mäßig hohe Communion ("beteiligend-tolerierend") charakterisiert war. Weiterhin waren, entsprechend den Erwartungen, hoch kommunale Verhaltensweisen der Schüler:innen mit hoch kommunalen Lehrkraftverhaltensweisen ("helfend-lenkend" und "verständnisvoll-interessiert") verbunden, während niedrig kommunale Verhaltensweisen der Schüler:innen mit niedrigen kommunalen Lehrkraftverhaltensweisen ("ermahnend" und "ignorierend-resignierend") assoziiert waren.

Studie 2 untersuchte, wie mathematikbezogene Angst während des Unterrichtens bei Grundschullehrkräften mit ihrem dyadischen interpersonalen Verhalten zusammenhing. Die Stichprobe bestand aus insgesamt 161 Grundschul-Mathematiklehrkräften, die ihr interpersonales Verhalten gegenüber 2,235 Schüler:innen beschrieben. Die mathematikbezogene Angst während des Unterrichtens war signifikant mit niedriger Communion verbunden. Darüber hinaus zeigten sich Geschlechterunterschiede in der Assoziation mit der Agency: Während die mathematikbezogene Angst während des Unterrichtens bei männlichen Lehrkräften mit Verhalten verbunden war, das sowohl in Communion als auch in Agency niedrig war ("ignorierend-resignierend" und "unbestimmt-abwartend"), war mathematikbezogene Angst während des Unterrichtens bei weiblichen Lehrkräften mit niedriger Communion, aber mäßiger Agency assoziiert ("ermahnend" und "ignorierend-resignierend").

Studie 3 untersuchte, wie dyadisches interpersonales Lehrkraftverhalten mit der mathematikbezogenen Angst von Schüler:innen zusammenhängt, unter Berücksichtigung vermittelnder Faktoren wie des Selbstkonzeptes und wahrgenommener Lehrkrafterwartungen. Die Stichprobe umfasste 42 Grundschullehrkräfte und ihre 731

Schüler:innen. Die Ergebnisse zeigten, dass hohe Agency der Lehrkraft mit erhöhter mathematikbezogener Angst der Schüler:innen verbunden war. Darüber hinaus zeigten sich signifikante Geschlechterunterschiede: Die mathematikbezogene Angst von Jungen war mit hoher Agency bei mäßiger Communion ("fordernd-streng") verbunden, während die mathematikbezogene Angst von Mädchen mit hoher Agency und niedriger Communion ("ermahnend") assoziiert war. Bei Mädchen war sowohl der Zusammenhang von mathematikbezogener Angst mit Agency als auch mit Communion durch das Selbstkonzept und wahrgenommene Lehrkrafterwartungen mediiert, während sich diese Mediation bei Jungen nur bezüglich des Zusammenhangs mit der Agency zeigte.

Diese Forschung erweitert das Verständnis der interpersonalen Dynamiken zwischen Lehrkräften und Schüler:innen, indem sie dyadische Verhaltensweisen auf den Dimensionen Agency und Communion beschreibt und die Annahmen der Zirkumplex-Struktur nutzt. Dementsprechend zeigte sich, dass das dyadische interpersonale Verhalten von Lehrkräften (1) in komplementären Mustern mit individuellen Charakteristika und Kompetenzen der Schüler:innen verbunden ist, (2) substanziell mit der mathematikbezogenen Angst während des Unterrichtens von Lehrkräften zusammenhängt und (3) mit der mathematikbezogenen Angst von Schüler:innen in Verbindung steht. Bemerkenswert ist, dass sowohl die Zusammenhänge mit den Lehrkraftemotionen als auch die Zusammenhänge mit den Schüler:innenemotionen signifikante Geschlechterunterschiede aufwiesen. Diese Ergebnisse tragen zum aktuellen Verständnis von Lehrkraft-Schüler:innen-Interaktionen bei, indem sie betonen, den Fokus auf dyadische Prozesse zu legen, um wechselseitige Einflüsse und das emotionale Zusammenspiel innerhalb von Klassenzimmern zu beleuchten. Dies hat kritische Implikationen für zukünftige Forschung und Bildungspraxis, um Verhaltensweisen zu identifizieren, die für Schüler:innen am lernförderlichsten sind, sowie welche Prozesse zu verstehen, die Lehrkräfte daran hindern, optimales Verhalten zu zeigen.

CHAPTER 1 – General Introduction

Classrooms are, at their core, interpersonal spaces. Every day, teachers and students come together and connect through countless small moments, such as helping with a tricky mathematical problem, sharing a success, or working through frustration. For teachers, this means engaging with dozens of students daily, each bringing their own background and emotional responses to learning. These exchanges go far beyond the delivery of curriculum; they shape the unique relationships between each teacher and student.

The significance of these teacher-student relationships for academic success is well-established, with John Hattie's recent sequel of his synthesis of over 2,100 meta-analyses (Hattie, 2023) demonstrating that teacher-student relationships rank among the most impactful classroom factors for student learning ($d = 0.62$). However, it is important to recognize that no two relationships are exactly the same, because each one is influenced by the individual characteristics, experiences, and needs of the teachers and students involved. This necessitates a focus on dyadic teacher-student interactions and relationships. Such a relational emphasis aligns with Bronfenbrenner's ecological systems theory (1979), which explains development as a result of ongoing interactions between an individual and their environment. In this framework, dyadic teacher-student interactions happen within the "microsystem", the immediate context that exerts the most direct and powerful influence on an individual child's learning and development (Bronfenbrenner & Ceci, 1994; Bronfenbrenner & Morris, 2007).

Despite extensive research on teacher-student interactions, most studies examine interactions between the teacher and the entire classrooms rather than individual relationships between specific teachers and students. This approach underemphasizes an important point: teachers form different bonds with each student, and these one-on-one interactions play an important role in shaping the classroom experience. This becomes especially critical when considering emotionally challenging situations or subjects. One of these subjects being mathematics (math), where, particularly at the primary level, both teachers and students experience anxiety and negative emotions that can significantly impact learning outcomes

(Barroso et al., 2021; Hembree, 1990; OECD, 2023). Since strong math skills developed in primary school form the essential foundation for future academic achievement and career opportunities (Duncan et al., 2007; S. Parsons & Bynner, 2005), gaining a clear understanding of the emotional dynamics within individual teacher-student relationships at this stage is vital for identifying factors that support or hinder student learning.

This dissertation aims to shed light on dyadic interactions between teachers and students by examining how teachers' interpersonal behavior (1) relates to students' behaviors and scholastic competencies, as well as (2) how these interactions connect to both teachers' and students' emotional experiences, particularly in relation to math anxiety. To answer these questions, I will draw on Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957), describing dyadic teacher behavior along two fundamental dimensions: communion (e.g., warmth, sensitivity) and agency (e.g., direction, guidance). The intersection of these dimensions creates a circumplex model that recognizes how interpersonal behavior emerges from combinations of both dimensions within a circular structure. This allows for a more fine-grained understanding of how teachers' interpersonal behaviors relate to students' behaviors and scholastic competencies as well as math anxiety in teachers and students.

In order to understand dyadic interactions between a teacher and a student, it is important to note that both actors mutually influence one another. Professional teaching standards require teachers to adapt their behavior to individual students' academic needs, typically providing more guidance to lower-achieving students and reducing guidance as competencies increase (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018; Tetzlaff et al., 2025). However, this might not be the only interpersonal adaptation that is occurring. By integrating the complementarity principle (Carson, 1969; Sadler et al., 2009) with research on adaptive teaching (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018; Tetzlaff et al., 2025), this dissertation seeks to better understand these mutual influences within the specific context of education.

Moreover, it is important to note that these interactions are often emotionally charged (Frijda & Mesquita, 1994; Van Kleef, 2016). Research suggests that teachers' behavior should be systematically related to emotions of both teachers (Frenzel, 2014; Frenzel et al., 2021) and students (Pekrun, 2006; Pekrun et al., 2023). This dissertation substantiates these propositions through the lens of Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) by investigating how specific configurations of agency and communion in dyadic interpersonal teacher behavior relate to both teachers' own experience of math anxiety in the teaching context and to students' experiences of math anxiety.

Methodologically, this dissertation advances previous research on teacher behavior by assessing interpersonal dynamics within dyads using both self-report and observational data. Moreover, the circumplex structure of interpersonal teacher behavior enables precise mathematical modeling and empirical testing of specific theoretical implications (Gurtman, 1991, 1992; Gurtman & Balakrishnan, 1998). This framework not only facilitates the assessment of teacher behavior itself but also allows for the examination of how specific configurations of agency and communion are associated with related variables, such as student behaviors, scholastic competencies, and both teacher and student math anxiety.

The dissertation is organized as follows: Chapter 2 outlines the theoretical foundation, exploring the importance of teacher-student relationships and introducing Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) and recent methodological advances in the Interpersonal Circumplex (Gurtman, 1991, 1992; Gurtman & Balakrishnan, 1998). It examines how the complementarity principle (Carson, 1969; Sadler et al., 2009) drives mutual influence between teachers and students, and situates teacher behavior within broader research on teacher (Frenzel, 2014; Frenzel et al., 2021) and student (Pekrun, 2006; Pekrun et al., 2023) emotions, with particular emphasis on math anxiety in primary education. Chapters 3-5 present the three empirical studies, and Chapter 6 synthesizes and discusses the findings across all studies, with implications for both theory and educational practice.

Teacher-Student Relationships and the Role of Teacher Behavior in Shaping Interpersonal Dynamics with Students

The significance of teacher-student relationships is well-documented in the academic literature. For example, a search in the scholarly database EBSCOhost yields 27,160 peer-reviewed articles (as of May 31, 2025) published within the last ten years containing the term *teacher-student relationship*, underscoring the sustained research interest in this topic. To gain a deeper understanding of teacher-student relationships, attachment theory offers an useful theoretical perspective (Ainsworth, 1989; Bowlby, 1969). Interactions in attachment relationships establish a child's so-called *working model* of social relationships. These working models consist of beliefs about the availability, responsiveness, and sensitivity of interaction partners, and also shape self-perceptions, such as self-worth and expectations of support in times of distress (Bretherton, 1985; N. L. Collins & Read, 1990). From a developmental perspective, teachers can serve as important, temporary attachment figures for children (Verschueren & Koomen, 2012). Teachers often function as a "secure base" and "safe haven", providing emotional support and comfort in times of need (Verschueren, 2015). A meta-analysis by Ahnert et al. (2006) further supports this view, demonstrating that teacher-child relationships can be conceptualized using the same attachment dimensions as parent-child relationships, highlighting their notable similarities. The most prominent model in teacher-student relationships is the model by Robert Pianta (Hamre & Pianta, 2001; Pianta, 1999; Pianta et al., 2003), which highlights three dimensions: closeness, conflict, and dependency. High-quality teacher-student relationships are characterized by high levels of closeness, along with low levels of conflict, and additionally, they involve minimal dependency, meaning students exhibit independence rather than clinginess or autonomy issues (Pianta et al., 2003). Numerous empirical studies, including meta-analyses, have confirmed the importance of these relational dimensions for student development. A recent second-order meta-analysis synthesizing the results of 26 prior meta-analyses substantiated these findings

(Emslander et al., 2025). These results demonstrate that teacher-student relationships play a crucial role in shaping student outcomes, influencing not only academic achievement but also emotional well-being, behavior, and cognitive development.

Positive teacher-student relationships are widely recognized as a cornerstone of effective teaching and learning, influencing students' academic achievement, emotional well-being, and social development (for reviews, see Burns & Van Bergen, 2025; Wentzel, 2022). A critical factor in building and maintaining these relationships is the teacher's behavior. Teacher behavior shapes students' perceptions of safety, belonging, emotional well-being, and engagement in the classroom (for reviews, see Burns & Van Bergen, 2025; Wentzel, 2022). According to the dynamic-systems approach (Granic & Hollenstein, 2003; E. O'Connor, 2010), teacher-student relationships develop through ongoing, repeated interactions. Through ongoing interactions, both teachers and students form mental representations of their dyadic relationship. These representations shape how each actor interprets and responds to future exchanges, reinforcing patterns of behavior and emotional tone within the relationship (Kenny & La Voie, 1984, 1984; Wubbels et al., 2014). But how exactly are these interactions structured? And how do they shape and reflect the emotional experiences of both teachers and students?

In educational research, there are several models that operationalize how a teacher behaves in the classroom (for an overview, see Opdenakker, 2023). Across different paradigms, two dimensions can be identified that underlie these constructs within those models: On the one hand, constructs emphasize *managerial-guiding* aspects—such as instructional support and classroom organization (in the Classroom Assessment Scoring System; Pianta & Hamre, 2009), classroom management (Ophardt & Thiel, 2017; Thiel & Ophardt, 2022), cognitive activation and content-focused constructive support (as aspects of teaching quality; Decristan et al., 2022; Fauth et al., 2014b; Klieme et al., 2009), and directiveness (in Self-Determination Theory; Aelterman & Vansteenkiste, 2023). On the other

hand, constructs highlight *social-emotional* aspects, including emotional support (Pianta & Hamre, 2009), social-emotional constructive support (Decristan et al., 2022; Fauth et al., 2014b; Klieme et al., 2009), and need-support (Aelterman & Vansteenkiste, 2023). The consistent emergence of managerial-guiding and social-emotional dimensions across diverse educational frameworks suggests these represent fundamental aspects of teacher behavior. However, these models typically focus on teacher interactions with the class as a whole, rather than with individual students, thereby overlooking the possibility that teacher behavior may vary across different students within the same classroom (for an exception, see supportive climate; Fauth et al., 2014b). The differentiation of interpersonal behavior into a managerial-guiding (agency) and social-emotional (communion) dimensions in dyadic interactions is reflected in Interpersonal Theory as a comprehensive psychological framework to describe interpersonal behavior in dyads (Horowitz & Strack, 2011; Leary, 1957).

Interpersonal Behavior in Dyadic Interactions

Interpersonal behavior, broadly understood as any overt, intentional, ethical, or symbolic action directed toward an individual, was systematically conceptualized by Timothy Leary (1957). In his seminal work, Leary (1957) introduced a foundational framework for describing personality through stable interaction patterns. For doing so, he developed a now widely recognized model to describe interpersonal behavior between two interaction partners. Interpersonal Theory (Horowitz & Strack, 2011; Leary, 1957) provides a theoretical framework to describe interactions between two individuals, such as a teacher and a student, and proposes that interpersonal behavior can be categorized along two key dimensions (Fabrigar et al., 1997; Horowitz & Strack, 2011): *Agency* refers to the degree of control, including aspects such as guidance, control, dominance, and activity-related support. *Communion* reflects the degree of affective involvement, encompassing warmth, social connectedness, and socio-emotional support. By crossing these two dimensions orthogonally, the dimensions form the basis of a two-dimensional circumplex space that describes

interpersonal behavior as a combination of both dimensions, the *Interpersonal Circumplex* (Gurtman, 1991, 1992; Gurtman & Balakrishnan, 1998).

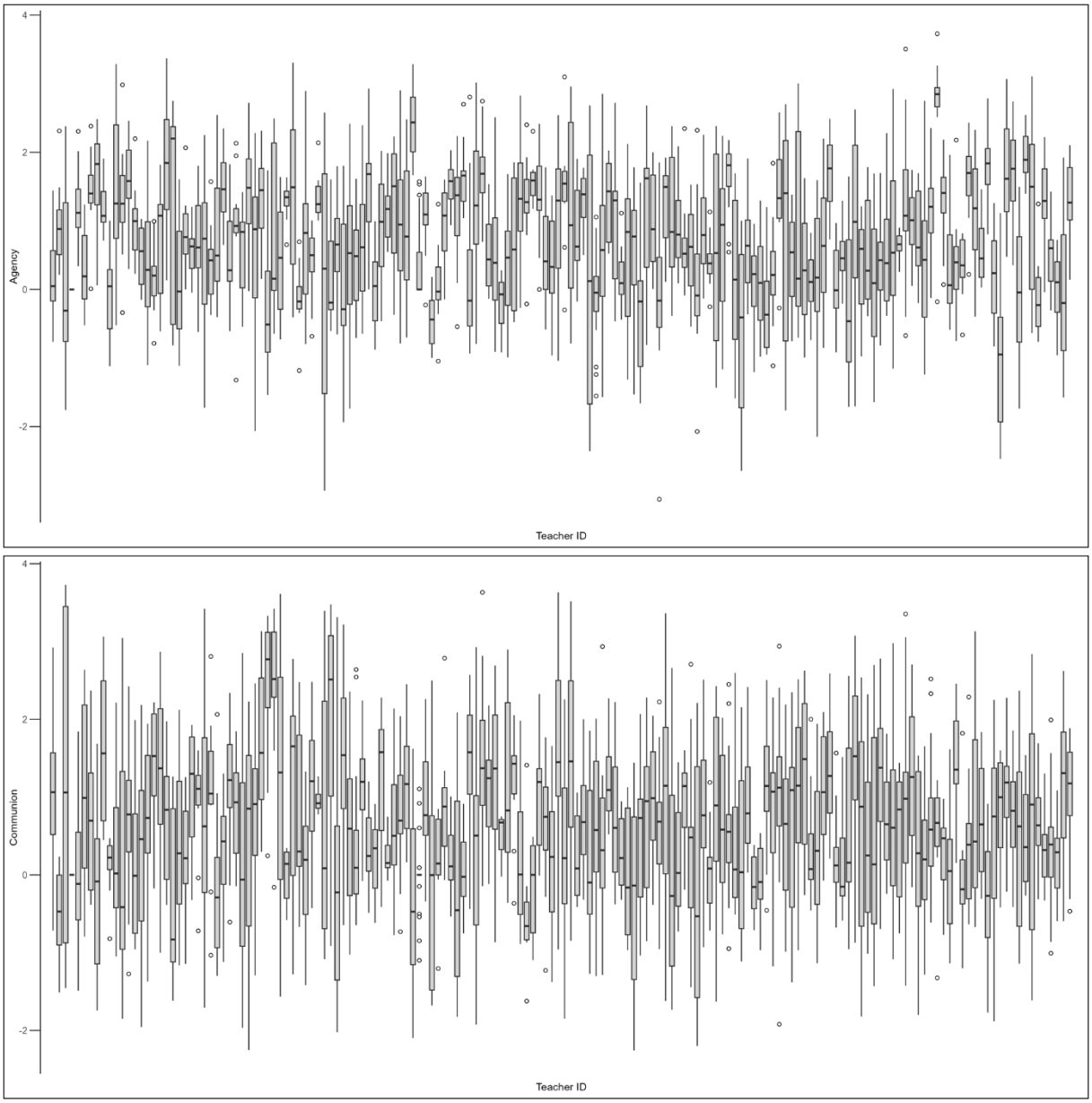
This model of interpersonal behavior has been further developed and applied in various psychological fields, including social and personality psychology (Wiggins, 2003; Wiggins et al., 1989), psychopathology (Wright et al., 2023), and, most importantly, also in educational psychology (Aelterman et al., 2019; Wubbels et al., 1993; Wubbels & Brekelmans, 2005). Research has shown that teaching styles described on the dimensions of agency and communion validly assess teachers behavior towards a class, and the authors were able to identify that these teaching styles systematically relate to students' academic outcomes (den Brok et al., 2004; Den Brok et al., 2023; Wubbels & Brekelmans, 2005). However, in any case interpersonal teacher behavior is assessed at the class level, overlooking the fact that teachers' interpersonal behavior varies across interactions with individual students. For instance, the Questionnaire on Teacher Interaction (QTI; Wubbels & Levy, 1991) assesses teaching styles with items such as "S/he is a good leader" for high agentic and moderately high communal styles, and "S/he is suspicious" for moderately low agentic and low communal styles. Similarly, the Situations in School Questionnaire (SiS; Aelterman et al., 2019) presents teachers with classroom scenarios, such as "The class period begins. You provide a clear, step-by-step schedule and overview" for high agentic/directive, low communal/need-supportive behavior, and "You don't plan too much. Instead, take things as they come" for low communal/need-supportive, low agentic/directive behavior. While both QTI and SiS measure teaching styles at the classroom level, they do not account for individualized teacher-student interactions. This approach limits the ability to examine dyadic interaction processes that depend on individual student characteristics.

According to Good and Brophy (1970), assessing teacher behavior at the class level relies on two violated assumptions: that interactions occur primarily between the teacher and the class as a whole, and that teachers behave consistently across all students. These

assumptions are particularly problematic in contemporary classrooms, where students from diverse backgrounds and with varying learning needs learn together (as also noted by Burns & Van Bergen, 2025). Figure 1.1 provides empirical evidence that teacher behavior varies among students within the same classroom. The figure displays boxplots of teacher agency and communion ratings for 162 German primary school teachers (for more information about this sample, see Study 2 of this dissertation) as described in relation to individual students in their respective classes. Each boxplot represents the distribution of ratings from a teacher, illustrating how that teacher's behavior differs across students in their class. The figure highlights two key patterns: first, that there is considerable within-teacher variation, indicating that teachers adapt differently depending on the student; and second, that the degree of this variation differs across teachers, suggesting individual differences in how consistently teachers interact with their students.

Figure 1.1

Distribution of Agency (Top) and Communion (Bottom) Scores Across Teachers

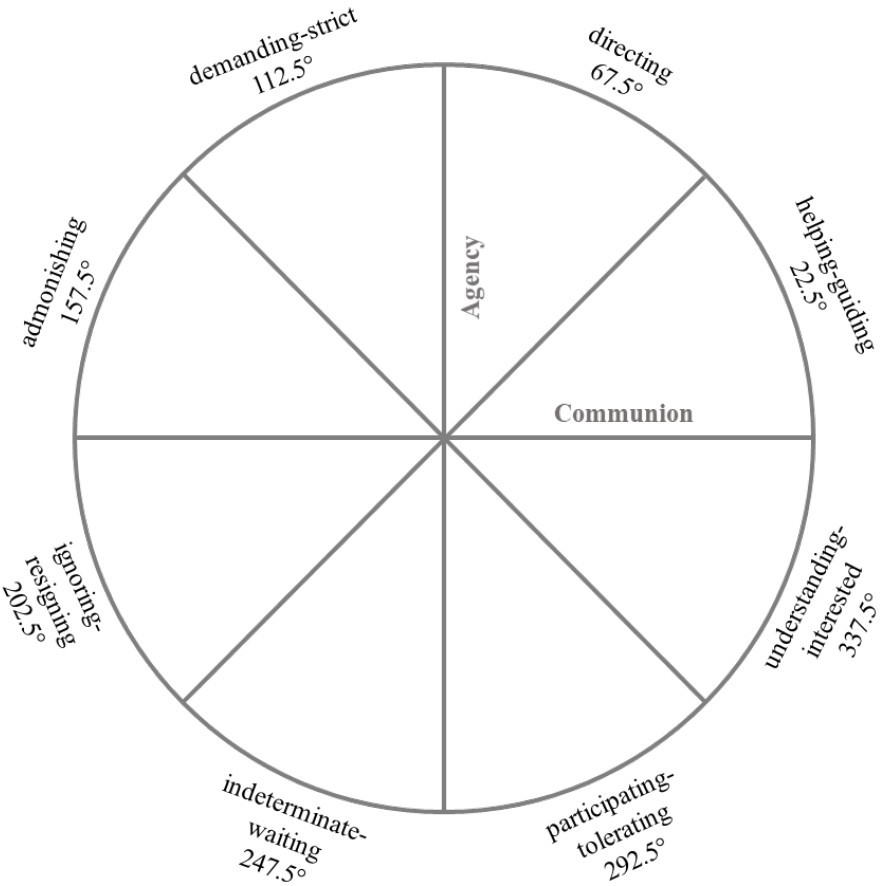


Note. A total of 162 teachers were asked to describe their interpersonal teacher behavior towards individual students from their class using the questionnaire on Dyadic Teacher Interpersonal Behavior (Kreutzmann et al., 2024). Agency and communion scores were calculated based on the underlying octant scores (for more information on score calculation see below or Gurtman & Pincus, 2003) and are depicted in the boxplots to illustrate variation within and between teachers.

To address this limitation, this dissertation utilizes the model on Dyadic Teacher Interpersonal Behavior (Hannover et al., 2022; Kreutzmann et al., 2024), which assesses teacher behavior towards individual students from their classroom, capturing interindividual differences and allowing for a more precise assessment of teacher behavior. This model reflects the Interpersonal Circumplex Model (Kiesler, 1996; Leary, 1957), conceptualizing interpersonal teacher behavior in dyadic interactions as a circumplex organized along two fundamental dimensions: agency and communion (see Figure 1.2). By intersecting the dimensions of agency and communion, the circumplex model generates eight distinct interpersonal behavior facets (octants) arranged around the circumference, each occupying a 45-degree angular span.

Figure 1.2

The Circumplex Model of Dyadic Teacher Interpersonal Behavior



Each octant represents interpersonal behavior as combinations of varying degrees of agency and communion (see Table 1.1), occupying a specific position in the interpersonal space: helping-guiding (high communion, moderately high agency), directing (moderately high communion, high agency), demanding-strict (moderately low communion, high agency), admonishing (low communion, moderately high agency), ignoring-resigning (low communion, moderately low agency), indeterminate-waiting (moderately low communion, low agency), participating-tolerating (moderately high communion, low agency), and understanding-interested (high communion, moderately low agency). There are three key advantages of this theoretical model: (1) it assesses interpersonal teacher behavior in dyadic interactions, (2) it describes teacher behavior as a combination of agency and communion, (3) the circumplex structure carries specific theoretical implications that can be empirically tested using precise mathematical models.

Table 1.1

Octant Descriptions of the Circumplex Model on Dyadic Teacher Interpersonal Behavior

Octant Label	Theoretical Position	Description	Sample Item
Helping-guiding	22.5° [0°- 45°]	In a warm, affectionate, and caring manner, the teacher provides clear structures for the child to orientate themselves.	*If X has difficulties solving a task, I am happy to show them step by step how to solve the problem.*
Directing	67.5° [45°- 90°]	In an appreciative manner, the teacher gives the child very precise instructions, monitors, and, if necessary, corrects each of their behavior.	*When I give assignments, I always check that X understands what they need to do.*

Table 1.1 (continued).

Demanding-strict	112.5° [90°- 135°]	The teacher does not address the child's interests or perspective in particular but rather gives very precise instructions, monitors, and, if necessary, corrects any of their behaviors.	*I require X to complete assigned tasks exactly as given.*
Admonishing	157.5° [135°- 180°]	The teacher has a distant, dismissive attitude towards the child and tries to guide and control the child's behavior through frequent admonitions.	*I do not give X too much leeway so that they do not ruin my lesson plan.*
Ignoring-resigning	202.5° [180°- 225°]	The teacher has a distant, dismissive attitude towards the child and turns to them only when it cannot be avoided.	*I teach the learning content according to plan, without letting X get in the way.*
Indeterminate-waiting	247.5° [225°- 270°]	The teacher is not concerned with the interests or the perspective of the child in particular but simply lets the child have their way.	*When X is working on tasks, I rarely interfere, they will be fine.*
Participating-tolerating	292.5° [270°- 315°]	In an appreciative manner, the teacher signals to the child that they can pursue their own interests and then simply lets them do so.	*I give X in particular a lot of freedom when learning.*
Understanding-interested	337.5° [315°- 360°]	In a cordial, attentive, and caring manner, the teacher creates freedom for the child to identify their interests.	*I particularly listen to X patiently and interested when they contribute something in class.*

Note. Octant descriptions are translated and adopted from (Hannover et al., 2022). Sample items are taken from Kreutzmann et al. (2024). In each case, "X" has to be replaced by an anonymized unique identifier allocated to each individual student in the class.

Apart from interpersonal behavior, circumplex models have been applied in many domains of psychological research, such as personality traits (e.g., Hofstee et al., 1992), affect (e.g., Russell, 1980), psychopathology (e.g., Wright et al., 2023), and vocational interests (e.g., Nagy et al., 2010; T. J. Tracey & Rounds, 1993). The methodological advantage of the circumplex extends beyond simply capturing interpersonal behavior along two dimensions. The circumplex structure has specific theoretical implications that are empirically testable through precise mathematical models (Guttman, 1954). This mathematical precision enables researchers to (1) validate and assess the underlying structure of the circumplex measure of interpersonal teacher behavior, (2) describe individual teacher behavior profiles, and (3) systematically examine associations with external variables (such as student competencies, teacher and student math anxiety), representing significant methodological advances in the study of interpersonal dynamics. As all analytical approaches are central to interpreting the results of the studies presented in this dissertation, they will be briefly outlined in the following chapter.

Methodological Advances in the Circumplex Structure

Testing the Circumplex Structure

As shown in the previous chapter, interpersonal teacher behavior reflects a blend of agency and communion (see Figure 1.2), requiring corresponding measurement and analysis methods that are utilized in this dissertation. The interpersonal circumplex model captures this through a geometric structure where each octant's position reflects a theoretically derived degree of agency and communion. Ideally, octants are equally spaced (45° apart) and equidistant from the center, indicating uniform behavioral intensity, a circulant circumplex. However, empirical data often diverge from this ideal, leading researchers to adopt quasi-circumplex models (Guttman, 1954), that allow slight deviations from a perfectly equidistant and equal-radii circumplex, while maintaining the circular structure. Moreover, the circumplex model imposes systematic constraints on the covariance structure between octants

(Browne, 1992; Fabrigar et al., 1997). Adjacent octants share similar behavioral characteristics, which results in higher correlations between them. For instance, behaviors high in both agency and communion, such as "directing" and "helping-guiding" (see Figure 1.2), are located in the upper-right quadrant. In contrast, octants positioned further apart display decreasing similarity.

This structured pattern of relationships leads to specific, testable predictions (for an overview, see Gurtman & Pincus, 2003). Adjacent octants are expected to be positively correlated. Octants that are orthogonal to one another, separated by 90 degrees, should show no correlation. Octants in opposite positions, separated by 180 degrees, should exhibit negative correlations. The correlation between any two octants can be mathematically expressed as the cosine of the angle separating them ($r_{ij} = \cos(\theta_i - \theta_j)$). For illustration, the correlation between "demanding-strict" and "directing", which should ideally be 45 degrees apart, is given by $\cos(45°) \approx 0.707$. The correlation between orthogonal octants is $\cos(90°) = 0$, and between opposite octants is $\cos(180°) = -1$.

As this dissertation utilizes a circumplex measure to assess teacher interpersonal behavior in self-report (Kreutzmann et al., 2024) and a newly developed observation tool (Study 1, Frühauf et al., 2025), I will investigate the empirical alignment with the circumplex structure. To this end, both exploratory (e.g., such as Principal Component Analysis, PCA), and confirmatory approaches based on structural equation modeling are applied (Fabrigar et al., 1997; Hopwood & Donnellan, 2010). PCA examines item loadings as Cartesian coordinates to locate the items in the two-dimensional space. The circular structure is evaluated through correlations between octants (see above), which ideally follow a cosine function of their angular distances. This is modeled through a Fourier series function (Stochastic Process Model for the Circumplex; Browne, 1992; Nagy et al., 2009), expressing correlations as a function of angular separation, while accounting for measurement error and enabling to test quasi-circumplex structures (see Studies 1, 2, and 3).

Thus, the structural validity of the proposed measure is evaluated in terms of its alignment with the expected circular configuration and associated correlational constraints of the circumplex model. The examination of the circumplex structure is of central importance, as this structural foundation underlies all subsequent analytical steps. The assumptions of the circumplex model do not apply solely to the relationships between octants but extend to intrapersonal behavioral profiles—that is, how individual persons (such as teachers) exhibit patterns of behavior across the circumplex octants. Furthermore, these assumptions are also relevant when examining the associations between individual behavioral profiles and external measures (such as teacher and student emotions and students' behavior).

Teacher Behavior Profiles

The circumplex structure also implies that the mean profile of a teacher across octants should exhibit a coherent structure: High scores in one octant (e.g., "understanding-interested") are accompanied by elevated scores in adjacent octants (e.g., "helping-guiding", "participating-tolerating") and lower scores in opposite ones (e.g., "admonishing", "strict-ignoring"). This creates a cosine-like pattern, with scores declining as distance from the dominant octant increases. To illustrate, Table 1.2 depicts a mean profile a teacher may have reported with regards to their behavior towards an individual student using the questionnaire on Dyadic Interpersonal Teacher Behavior (DITeB; Kreutzmann et al., 2024) that is used in Studies 2 and 3 of this dissertation. The full item set to this questionnaire can be found in the Appendix. The highest mean appears in the "understanding-interested" octant, with similarly high scores in adjacent octants and decreasing values in more distant octants—reflecting the expected cosine shape consistent with the circumplex model.

Table 1.2

Illustrative Mean Profile of a Teacher's Dyadic Behavior Toward a Student Using the DITeB

Octant Scale	Mean
1. Helping-guiding	6.3
2. Directing	4.9
3. Demanding-strict	3.1
4. Admonishing	2.3
5. Ignoring-resigning	3.9
6. Indeterminate-waiting	4.7
7. Participating-tolerating	6.4
8. Understanding-interested	6.8

Although such profiles may appear complex and capture a lot of information, they can be summarized with two approaches: summarizing the profile through a vector in the circumplex space (LaForge, et al., 1954; Wiggins et al., 1989) or through cosine-curve modeling (also known as Structural Summary Method, Gurtman, 1992; Gurtman & Balakrishnan, 1998).

Regarding the summary through a vector, axis scores have to be derived to obtain the polar coordinates in the circumplex space. For that, it is critical to note that each octant is defined by a known degree of agency and communion, determined by its angular position within the circumplex. Hence, the values derived from the sine and cosine of the octant's angle can be extracted and used to decompose a person's full profile into its underlying dimensions. Specifically, agency and communion scores for the dyadic interaction can be calculated by weighing the octant mean score S_i by the sine for the agency score and the cosine for the communion score of the octants' angular location θ_i and taking the sum:

$$AGscore = \frac{1}{4}\sum_{i=1}^{8}(sin\,(\theta_i)S_i) \tag{1.1}$$

$$COscore = \frac{1}{4}\sum_{i=1}^{8}(cos\ (\theta_i)S_i) \tag{1.2}$$

To correct for scale, the sum is multiplied by ¼ by convention (Gurtman & Pincus, 2003; LaForge, et al., 1954). These Cartesian coordinates can then be converted into polar coordinates that project the mean profile as a vector in the circumplex space. The angular location δ can be computed from the axis score as follows:

$$\delta = \tan^{-1}\left(\frac{AGscore}{COscore}\right) * \frac{180}{\pi} \tag{1.3}$$

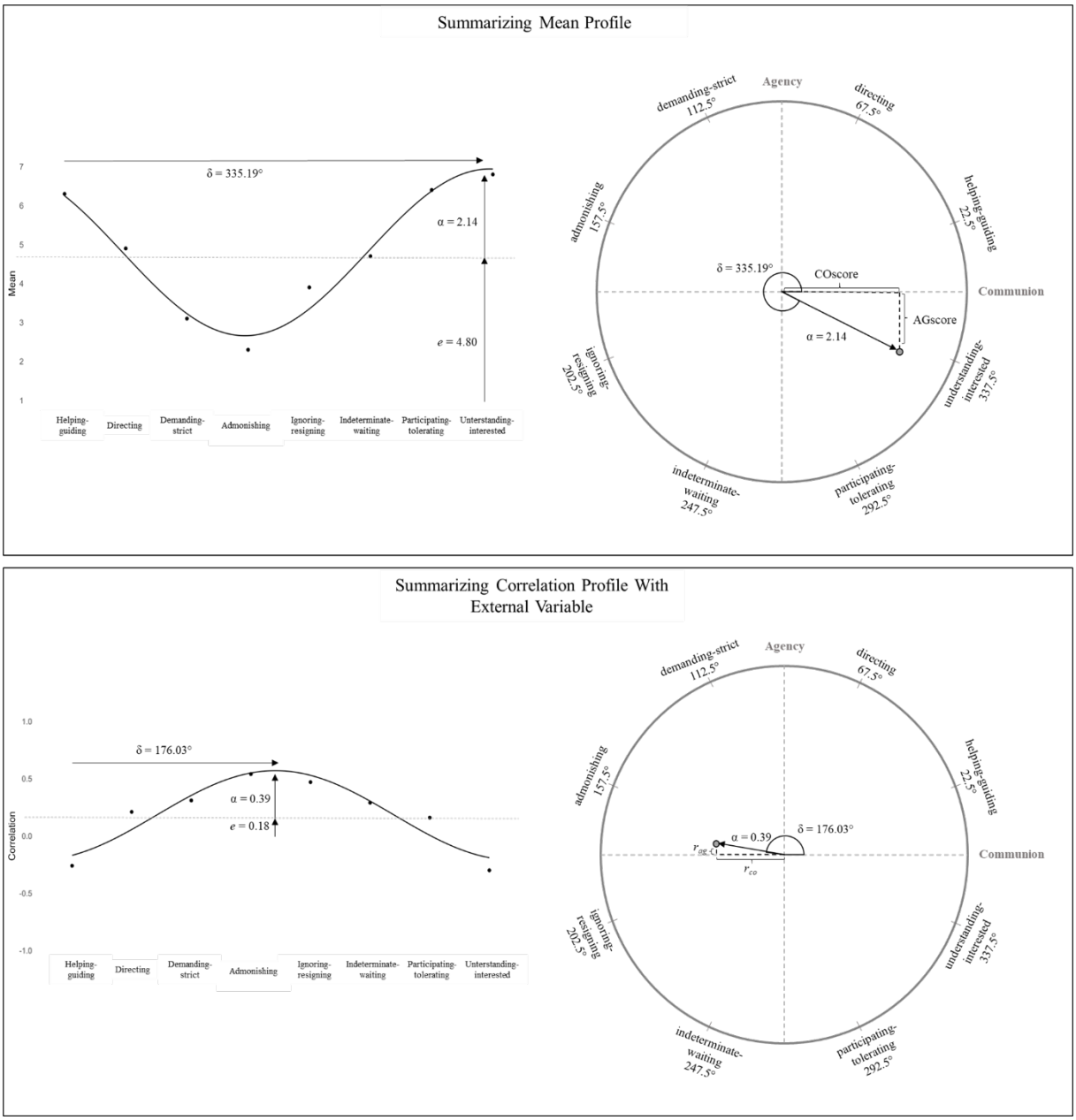
And the vector length (VL) follows from the Pythagorean Theorem:

$$\text{VL} = \sqrt{AGscore^2 + AGscore^2} \tag{1.4}$$

As illustrated in Figure 1.3 (top right), with regards to the mean profile illustrated in Table1.2, the angular location of the profile is 335.19° which points to the octant "understanding-interested". The angular location can be interpreted as the central tendency of the profile thus a person's vector angle can be understood in terms of their position along the two primary dimensions of the interpersonal domain (sometimes called the *predominant interpersonal theme*; Gurtman & Balakrishnan, 1998). The vector summarizing the interpersonal profile is pointing to the octant "understanding-interested" which was also the octant with the highest mean value (see Table 1.2). The length of the vector, which was 2.14, reflects the variability within the profile. A longer vector indicates more variation in the teacher's ratings, suggesting the teacher displays certain behaviors toward the student more than others. A key advantage of computing individual axis scores for each dyad in the dataset is that these scores can be treated as linear variables. This allows for their inclusion in standard correlation-based statistical procedures, such as linear regressions(for instance, see Junkuhn & Nagy, 2022; Warwas, Nagy, et al., 2009; Warwas, Watermann, et al., 2009). This methodological benefit is utilized in the present dissertation (specifically, in the supplemental analyses of Study 1 and in the main analyses of Studies 2 and 3).

Figure 1.3

Illustration of Summarizing Mean Profiles and Correlation Profiles with an External Measure Using Dimension Scores (Right) and Structural Summary Method (Left)



The cosine-shaped pattern of mean scores is accounted for in the Structural Summary Method (SSM; Gurtman & Balakrishnan, 1998; Gurtman & Pincus, 2003). The teacher's mean values (Table 1.2) are plotted in the top-left panel of Figure 1.3. This pattern of means

can be approximated by a cosine curve. Consequently, the profile scores can be mathematically represented as follows:

$$S_i = e + a * cos(\theta_i - \delta) + d_i \quad (1.5)$$

With S_i persons mean on the octant *i* and θ_i the octants angle, the elevation $e = 4.80$ being the mean level across all octants, the amplitude *a,* the distance from the mean value to the peak of the curve, showing the individual differentiation within a mean profile, which is equivalent to the vector length as computed above (see Equation 1.4). The angular displacement of the curve δ (the phase shift of the cosine curve) denotes the peak of the curve. As depicted in Figure 1.3 (top left), the SSM shows that the peak δ = 335.19° of the curve is placed at the octant "understanding-interested" and the amplitude is 2.14, shows that the means across octants substantially differentiate within the teacher's mean profile. Finally, d_i reflects the deviation of the structural components from the actual scores. Building on that, R^2 can be computed as a goodness-of-fit indicator reflecting how much the observed profile matches the cosine shape.

While the SSM provides a detailed structural summary of the profile's shape and fit to the model, axis scores offer a more direct, linear representation of behavior along the primary dimensions. Hence, the two representations are two complementary ways to summarize teachers' behavior profiles (Wright et al., 2009). Both approaches can also be used to assess how teacher interpersonal behavior associates with variables outside the circumplex.

Testing Associations of External Variables with Teacher Behavior

The circumplex framework can also be used to understand how interpersonal teacher behavior relates to external variables outside the circumplex octants. In this dissertation, these external variables are the student's behavior, scholastic competencies, and math anxiety as well as the teachers' math anxiety. Just like the mean profiles, the association of an external measure with the circumplex of dyadic teacher interpersonal behavior should also adhere to the structural propositions of the circumplex model and can be rigidly tested. To illustrate,

Table 1.3 shows a correlation profile that arises when correlation coefficients are computed between an external variable (such as student behavior, scholastic competencies, math anxiety, or the teacher's math anxiety) and each octant of interpersonal teacher behavior. Again, by visual inspection, it can be observed that the highest correlation can be found for the octant "admonishing" (see Table 1.3), correlations being similarly high for adjacent octants and then correlations further decreasing the further away the octant is, which again, reflects the structural pattern of the circumplex. This indicates that the external variable has a systematic relationship with the interpersonal behavior and thus has *interpersonal content* (Gurtman, 1991). This profile can also be summarized by a vector in the circumplex space or by a cosine curve.

Table 1.3

Illustrative Correlation Profile Between Teachers Dyadic Behavior and an External Variable

Octant Scale	Correlation With External Variable
1. Helping-guiding	-0.26
2. Directing	0.21
3. Demanding-strict	0.31
4. Admonishing	0.54
5. Ignoring-resigning	0.47
6. Indeterminate-waiting	0.29
7. Participating-tolerating	0.16
8. Understanding-interested	-0.30

The correlation profile can also be represented as a vector in the circumplex space (Gurtman & Pincus, 2003; Wiggins & Broughton, 1991), with the vector's angular location indicating which teacher behavior octant is most strongly associated with the external variable, while its vector length represents the degree of differentiation between associations, hence the overall effect size of the association with the circumplex. For computing this vector,

the association between the external variable and axis scores of agency (*AGscore*) and communion (*COscore*) are computed, resulting in two correlation coefficients, r_{ag} and r_{co} that serve as Cartesian coordinates in the circumplex space (Wiggins & Broughton, 1991).[1] These Cartesian coordinates can now be converted into polar coordinates to project the correlation profile as a vector into the circumplex space. The angular location of the vector δ can then be computed by substituting r_{ag} and r_{co} into Equation 1.2, in place of the original axis scores. Similarly, the VL can be determined using Equation 1.3, again replacing the dimension scores with the r_{ag} and r_{co}. As illustrated in Figure 1.3 (bottom right), in our example the vector points to 176.03°, indicating that the predominant profile lies in the "admonishing″ octant, which is also reflected in the highest observed correlation between the interpersonal teacher behavior and the external variable (see Table 1.3). The vector length of 0.39 reflects that the correlations differentiate between octants and that there is a substantial association between the external variable and the circumplex of dyadic teacher interpersonal behavior.

Just like the mean-profile, the correlation profile can also be summarized by a cosine curve using the SSM (Gurtman, 1992; Gurtman & Balakrishnan, 1998). Hence, similarly to the mean profile summary, the r_i, which is the correlation between each octant *i* and the external variable, can be expressed by the same formula in Equation 1.5. In this case, *e* reflects the average correlation across all octants, *a* captures how much the correlation of the construct with the circumplex differs across octants, and δ reflects the peak of the curve. Figure 1.3 (bottom left) illustrates the SSM parameters for the correlation profile.

[1] The associations between the axis scores and the external variable can not only be derived from simple correlations but also from a multiple regression model predicting the external variable by the agency and communion axis scores with the resulting regression weights b_{ag} and b_{co} serving as Cartesian coordinates. For simplicity, this illustration will only refer to simple correlations.

To summarize, the Interpersonal Circumplex (Gurtman, 1991, 1992; Gurtman & Balakrishnan, 1998) does not only provide a comprehensive theoretical lens to describe teacher-student interactions as a blend of agency and communion. This model also provides rigorous ways to test the circumplex model's assumptions that apply to validating the underlying structure of circumplex measures of teacher behavior, describing and summarizing individual teachers' behavior profiles, and examining associations with external variables outside the circumplex. This represents significant methodological advances in the study of interpersonal dynamics.

Observational Tools to Assess Interpersonal Teacher Behavior

As outlined in the previous chapter, the Interpersonal Circumplex (Gurtman & Balakrishnan, 1998) provides a valuable framework for describing interpersonal teacher behavior in dyadic interactions. One instrument developed to operationalize this framework is the DITeB questionnaire (Kreutzmann et al., 2024), a validated measure capturing teacher behavior from the teacher's perspective within the circumplex model.

However, while self-report measures provide important insights, research on classroom processes increasingly incorporates observational methods (Turner & Meyer, 2000). Incorporating observational perspectives offers key methodological advantages over self-reports. Observations reduce recall inaccuracy, which occurs when teachers inaccurately remember or reconstruct past behavior (Robinson & Clore, 2002; Thomas & Diener, 1990), and mitigate social desirability bias, where teachers may report behaviors that align with perceived professional norms rather than their actual conduct (Wubbels et al., 1992). By relying on trained external raters, observational methods provide a more objective, context-sensitive, and ecologically valid assessment of classroom interactions (Clausen, 2002; Fauth et al., 2014a). Although some instruments allow for live classroom observation (Curby et al., 2016), the majority require video recordings of lessons, making the process time- and resource-intensive.

With regard to the observation of interpersonal teacher behavior that is described on the dimensions of agency and communion, two observational approaches exist. One approach uses bipolar rating scales (Roorda et al., 2013; Thijs et al., 2011) along the dimensions of dominance–submission, reflecting teacher agency, and cooperation–opposition, reflecting teacher communion. For example, teacher agency was rated on a six-point scale ranging from passive, uninvolved behavior to controlling, authoritarian behavior (Roorda et al., 2013). The second approach is the Continuous Assessment of Interpersonal Dynamics (CAID; Donker et al., 2020, 2025; Lizdek et al., 2012; Mainhard et al., 2012; Pennings et al., 2014), in which trained observers use a joystick to position the teacher's behavior in the Circumplex space. This coding occurs continuously (e.g., every 0.5 seconds) and assigns agency and communion coordinates ranging from –1000 to 1000 (Lizdek et al., 2012), allowing for near-continuous assessment of teacher behavior. However, both approaches share a key limitation: they yield only single values per time point along the agency and communion dimensions, rather than assessing the behavior in an octant model. This format prevents direct assessment of the circular structure implied by the circumplex model. As a result, these observational assessments differ substantially in their structure from their corresponding self-report measures (such as the DITeB; Kreutzmann et al., 2024; or the QTI; Wubbels et al., 1993), which categorize behavior into octants. Consequently, these measurement differences may account for inconsistencies between results obtained from observational methods and those from self-report assessments (Donker et al., 2021).

Moreover, continuous coding procedures such as CAID are highly time- and cost-intensive, requiring specialized computer equipment and making them unsuitable for real-time classroom observations. Therefore, in Study 1 of this dissertation, I introduce and validate an observational tool that can be used by trained raters to assess dyadic interpersonal behavior on Likert-scale ratings. Each item is assigned to a specific octant in the circumplex model and is closely aligned with the corresponding items in the self-report measure (Kreutzmann et al.,

2024). For example, an observational item representing the "helping–guiding" octant is: "The teacher willingly shows the student step by step how to solve a problem when difficulties arise" (Study 1; Frühauf et al., 2025). The corresponding self-report item is: "If the student has difficulties solving a task, I am happy to show them step by step how to solve the problem" (Kreutzmann et al., 2024).

Accordingly, this dissertation does not solely rely on teacher self-reports (Studies 2 and 3) but also introduces an observational instrument in Study 1 that: (1) closely mirrors the item formulations of the self-report scale, (2) assesses teacher behavior across circumplex octants, thereby permitting circular data analysis, and (3) can be used in live-classroom settings without requiring specialized hardware.

Building on the theoretical and methodological considerations outlined above, the following paragraphs will address how Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) and the circumplex model of dyadic interpersonal teacher behavior (Hannover et al., 2022; Kreutzmann et al., 2024) in particular can be utilized to understand classroom processes. In particular, I will examine how dyadic interpersonal teacher behavior dynamically relates to student behavior and characteristics and how it is associated with both teachers' and students' math anxiety.

How Teacher Interpersonal Behavior Adapts to Students' Behavior and Characteristics

Many theories in teacher-student interaction research posit that the behaviors of teachers and students are reciprocally related (for an overview, see Trauernicht et al., 2025). However, these theories often underemphasize the significance of students' competence levels, even though according to professional standards of teaching (e.g., adaptive teaching S. A. Parsons et al., 2018), this should be a central factor in gearing teacher behavior to students' needs. This consideration marks a key distinction between teacher–student interactions and naturally occurring interactions between individuals in other contexts. To address this gap, this dissertation integrates assumptions from interpersonal complementarity (Carson, 1969;

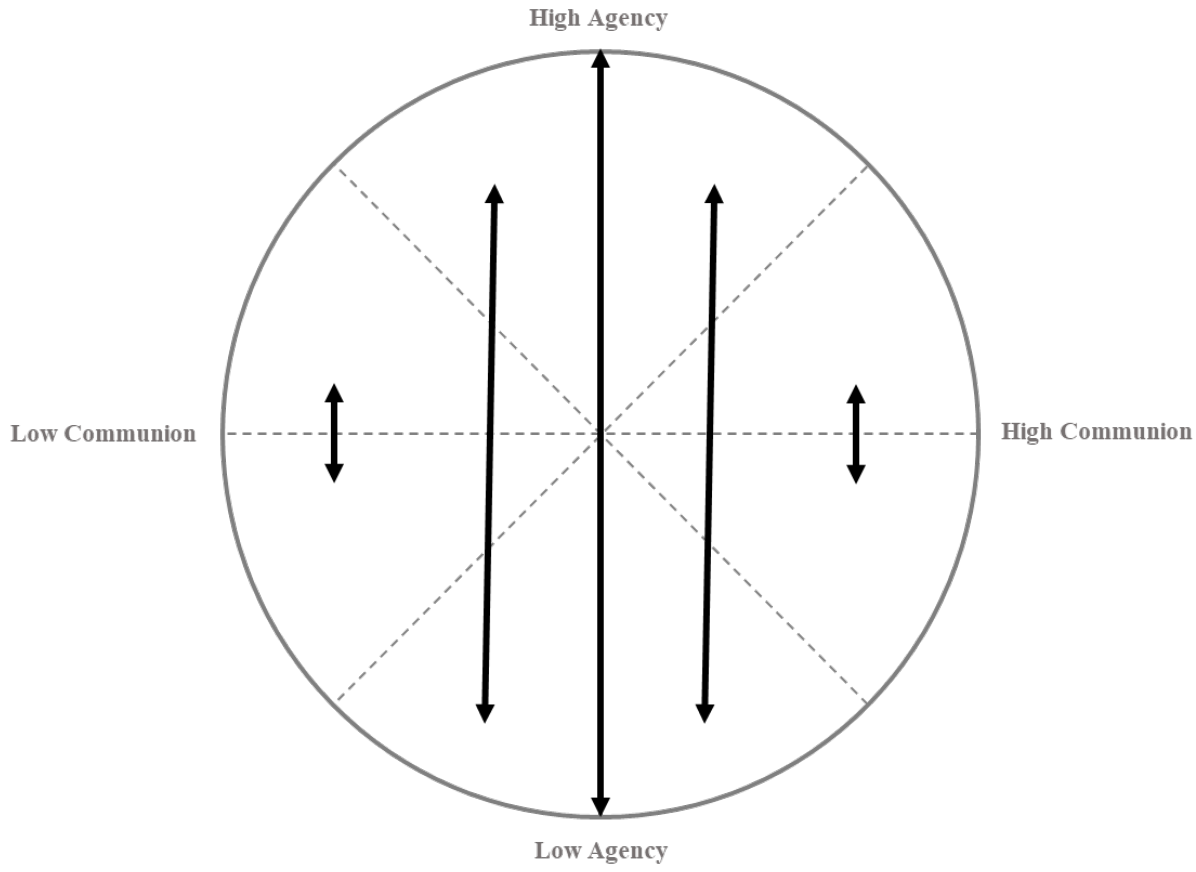
Sadler et al., 2009) with key propositions from research on adaptive teaching (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018).

When considering interpersonal interactions outside of the school context, Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) not only describes patterns of interpersonal behavior but also makes predictions about how individuals mutually influence each other within interactions. A central concept of this theory is the complementarity principle (Carson, 1969; Sadler et al., 2009), which posits that interpersonal behaviors tend to elicit specific, patterned responses from the interaction partner. When two individuals interact, they adapt their behaviors in predictable ways: warm and affective behavior in one person typically evokes similarly affiliative responses in the other person, thus maintaining sameness in communion (correspondence of communion). In contrast, high degrees of agency often elicit more submissive or yielding responses, thereby creating oppositeness in agency (reciprocity of agency). As illustrated in Figure 1.4, a certain degree of communion in one actor "pulls" the same degree of communion in the other person, while a certain degree of agency elicits oppositeness of agency in the other person. For instance, behavior of one actor that is allocated to the bottom left (low agency, low communion) quadrant is likely to be responded to with behavior that is allocated in the top left quadrant (high agency, low communion).

In educational contexts, this suggests that when teachers display warmth and support, students are likely to reciprocate with similarly affiliative behaviors—and vice versa. Conversely, directive or controlling teacher behaviors may provoke passivity and disengagement in students—and vice versa. These dynamics have been well documented in empirical studies on teacher-student interactions (Mainhard et al., 2012; Pennings et al., 2014, 2018; Roorda, Spilt, et al., 2017; Thijs et al., 2011). However, this view overlooks that the degree to which a teacher is agentic towards a student also depends on level of academic competencies of the respective student.

Figure 1.4

Illustrating Interpersonal Complementarity



Note. Figure by the author, based on Kiesler (1983).

According to professional standards, the students' skill levels should significantly shape the degree of support teachers provide, as well as the extent to which students can or are expected to take initiative. Although warmth and emotional support are generally associated with positive student outcomes (Emslander et al., 2025), effective teaching also requires that instruction be attuned to students' cognitive and developmental characteristics (S. A. Parsons et al., 2018).

A substantial body of research has examined how teachers adapt their instructional behaviors in response to individual student needs, a concept commonly addressed within the framework of adaptive teaching (Bernard et al., 2019; Carson, 1969; Hardy et al., 2019). In

line with this, teachers are required to continuously adapt their teaching to meet a wide range of learning needs. According to Corno (2008), teachers implement adaptations at two distinct levels: macro-adaptations, which encompass long-term modifications to instructional design, and micro-adaptations, which are spontaneous, situational adjustments made during interactions with students—often encompassing interpersonal teacher behavior. Building on this, the concept of aptitude-treatment interaction (Cronbach & Snow, 1977) suggests that the effectiveness of instructional interventions depends on the alignment between teaching methods and individual learner characteristics. In other words, instructional strategies should be tailored to fit student aptitudes. A more specific illustration of this is the *expertise reversal effect* (Kalyuga, 2007), which highlights that novice learners typically benefit from more structured guidance, whereas advanced learners tend to thrive under conditions of reduced support (for meta-analysis, see Tetzlaff et al., 2025). However, these theoretical frameworks oftentimes overlook the interpersonal processes that underlie the reciprocity of teachers' behavior with students' scholastic competencies. Reappraising the expertise reversal effect (Kalyuga, 2007) within the propositions of interpersonal theory, this notion resonates with the complementarity principle (Carson, 1969; Sadler et al., 2009), particularly its assumption of reciprocity in agency to learner needs. This is addressed in Study 1 of this dissertation.

How Interpersonal Behavior and Emotions are Intertwined

In academic settings, not only are the behaviors of two interacting individuals interrelated, but their emotions are also closely linked to these behaviors. Emotions and behavior influence each other in multiple ways. Shared neural circuitry processes both emotional and social information, with key brain regions, collectively known as the *social brain* (Blakemore, 2008; Dunbar & Shultz, 2007; Porcelli et al., 2019), supporting emotional and interpersonal functions simultaneously.

Emotions serve as a dynamic interface between individuals and their environments, consisting of coordinated patterns of neural and physiological responses (Scherer & Moors,

2019). This multi-component system includes action tendencies, facial and gestural expressions, and subjective experiences (Scherer & Moors, 2019). The inherently social nature of emotions has been extensively recognized in emotion theories (Frijda & Mesquita, 1994)[2]. In particular, the Emotion as Social Information framework (EASI; Fischer & Van Kleef, 2010; Van Kleef, 2009, 2016) posits that emotional expressions serve as cues that trigger inferential processes and emotional reactions in others, ultimately shaping their behavior and emotional states. Importantly, emotional expressions may not always be straightforward. Emotions can be conveyed not only through facial expressions but also through behavior, which may need inferential processing to decode the underlying emotional information. For example, if a teacher frowns while simultaneously exerting strong control by providing highly specific instructions, the student may perceive conflicting cues. The frown may signal dissatisfaction, and the detailed guidance might suggest that the previous response was inadequate or that the teacher has low expectations regarding the student's ability to solve the task independently. This highlights the importance of considering the behavioral context in which emotions are expressed and how this context shapes the emotional responses of others. This is especially relevant for negative emotions, such as anxiety, which tend to be less expressive (Marx et al., 2025) and are often socially discouraged from being openly displayed (Stark & Bettini, 2021).

[2] Even in the early foundational work by Leary (1957) has acknowledges that behavior can serve as an expression of emotion or elicit emotions in others. For instance, the Interpersonal Adjective List (Wiggins, 1979; Wiggins et al., 1988) includes adjectives such as "timid", "softhearted", "kind", "ruthless", "ironhearted", "cheerful", and "enthusiastic"—all of which carry clear emotional valence and are capable of expressing or evoking emotions in oneself or others.

In dyadic interactions between teachers and students, emotional interdependence can occur through multiple mechanisms. One way is through direct emotional transmission, often called emotional contagion (Hatfield et al., 1994), which involves the automatic imitation and synchronization of facial expressions, vocal tones, body language, and movements with another person, leading to shared emotional experiences. Beyond direct transmission, the interpersonal process plays a crucial role in the emotional dynamic in the classroom. At first, teachers constantly regulate their emotions through their instructional behavior (for a review, see Aldrup et al., 2024). Secondly, a teacher's behavior can also serve as an environmental aspect influencing a student's appraisal and emotions in the classroom setting (Pekrun, 2006).

Building on this, the dissertation aims to illuminate these interpersonal dynamics of emotional interdependence through the lens of interpersonal theory, focusing on how they manifest in specific emotional contexts that are especially relevant in educational settings, such as math anxiety.

The Special Case of Math Anxiety in Primary Education

Developing mathematical competencies, especially in primary school, is crucial for academic success and broader life outcomes. While high math competencies supports educational and professional achievement, low competencies are associated with increased risks of dropout, unemployment, and even mental health issues (Duncan et al., 2007; S. Parsons & Bynner, 2005). As such, fostering mathematical competencies is a central educational objective. However, in Germany, declines in math performance are observed in large-scale assessment studies at both primary and secondary levels (Diedrich, Reinhold, et al., 2023; Selter et al., 2024), highlighting the importance of identifying factors that hinder math learning. One such factor is math anxiety.

Math anxiety is commonly defined as feelings of fear, tension, or apprehension when engaging with math-related tasks (Ashcraft, 2002; Hembree, 1990; Putwain & Wood, 2023), which is typically linked to achievement settings but can also go beyond and play out in daily

situations (such as managing daily finances). Thus, it differs from general test anxiety that is only experienced in test situations (Caviola et al., 2022; Kazelskis et al., 2000). It is one of the most widely studied emotions in math education (Cipora et al., 2022; Putwain & Wood, 2023; Schoenherr et al., 2025)—and for good reason: Different meta-analyses repeatedly report a negative link between students' math anxiety and their math achievement (Barroso et al., 2021; Ma, 1999; Namkung et al., 2019). Regarding the causal direction of this relationship, two different mechanisms are discussed in the literature: On the one hand, poor performance in math can lead to increased math anxiety. On the other hand, math anxiety itself can have a blocking effect, consuming cognitive resources and thereby reducing mathematical competencies in performance or learning situations (for an overview, see Ramirez, Shaw, et al., 2018). Relatedly, math anxiety is linked to lower self-concepts (e.g., Ahmed et al., 2012), avoidance of math-related activities and in-depth engagement with math tasks (Choe et al., 2019; Quintero et al., 2022; Y. Wang et al., 2025), and lower participation in STEM fields (Ahmed, 2018; Daker et al., 2021). Furthermore, math anxiety is an emotion that often emerges in early childhood (Ramirez et al., 2013; Vukovic et al., 2013) and typically persists throughout an individual's entire academic trajectory and beyond (Barroso et al., 2021; Hembree, 1990). Notably, teachers are also affected by math anxiety, with primary school teachers being particularly strongly impacted (Artemenko et al., 2021; Hembree, 1990; Porsch, 2017).

Although this topic is important, the connections between teacher and student math anxiety and teachers' interpersonal behavior have been largely overlooked. Most previous research has focused on how teacher behaviors at the classroom level relate to students' and teachers' general emotional experiences, without focusing on specific subjects (Donker et al., 2020; Mainhard et al., 2018). However, emotions in both teachers and students are often highly subject-specific (Frenzel et al., 2015; Goetz et al., 2007, 2010; Kunter et al., 2011). This subject specificity is especially relevant in math, which tends to provoke stronger

negative emotions compared to other school subjects (Goetz et al., 2007; Sparfeldt et al., 2016).

The investigation of math as a domain is also particularly important due to its gendered implications, which begin to emerge as early as primary education. Findings regarding gender differences in math performance are mixed and seem to vary depending on cultural and national contexts (Else-Quest et al., 2010; Lindberg et al., 2010; for recent PISA results, see OECD, 2023). In Germany, recent results from the 2023 Trends in International Mathematics and Science Study (TIMSS) indicate that gender differences in math achievement continue to be present at the primary school level (Nonte et al., 2024). Notably, trend analyses from 2007, 2019, and 2023 show no significant change in the size of these differences over time (Nonte et al., 2024), suggesting that the gender gap has remained stable rather than narrowing, highlighting the persistence of gender-based disparities in early math education. Math is often socially constructed as a male-dominated field (Nosek et al., 2002), which contributes to the perception among women and girls that the subject is misaligned with their gender identity (Eccles, 1987; Hannover & Kessels, 2004; Kessels et al., 2014; Nosek & Smyth, 2011; Steffens et al., 2010; Steffens & Jelenec, 2011). As a result, they tend to have lower expectations of success in math (for meta-analysis on self-efficacy, see Huang, 2013), and have lower intrinsic value about the subject (Ganley & Lubienski, 2016; Gaspard et al., 2015; J. E. Jacobs et al., 2002). This in turn contributes to girls and women across all age levels reporting more math anxiety as compared to their male counterparts (Artemenko et al., 2021; Frenzel et al., 2007a; Ramirez et al., 2013; Vos et al., 2023). These gender differences are particularly concerning, as they are already evident at the primary school level, not only among students (Ramirez et al., 2013) but also among their teachers (Artemenko et al., 2021).

Despite the clear evidence of gendered emotional experiences in math, research has yet to systematically examine whether the associations between teacher math anxiety, teacher

behavior, and student math anxiety are also gendered. To address this gap, this dissertation explores the role of gender in two ways: (1) the association between teacher math anxiety and their interpersonal behavior (Study 2), and (2) the link between teacher interpersonal behavior and student math anxiety (Study 3).

Math Anxiety in Primary School Teachers

While the detrimental impact of math anxiety on student achievement has been well-documented, comparatively less attention has been paid to the fact that teachers themselves can experience math anxiety, both as learners and as educators. Recent studies reveal that math anxiety is particularly common among primary school teachers (Artemenko et al., 2021; Hughes et al., 2019) and may be partly attributed to educational systems, such as Germany's, where teachers are expected to teach math regardless of their own confidence or proficiency in the subject (Artemenko et al., 2021; Porsch, 2017). Furthermore, math anxiety is especially common among female primary school teachers (Artemenko et al., 2021; Beilock et al., 2010), who constitute approximately 89% of the primary education teachers in Germany (Statistisches Bundesamt [German Federal Statistical Office], 2024). Further, studies highlight that math anxiety in teachers might negatively relate to lower student achievement (Beilock et al., 2010; Ramirez, Hooper, et al., 2018; Schaeffer et al., 2021) or even to students themselves experiencing math anxiety (McLean et al., 2023).

Importantly, teacher math anxiety is not limited to performing math; it also encompasses anxiety specific to teaching math. This form, often referred to as math teaching anxiety (Ganley et al., 2019; Hadley & Dorward, 2011; F. Liu, 2016; Peker, 2009), involves worry or tension related to explaining mathematical concepts, solving problems in front of students, or responding to unexpected questions. To better understand the emotional experience underlying math teaching anxiety, appraisal theory offers a useful framework (Frenzel, 2014; Frenzel et al., 2020; Lazarus, 1991). Accordingly, (math) anxiety in the teaching context arises when the personal goal of appearing competent while delivering an

effective and engaging math lesson feels threatened. More specifically, teachers may appraise a (complex) math-related teaching situation as conflicting with their professional goals of appearing competent (also referred to as *goal congruence*; Frenzel, 2014), as obstructing rather than supporting their success (*goal conduciveness*), as highly significant to their sense of competence and professional identity (*goal relevance*), as failures for which they are personally to blame (*responsibility for goal attainment*), and as challenges they feel poorly equipped to manage (*coping potential*).

Relationship between Teacher Math Anxiety and Teacher Interpersonal Behavior

Frenzel et al.'s model on teacher emotions and their implications for student outcomes highly emphasizes that teacher emotions affect the classroom context, apart from direct transmission, through the teacher's behavior (Frenzel et al., 2021). Of particular importance is the fact that teachers do not express all emotions verbally and facially to the same extent. In the professional context of teaching, they have a clear understanding of which emotions are appropriate to display and which are institutionally discouraged, commonly referred to as display rules (Rafaeli & Sutton, 1989). As a result, teachers may employ various strategies to avoid directly expressing certain emotions in order to adhere to these professional norms. This regulation of emotional expression in the workplace is known as emotional labor (Keller et al., 2014; Taxer & Frenzel, 2015). Especially the expression of negative emotions, such as anxiety, is perceived by teachers as not conforming to their role and thus teachers agree on the norm that these emotions should not be expressed, with female teachers being particularly aware and feeling more constrained by these organizational norms (for a review see Stark & Bettini, 2021). Consequently, it is especially important to consider the specific action tendencies that may manifest in teachers' interpersonal behavior as a response to their emotional experiences (Gable & Impett, 2012). While research has demonstrated how positive emotions are displayed by teachers and how they play out in the instructional behavior (Burić

& Frenzel, 2023; Frenzel et al., 2025; Keller et al., 2016), less is known about the interpersonal consequences of negative emotions like math anxiety.

According to Fredrickson's broaden-and-build theory (Fredrickson, 2001, 2013), enjoyment broadens attention and fosters flexible thinking, thereby enhancing teaching quality and creative teaching approaches that meet students' needs. In contrast, negative emotions like anxiety require regulation to maintain professional conduct, which can drain cognitive resources and lead teachers to rely on traditional methods, avoid open student exploration, or adhere rigidly to the lesson plan or learning materials. This effect on specific instructional strategies is also supported by empirical evidence showing that math anxious teachers are likely to adopt traditional, teacher-centered approaches over student-centered methods, often avoiding practices such as open-ended problem solving, peer collaboration, and student-led discovery (Bush, 1989; Hadley & Dorward, 2011; Hughes et al., 2019). However, these empirical studies tend to concentrate on isolated, class-level instructional strategies, and it remains unclear how these strategies influence the overall quality of interpersonal interactions between teachers and students. Furthermore, existing research has not adequately explored potential gender differences in this association, despite documented gender disparities in both math anxiety (Artemenko et al., 2021) and adherence to emotional display rules (Stark & Bettini, 2021). This gap in the literature warrants further investigation into how math anxiety differentially affects teachers' interpersonal behavior across genders. These gaps in the literature are addressed by Study 2 of this dissertation.

Math Anxiety in Primary School Students

As already noted, math anxiety plays a critical role in school students' mathematical proficiency, which has also been emphasized by the recent PISA results. According to PISA 2022, about 25% of the variance in adolescent math performance across countries can be attributed to differences in math anxiety levels (OECD, 2023). In Germany specifically, PISA 2022 results reveal a concerning trend: over the past decade, interest and motivation in math

among adolescents have significantly decreased, while math anxiety has significantly increased (Diedrich, Platzl, et al., 2023). The detrimental effect of math anxiety on students' math achievement has been demonstrated by various meta-analyses (Barroso et al., 2021; Ma, 1999; Namkung et al., 2019). As research attention has increasingly focused on math anxiety in early school years, a recent meta-analysis has confirmed that the significant association between math achievement and math anxiety is also evident in the primary school years (Barroso et al., 2021), a critical period when foundational math skills are developed and students rely heavily on their teacher's guidance and support (Jerome et al., 2009; E. O'Connor, 2010).

To better understand the developmental mechanisms through which math anxiety emerges and persists in primary school settings, control-value theory (Pekrun, 2006, 2024; Pekrun et al., 2023) offers a comprehensive theoretical framework that explains how students' perceptions and appraisals contribute to academic emotions. Accordingly, math anxiety represents a negative, activating, prospective achievement emotion tied specifically to mathematical achievement situations (Pekrun, 2006, 2024; Pekrun et al., 2023; Putwain et al., 2021). The theory posits that (math) anxiety stems from two key appraisals (Pekrun & Stephens, 2010): a low perception of subjective control over the mathematical achievement situation, such as doubts about one's own competencies, and a high value attributed to the situation, for example, a strong desire to avoid failure. To effectively support students at risk for math anxiety, it is essential to understand how teacher behavior contributes to its development and reinforcement.

Relationship between Teacher Interpersonal Behavior and Student Math Anxiety

A teacher's behavior can function as an environmental factor influencing students' emotions. The appraisals of control and value leading to anxiety depend not only on students' individual characteristics but also on their environment (Pekrun, 2006; Pekrun et al., 2023), with research emphasizing the importance of teachers as a critical environmental factor in

math anxiety development (for a review, see O'Hara et al., 2022). According to control-value theory (Pekrun, 2006; Pekrun et al., 2023), the student's perception of classroom instruction provides information about the controllability and value of these situations. Accordingly, both instructional, task-related aspects (such as clarity, difficulty, cognitive stimulation, and discussion) and social-emotional aspects (such as rapport or enthusiasm) are related to students' appraisals and resulting emotions (Pekrun et al., 2023). For instance, when a teacher displays frustration while explaining mathematical concepts or demonstrates impatience with student questions, these behaviors may signal to students that the material is difficult and success is unlikely, potentially diminishing their sense of control.

Hence, a teacher's behavior can function as social information for the observing students (Van Kleef, 2009, 2016). The model of social referencing (Bandura, 1992; Feinman, 1982) helps explain how teachers' dyadic behavior might influence student math anxiety. In uncertain situations, students look to teachers for social cues to evaluate the situation. Students orient themselves to the teacher's reaction, using non-verbal and affective information to assess whether a situation is threatening or non-threatening. The two anchoring axes of interpersonal behavior (Horowitz & Strack, 2011; Leary, 1957), teacher agency and communion, may significantly contribute to students' perceptions of controllability and value. To illustrate, a teacher that exhibits an understanding-interested (high communion, moderately low agency) interpersonal behavior conveys confidence and trust in the student, thereby fostering a perception of controllability and increased expectation of success. Conversely, an admonishing (low communion, moderately high agency) teacher may be perceived by the student as lacking trust in their abilities and being dissatisfied with their performance, which can foster a sense of low controllability and an increased expectation of failure. However, there is no clear evidence on how agency and communion in interpersonal behavior relate to students' appraisals and their consecutive math anxiety.

Current findings regarding the relationship between teacher behavior and math anxiety are derived from disparate research paradigms and typically focus on class-level teacher behavior rather than examining how dyadic teacher-student interactions relate to individual students' math-related emotions. This approach yields results that are fragmented and scattered (for a review, see O'Hara et al., 2022), making it difficult to derive clear implications for teacher behavior. This inconsistency highlights the need for more systematic investigation of how teacher interpersonal behavior specifically relates to math anxiety in students. Furthermore, research attention must be directed toward potential gender differences in this relationship. Studies have repeatedly demonstrated that even at the primary school level, teachers hold lower expectations towards the math achievement of girls as compared to boys (Mizala et al., 2015). Correspondingly, boys often outperform girls in math, while girls report significantly lower levels of positive math-related attitudes and self-concept, as highlighted in recent TIMSS findings (Nonte et al., 2024). Additionally, girls experience higher levels of math anxiety than boys (Devine et al., 2012; Hill et al., 2016)

Dissertation Outline

Based on the theoretical and methodological considerations outlined in the general introduction, this dissertation comprises three empirical studies that approach two overarching research questions:

RQ1: *In what way is teachers' interpersonal behavior related to students' behaviors and scholastic competencies in dyadic interactions?*

RQ2: *In what way is dyadic teacher interpersonal behavior related to teachers' and students' emotions, particularly in the context of math anxiety?*

In the following, I will present three manuscripts, one of which is already published and two of which being submitted for publication. It is important to note that all of these studies were conducted in collaboration with other scholars. Therefore, I will refer to "we" when discussing these studies in detail. A complete list of authors will be provided at the

beginning of each chapter. All studies presented in this dissertation were financially supported by a grant from the German Research Foundation (DFG) awarded to Prof. Dr. Bettina Hannover (HA 2381/17-1). The contribution of all authors to the respective manuscript is stated for each manuscript according to the CRediT taxonomy.[3]

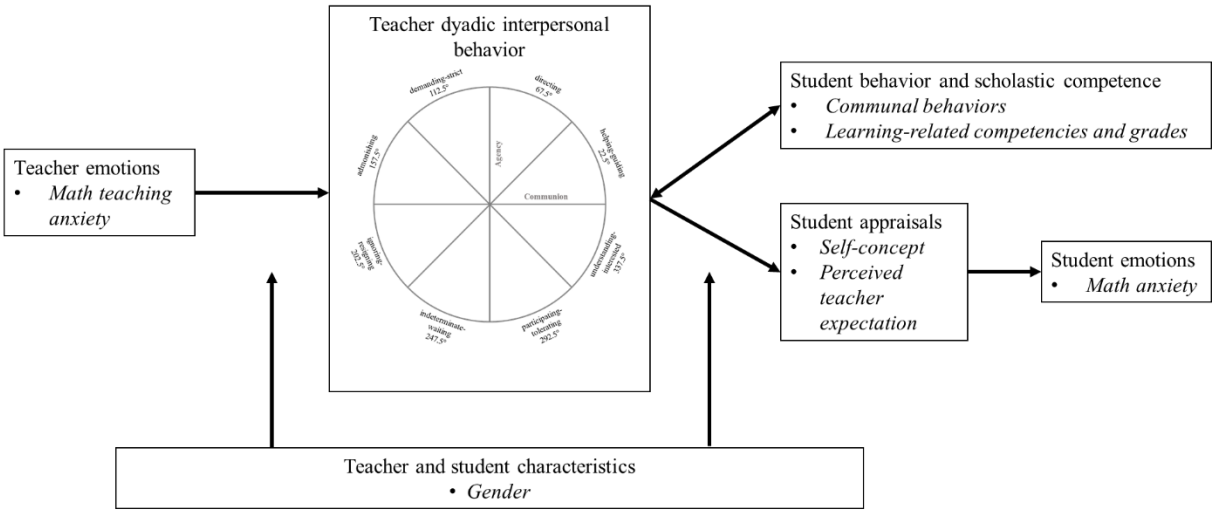
Both research questions are addressed through the lens of Interpersonal Theory (Leary, 1957). Across all studies, we operationalized teacher interpersonal behavior as a combination of agency and communion as proposed by the Interpersonal Circumplex (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957). This approach allows for precise and rigorous testing of the model's theoretical assumptions (Gurtman & Balakrishnan, 1998; Gurtman & Pincus, 2003). Crucially, teacher behavior was assessed within dyadic interactions, recognizing that it can vary significantly depending on the individual student and, consequently, can have a distinctive impact on each student (Good & Brophy, 1970).

This dissertation integrates the adaptive teaching paradigm (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018), the teacher emotions model (Frenzel, 2014; Frenzel et al., 2021), and the control-value theory of achievement emotions (Pekrun, 2006; Pekrun et al., 2023) through the lens of Interpersonal Theory and the Interpersonal Circumplex (Kiesler, 1996; Leary, 1957). From these theoretical considerations emerges the conceptual model presented in Figure 1.5 that visualizes the research questions addressed in this dissertation. The model illustrates how teacher interpersonal behavior (represented by the circumplex in the center) connects teacher emotions, student behavior and competencies, student appraisals, and student emotions, with teacher and student characteristics (particularly gender) as potentially moderating factors.

[3] https://credit.niso.org/ (retrieved May 2, 2025)

Figure 1.5

Conceptual Model of this Dissertation



Study 1 examines the top right part of the model in Figure 1.5, investigating how teachers' interpersonal behaviors adapt in response to students' communal behaviors and scholastic competencies. To this end, the study integrates the complementary principle of Interpersonal Theory (Carson, 1969; Sadler et al., 2009) with the adaptive teaching paradigm in educational research (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018), more specifically the expertise reversal effect (Kalyuga, 2007; Tetzlaff et al., 2025), which posits that teachers should adjust their instructional support based on students' levels of competence. Hence, this study explores not only how teachers' interpersonal behavior is associated with students' social behaviors, but also how it relates to students' scholastic competencies, an often-overlooked factor in studies of interpersonal complementarity. In 39 primary and secondary schools, we conducted direct classroom observations for two teacher-student dyads each (78 dyads). For this purpose, we developed and validated an observational rating tool that can be used to observe interpersonal teacher behavior within the circumplex framework. Additionally, we assessed students' communal behavior as well as scholastic competencies as indicated by their learning-related competencies and grades. We used SSM

analysis (Gurtman, 1992; Gurtman & Balakrishnan, 1998; Zimmermann & Wright, 2017) to examine how student behaviors and scholastic competencies relate to interpersonal teacher behavior.

Study 2 focuses on the left side of the model in Figure 1.5, examining how primary school teachers' math teaching anxiety relates to their interpersonal behavior in teacher-student interactions. This study addresses a critical gap in the literature since the interpersonal impact of negative teacher emotions like math anxiety remains understudied (Frenzel, 2014; Frenzel et al., 2021). By addressing this gap, the study investigates how math anxiety shapes not only instructional strategies but also the quality of student-teacher interactions. We collected data from 161 primary school math teachers who reported their interpersonal behavior toward individual students in their classroom (2,235 dyadic descriptions). Additionally, teachers reported their anxiety towards teaching math. Using multilevel path modeling, we investigated how math teaching anxiety relates to teachers' interpersonal profiles in dyadic interactions on the dimensions of agency and communion. Furthermore, since math is a gender-stereotyped domain (Nosek et al., 2002), we investigated how this relationship differs between men and women.

Transitioning to students' experience of math anxiety, Study 3 examines the bottom right part of the model in Figure 1.5, investigating how dyadic teacher interpersonal behaviors relate to primary school students' math anxiety. This study fills a gap in the literature by bringing together the scattered findings on how teacher behavior relates to students' experience of math anxiety as an environmental factor in the emergence of students' math anxiety (as proposed by CVT; Pekrun, 2006; Pekrun et al., 2023) and reappraising these findings within the Interpersonal Circumplex Framework (Kiesler, 1996; Leary, 1957). We surveyed 42 primary school math teachers and 731 students from their classes. Teachers described their interpersonal behavior toward individual students in their classroom. Additionally, we asked students to report their self-concepts in math, their perception of the

teacher's expectation, and math anxiety. Using structural equation modeling, we examined how teachers' dyadic interpersonal profiles on the dimensions of agency and communion relate to students' experience of math anxiety and whether this association differs between boys and girls. We further examined anteceding appraisals by testing whether this relationship is indirectly associated through students' self-concept and students' perception of the teacher's expectation regarding their competencies. Again, we also examined whether relationships differed in a gendered way for boys and girls.

CHAPTER 2 – Study 1: A Circumplex Approach to Identify Complementarity in Dyadic Teacher Behaviors Depending on Student Communion and Competence

Note. This is the first author's version of a work that was published in Psychology in the Schools. The final publication is available at:

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CRediT authorship contribution statement

MF: conceptualization, methodology, formal analysis, visualization, writing- original draft; KK: conceptualization, methodology, project administration, supervision, writing- review & editing; MK: conceptualization, writing- review & editing; BH: conceptualization, funding acquisition, supervision, writing- review & editing.

A Circumplex Approach to Identify Complementarity in Dyadic Teacher Behaviors Depending on Student Communion and Competence

Abstract

Interpersonal teacher behavior can be described with the Interpersonal Circumplex on the dimensions of communion (warmth, sensitivity) and agency (initiative, control). In an observational study, we investigated whether a teacher's interpersonal behavior in dyadic interactions with a student is complementary to the student's communion and scholastic competence: does the teacher act communal to the extent that the student behaves communal, and does the teacher act more agentic the less competent the student is? In 39 primary and secondary schools, we conducted direct classroom observations for two teacher-student dyads each (78 dyads). Using Structural Summary Method, we found as expected that teacher communion was positively associated with student communion, to the detriment of students who have not yet learned to behave in a communal manner. Further, results showed a negative association between teacher agency and student competence, suggesting that teachers engaged in adaptive teaching. Results further showed that weak teacher communion was related to low student competence. We discuss the implications for teacher education and training, namely that teachers should be trained to prevent falling into patterns of dysfunctional, non-communal behavior when confronted with a particular set of student characteristics and behaviors.

Keywords. Teacher-student-interaction, circumplex, complementarity

Practitioner Points

- In line with the principles of adaptive teaching, teachers adjusted the extent to which they guided and monitored a student based on the individual student's level of competence: lower competence related to stronger teacher agency.
- In line with the complementarity principle of Interpersonal Theory, teachers also adjusted the extent to which they behaved in a warm and sensitive manner (communion) according to the individual student's behaviors: higher student communion aligned with higher teacher communion.
- Less competent students received lower communion by the teacher which can neither be explained by adaptive teaching nor complementarity. This suggests that students with low competencies and children with socially incompetent behaviors run the risk of being treated unfavorably by their teacher in dyadic interactions.

Introduction

Interpersonal behavior can be described on the dimensions of communion and agency. Communion (e.g., warmth, cordiality, sensitivity, affiliation) refers to qualities required for establishing and maintaining social relationships, while agency (e.g., competence, dominance, initiative, guidance) describes qualities required for achieving goals (Leary, 1957). Professional interpersonal teacher behavior, characterized by strong communion, i.e., acting warmly and cordially toward the student and responding in a sensitive manner to the student's needs, has been found to positively affect student outcomes (see meta-analyses Roorda et al., 2011; Roorda, Jak, et al., 2017). It was the seminal work by Pianta which, building upon parent–child attachment relationship research, paved the way for the notion that the affective quality of the relationship between teacher and child is of fundamental importance for the child's development (e.g., Pianta, 1992; Pianta et al., 2003). Pianta speaks of closeness as the degree to which interactions between child and teacher are characterized by warmth, openness, and harmony and the extent to which the child seeks support and security from the teacher in stressful situations. Pianta also recognizes the reciprocal influences teacher and child have on each other in their dyadic relationship. Applied to our reasoning, strong teacher communion can be assumed to foster a close and secure teacher-student relationship (Pianta & Steinberg, 1992).

Professional teacher behavior is further characterized by adaptivity, i.e., by instructional support that is individualized and adjusted to the individual learner's abilities (for a review on adaptive teaching, see Bernard et al., 2019; Hardy et al., 2019). But what factors influence the degree to which a teacher exhibits communal and agentic behaviors in dyadic interactions with a student? We argue that it is the extent to which a student behaves in a communal manner and the level of a student's scholastic competence.

In dyadic interactions, behaviors of the two actors are interdependent (e.g., Kelley & Thibaut, 1978; Kenny & La Voie, 1984). Apart from the teacher's and the student's general

behavioral styles, each interaction also reflects the unique relational dynamic that evolves from their specific interaction history (the so-called relationship effect, Kenny, 1994; Kenny & La Voie, 1984), since teacher and student interact with one another on a daily basis. Interpersonal Theory (Horowitz & Strack, 2011; Leary, 1957) assumes that both actors adjust their interpersonal behavior toward the other person according to the so-called complementarity principle (Carson, 1969; Sadler et al., 2009): Warm and supportive behaviors (communion) encourage warm and supportive behaviors in the other person (sameness regarding communion), while active and domineering behaviors (agency) make passive and submissive behaviors in the other person more likely (oppositeness regarding agency).

Acknowledging that every interpersonal behavior is a blend of varying strengths of communion and agency, many scholars model teacher and student behaviors by an Interpersonal Circumplex (e.g., Aelterman et al., 2019; Pennings et al., 2014, 2018; Pennings & Hollenstein, 2020; Wubbels et al., 1993). Previous research on teacher-student interactions using a circumplex approach has mostly focused on the class level, describing typical behaviors displayed by teachers towards their entire class (Aelterman et al., 2019; Wubbels et al., 1993). In contrast, to investigate complementarity (Carson, 1969; Sadler et al., 2009), we measured teacher interpersonal behavior on the level of the individual teacher and student.

A specific characteristic of formal educational settings such as kindergarten or school is that the teacher's behavior should be geared primarily to the student's current level of competence. We go beyond previous approaches and operationalized student agency by scholastic competence rather than the extent of their activity/passivity or dominance/submissiveness, in order to investigate whether teachers do in fact align their agency to student competence. As teacher support and instruction that is individualized according to student competence level is found to significantly improve learning, determining

whether teachers do align their agency to student competence is important for improving educational outcomes (adaptive teaching; Decristan & Dumont, 2021; Hardy et al., 2019).

Complementarity Between Teacher Agency and Student Competence

As previously mentioned, empirical evidence for complementarity was found in several studies in which teacher and student behavior was observed over many measurement points, allowing to examine the relationships between behaviors recorded at different timepoints and thus the reciprocal influences of two actors on each other (Mainhard et al., 2012; Pennings et al., 2014, 2018; Roorda et al., 2013; Roorda, Spilt, et al., 2017; Thijs et al., 2011). For instance, Thijs et al. (2011) found that teacher communion and child communion, as perceived by trained observers, were positively correlated, and teacher agency and child agency ratings were negatively correlated. Cross-lagged panel analyses substantiated most of the predicted interrelations between the behaviors of the two interaction partners: teacher communion in a previous episode positively predicted child communion, and child agency in a previously observed episode negatively predicted teacher agency in an adjacent episode. Similarly, Roorda et al. (2013) had independent observers rate kindergarten teacher-child interactions and found complementarity on the agency dimension. In the studies by Mainhard et al. (2012), and Pennings et al. (2014, 2018; Pennings & Hollenstein, 2020), an Interpersonal Circumplex was used to measure interpersonal behaviors in secondary school teachers and students. Raters used a joystick coding device to map behaviors in moment-to-moment teacher-student interactions observed in video-recorded lessons onto the circumplex surface.

In the studies investigating teacher-student complementarity, agency was always operationalized in an analogous manner for both the teacher and the student. For instance, Thjjs et al. (2011, pp. 37-38) and Roorda et al. (2013, p. 177) had observers rate (at many timepoints) the teacher's agency on an item that ranged between the poles of passive non-

involvement and dominant control of the child, as well as the child's agency on an item ranging between the extremes of passive compliance and active, initiative behaviors. We wanted to contribute to research on adaptive teaching (Bernard et al., 2019; Hardy et al., 2019) by determining whether complementarity can also be demonstrated between the agency of the teacher's behavior in terms of guidance and supervision and the student's agency in terms of their competence. As first described within the Aptitude-Treatment-Interaction paradigm (Cronbach & Snow, 1977), the same degree of teacher agency can impact learning differently depending on the individual student's learning prerequisites. Against this background, we wanted to find out whether teacher agency is in fact complementary to student agency as defined by the student's scholastic competence[4].

Taken together, we defined teacher agency as the strength of guidance, initiative, and control the teacher displays toward the student and student agency as their subject-specific competence (grades) and subject-unspecific learning-related key competencies. We expected to find complementarity: a student who does not yet have well-developed competencies

[4] In fact, our study is not the first to define (student) agency in terms of competence rather than activity/dominance. The distinction between communion and agency is used in many lines of psychological research, not only to describe interpersonal behaviors, but also person perception, personality traits and personality disorders, values, motives, and goals (e.g., Abele et al., 2016; Locke, 2000). While within Interpersonal Theory agency is defined as whether the person takes the lead, influences and dominates the other person, or is passive and submissive in the relationship (e.g., Leary, 1957), within research on person perception, agency is called competence and assumed to be ascribed to varying extents to a person depending on whether they belong to a high or low status group (Stereotype Content Model, Fiske, 2018).

encourages the teacher to engage in high agentic behaviors, whereas a competent student invites the teacher to withdraw guidance and control providing a higher degree of freedom. We also expected to find complementarity regarding teacher communion: strongly communal teacher behavior should be associated with strongly communal student behavior and vice versa.

Teacher Agency and Teacher Communion in an Interpersonal Circumplex

In the studies by Roorda et al. (2013, Roorda, Spilt et al., 2017) and by Thijs et al. (2011) teacher communion, teacher agency, student communion, and student agency were measured with one item each (at many timepoints), implying that the dimensions of communion and agency can be measured independently. It appeared, however, that in some of the cases communion and agency were in fact positively correlated in both teachers and children (Roorda, Spilt, et al., 2017; Thijs et al., 2011) indicating that agency and communion share variance. To account for the common variance in both variables, measurement in the Interpersonal Circumplex Framework (Mainhard et al., 2012; Pennings et al., 2014, 2018; Pennings & Hollenstein, 2020) is advisable as it acknowledges that, strictly speaking, any interpersonal behavior originates from a combination of both agency and communion. For instance, high communal teacher behavior is perceived differently depending on its co-delivery with either increased guidance and control (high agency) or decreased guidance and more freedom (low agency) by the teacher. In a similar vein, high agentic teacher behavior has different implications for the student depending on whether it is combined with a lot of warmth and responsiveness (high communion) or with emotional indifference or even coldness (low communion).

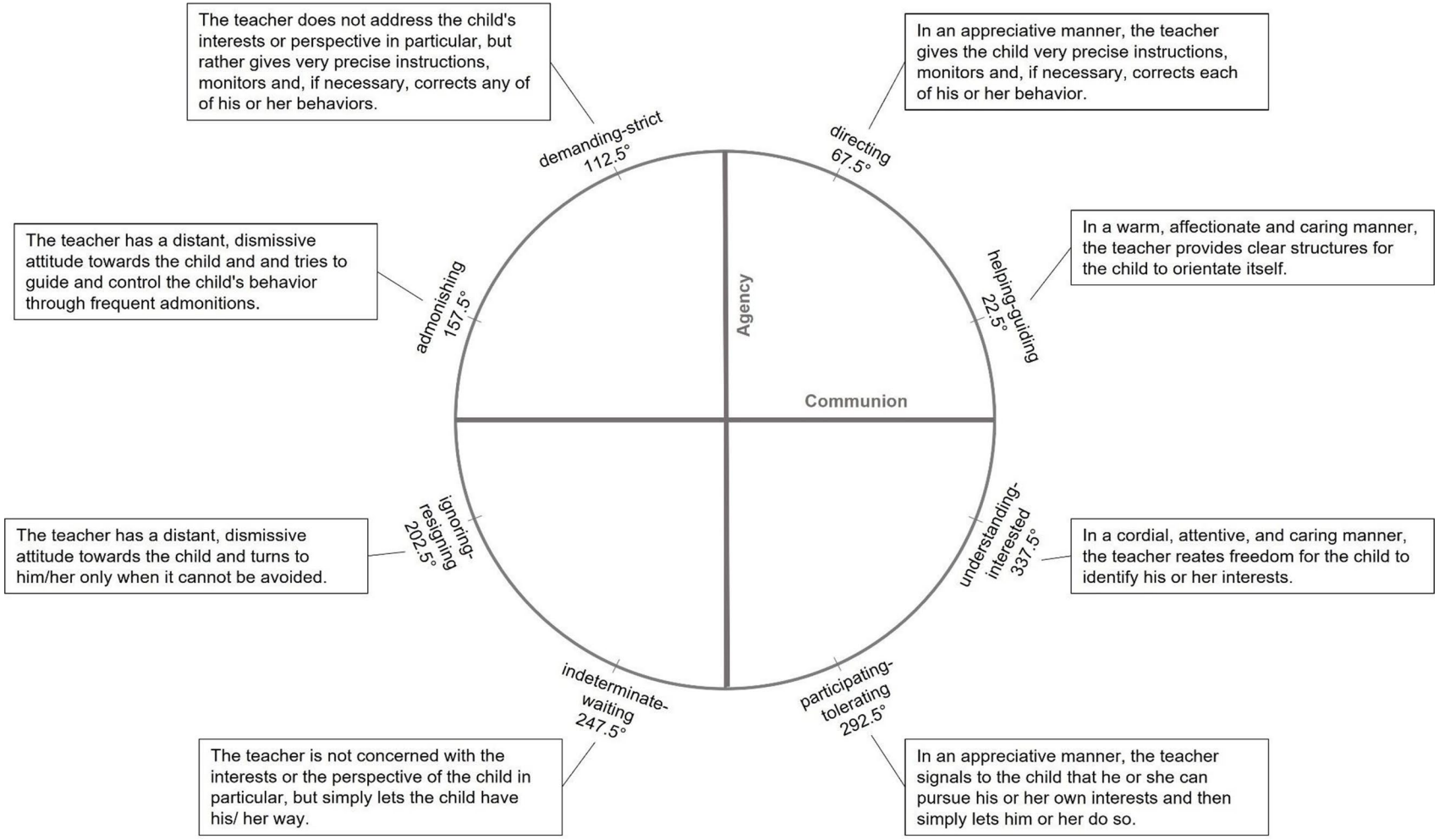
By crossing the dimensions of agency and communion orthogonally, they form the basis of a circular structure, a so-called Interpersonal Circumplex (Gurtman, 2009; Horowitz & Strack, 2011; Kiesler, 1996). Figure 2.1 shows the circumplex on dyadic interpersonal

teacher behavior used in the present study (see also Kreutzmann et al., 2024), consisting of eight distinct segments (in the following: octants) describing interpersonal behaviors: (a) "helping-guiding" (high communion, moderately high agency), (b) "directing" (moderately high communion, high agency), (c) "demanding-strict" (moderately low communion, high agency), (d) "admonishing" (low communion, moderately high agency), (e) "ignoring-resigning" (low communion, moderately low agency), (f) "indeterminate-waiting" (moderately low communion, low agency), (g) "participating- tolerating" (moderately high communion, low agency), and (h) "understanding-interested" (high communion, moderately low agency). The interpersonal behavior octants are represented by their angular positions on the circle's circumference. The model is defined through the relation of the octants to each other (Gurtman, 1991): adjacent octants should be more closely related than octants further apart, and opposite octants should be most dissimilar.

We applied Structural Summary Method (SSM; Gurtman, 1992; Zimmermann & Wright, 2017) which has primarily been used in research on personality (e.g., Ansell & Pincus, 2004; Locke, 2000), psychopathology (e.g., Girard et al., 2017), and vocational interests (e.g., Etzel et al., 2019). This allows to examine the relationship of an external variable (in our case student communion and competence) with the interpersonal circumplex (in our case interpersonal teacher behaviors) and its core dimensions agency and communion (see Gurtman & Balakrishnan, 1998). The strengths of a circumplex model lie in (1) capturing

Figure 2.1

Interpersonal Circumplex for Teacher Behavior



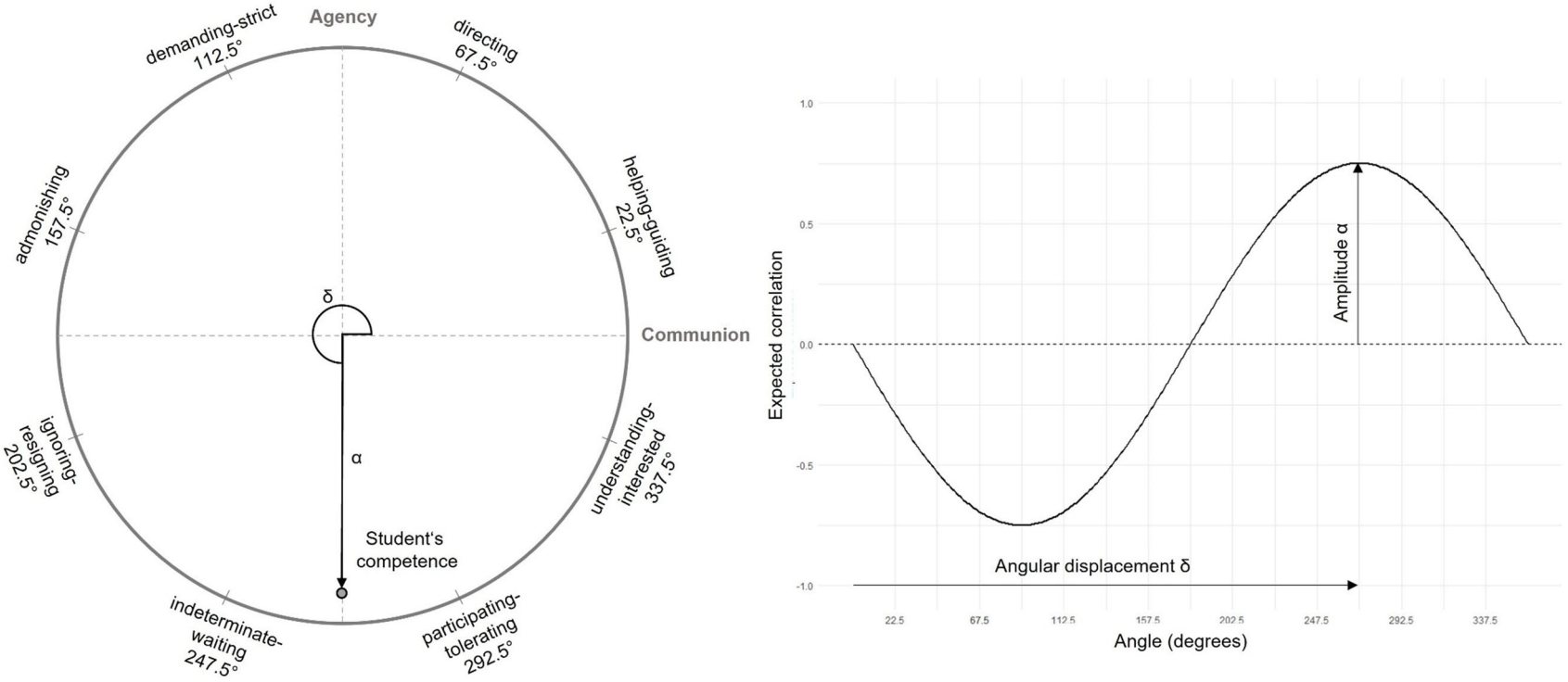
Note. Descriptions are adopted from Hannover et al. (2022).

each interpersonal behavior as a blend of both dimensions and (2) acknowledging the circular structure implied by the model (Gurtman & Pincus, 2003). Just as associations among octants within the circumplex structure should adhere to a particular pattern, so should the association of the octants with an external variable align with that pattern.

In our case, we expect that student competence is negatively associated with the teacher agency axis. This relationship should reveal itself in a strongly positive correlation between the two octants with very weak teacher agency ("indeterminate-waiting", "participating-tolerating") and the external variable of student competence (key-competencies, grades). The correlations should become weaker with increasing distance of the teacher behavior octant from the two octants with the weakest teacher agency (Gurtman, 1992; Gurtman & Pincus, 2003). Such a pattern would be met when the correlational pattern between the interpersonal teacher behavior octants and student competence follows a cosine curve. Figure 2.2 illustrates the case regarding the association between student competence and teacher behavior that would fully meet our expectation (see Hypothesis 1 below). The projection onto the circumplex is depicted on the left-hand side and the representation as a cosine curve on the right-hand side. The relationship between student competence and teacher behavior can be summarized by two central parameters (Gurtman, 1992): (1) the angular orientation (displacement δ) representing the teacher behavior most strongly associated with student competence, and (2) the degree of differentiation in the correlational profile (α). In our example in Figure 2.2, the angular orientation of the association between teacher behavior and student competence lies at 270°, exactly between the octants "indeterminate-waiting" and "participating-tolerating" in the circumplex plot (left-hand side). In the cosine curve representation (right-hand side), this same angle indicates the peak of the curve, i.e., the strongest positive correlation. The curve also shows that in our example the correlations between the student competence and teacher behavior octants become weaker the further

Figure 2.2

Exemplary Circumplex Projection (Left) and Cosine Curve (Right) for the Expected Correlational Profile between Interpersonal Teacher Behavior and Student Competence



away from the octants "indeterminate-waiting" and "participating-tolerating" with the lowest correlation being with the octants "demanding-strict" and "directing". The differentiation between correlations within this profile is represented by the vector length in the circumplex plot (left-hand side) and the amplitude of the cosine curve (right-hand side), with a large vector length and amplitude indicating that correlations differ greatly between octants (Gurtman, 1992).

Analogously, we expected student communion to be positively associated with the teacher communion axis, with the strongest negative correlations appearing between student communion and octants representing very strong teacher communion ("helping-guiding", "understanding-interested"), and with correlations decreasing to the extent that an octant is further away within the circumplex space thereby forming the expected cosine curve.

Aims and Research Hypotheses

To investigate whether teacher communion and agency were complementary to student communion and competence, we trained university students to observe the interpersonal behaviors of various teachers toward individual students in ecologically valid, live classroom situations in primary and secondary schools. Observations were made using our self-developed circumplex measure capturing teacher agency and communion simultaneously. To capture student competence, raters administered the student's subject-unspecific learning-related key competencies (e.g., can concentrate on one thing; works and learns independently), using a scale by Helm et al. (2012). Additionally, to measure student subject-specific competence, we inquired their grades in the observed school subject. To measure student communion, the raters noted their observations on an inventory that records the student's high (sincere, cooperative, polite and respectful) and low (cold and reserved, hostile) communal behaviors toward the teacher (Scherzinger et al., 2021). In line with the complementarity principle (Sadler et al., 2009), we expected the following:

(H1) Teacher agency and student competence are complementary (i.e., they are reciprocal): the strongest correlations appear between high student competence (key competencies, grades) and the behavioral octants comprising the weakest possible teacher agency ("indeterminate- waiting" and "participating- tolerating", Figure 2.1).

(H2) Teacher and student communion are complementary (i.e., they correspond): the strongest correlations appear between items measuring high communal student behavior (sincere, cooperative, polite and respectful) and behavioral octants comprising the strongest possible teacher communion ("helping- guiding" and "understanding-interested", Figure 2.1) and between items measuring low communal student behavior (cold and reserved, hostile) and octants indicating the lowest possible teacher communion ("admonishing" and "ignoring-resigning", Figure 2.1).

Method

Sample

Observations were conducted in 39 different primary and secondary schools in Berlin, Germany[5]. Thirty-nine trained university students enrolled in a teacher education bachelor program (in the following: observers) each observed and assessed a different teacher's interpersonal behavior with two unique randomly selected students from the teacher's classroom. Hence, a total of 78 teacher-student-dyads were observed. All teachers gave consent to the observations during their lessons. Observers also noted and rated student and teacher gender. Ten male teachers and 23 female teachers (six missing values) were observed. Among the observed school students, 44 were boys and 25 were girls with nine

[5] The school system in Berlin, Germany, consists of primary education ("Grundschule", grades 1–6) followed by secondary education, which is divided into lower ("Integrierte Sekundarschule") and upper ("Gymnasium") academic tracks (grades 7-13).

cases in which gender was not observable. Among all dyads, 48 observations were conducted in primary schools ($n_{grade1} = 6$, $n_{grade2} = 8$, $n_{grade3} = 8$, $n_{grade4} = 8$, $n_{grade5} = 6$, $n_{grade6} = 2$, $n_{mixed\text{-}year} = 10$) and 28 in secondary schools ($n_{grade7} = 2$, $n_{grade8} = 8$, $n_{grade9} = 4$, $n_{grade10} = 2$, $n_{grade11} = 4$, $n_{grade12} = 4$, $n_{grade13} = 2$, $n_{mixed\text{-}year} = 2$) with two missing values. Since observations were conducted in 39 schools from different neighborhoods, we assume that socioeconomic status and ethnicity of the students were distributed roughly as they are in schools Berlin where the study was conducted in general. In 2022, 51.2 % of the students attending school in the city had a migration background (Henschel, Heppt, et al., 2023, p. 303), which is higher than the average percentage of students with migration background in Germany as a whole (37.7 %; Henschel, Heppt, et al., 2023, p. 303). Further, in 2015 (no more recent data available), the Highest International Socio-Economic Index of Occupational Status (HISEI; Ganzeboom et al., 1992) which categorizes the highest educational level of the parents from 10 (e.g., unskilled labor) to 90 (e.g., judges) indicated a mean of 51.7 ($SD = 21.6$) for students attending school in the large city which is similar to the mean level and standard deviation of socioeconomic status observed across all school students in Germany (Kuhl et al., 2016, p. 414).

Measures

Teacher's Interpersonal Behavior

Building on a self-description Questionnaire on Dyadic Interpersonal Teacher Behavior (DITeB) by Kreutzmann et al. (2024), we developed a 35-item observational measure designed to allow observers to describe a teacher's behavior towards an individual student. Each item is a blend of agency and communion and assigned to one of the circumplex octants (see Figure 2.1). For instance, strong endorsement of the item "The teacher very often explains the solution to a problem to the student step-by-step." ("directing") indicates teacher behavior with high agency and moderately high communion. Conversely,

strong endorsement of the item "The teacher simply lets the student run along in class." ("indeterminate-waiting") indicates teacher behavior with low agency and moderately low communion. All items from our observational tool can be found in the Supplementary Material (for English translation see Table S2.1; German originals can be found in the OSF).

Each observer rated the teacher in the two teacher-student dyads over the course of three 45-minute lessons before finally reporting their observations via response on a five-point Likert-scale from 1 (*strongly disagree*) to 5 (*strongly agree*). In case a particular behavior was not observed at all during the observation period, the response option "*not observable*" could be checked.

To ensure the content validity and interrater reliability of our observational measure we carried out two pilot tests. A detailed report of the pilot tests can be found in the Supplementary Material (see Note S2.1). In the first pilot test, trained university students enrolled in a teacher education master program (n = 66) evaluated whether the content of each item of the measure was in line with the theoretical octant by rating how agentic and communal the described teacher behavior was. A two-way mixed, absolute agreement, average-measures intraclass-correlation-coefficient (ICC; McGraw & Wong, 1996) resulted in ICC = .99, indicating that the level of agency and communion for each item was rated similarly across raters (Koo & Li, 2016) and proving excellent fit to the intended underlying theoretical construct.[6] Results from this pilot test were also used for the item selection procedure (see Note S2.3).

[6] The results of the pilot test support the idea that all forms of interpersonal behavior combine elements of both agency and communion. Table S2.1 shows the angles for each item based on the ratings (see Note S2.1). These angles tell us that none of the items align perfectly with either axis. If an item had aligned perfectly with the agency axis, we would see angles of

In the second pilot test (for a detailed description, see Note S2.1), university students that were enrolled in a teacher education bachelor program (n = 95) were distributed equally across eight video-recorded lessons each showing a short sequence of one dyadic teacher-student interaction during a regular school lesson (Qualitäts- und UnterstützungsAgentur - Landesinstitut für Schule (QUA-LiS NRW) [Federal quality and support agency for schools in Northrhine-Westphalia], n.d.). They used our observational measure to observe dyadic interpersonal teacher behavior as well as the student's behavior (see below for details in student measures). This allowed us to examine the interrater reliability of the measure (for more information, see Koo & Li, 2016). The average measure ICC was .99 (ranging from .92 to .99 across videos), showing a high agreement between different raters based on the average ratings they gave on the interpersonal teacher behavior measure.

Student's Communion and Competence

We used five items that were adapted from a German observational scale by Scherzinger et al. (2021) capturing the student's communion. Observers indicated their perception on a five-point Likert-scale from 1 (*strongly disagree*) to 5 (*strongly agree*). Items read as followed: "In my perception the student behaves (a) … sincerely toward the teacher (e.g., is happy when he/she interacts with the teacher, expresses that he/she likes having the teacher around (relaxed posture, smile, cheerful voice)), (b)… cooperatively toward the teacher (e.g., voluntarily takes on tasks or assigned work tasks and requests from the teacher), (c) …politely and respectfully toward the teacher (e.g., listens attentively to the teacher, lets

90° or 270°, and if it aligned perfectly with the communion axis, the angles would be 180° or 360°. Since no item showed these angles, raters did not view any item as one-dimensional — either entirely agentic or entirely communal. Instead, every item reflects a mix of both qualities, with varying levels of agency and communion combined in each.

the teacher finish speaking, thanks the teacher when appropriate), (d) … cold and reserved toward the teacher (e.g., ignores the teacher, supplies little responses to the teacher, avoids (eye) contact with the teacher), and (e) … hostile toward the teacher (e.g., behaves aggressively, actively disobeys the teacher's instructions)". Again, the option "*not observable*" could be checked. The overall reliability was Cronbach's α = .88. For an in-depth understanding of the complementarity, we incorporated the items separately as single item measures.

As a proxy for the student's competence, we measured (a) subject-specific competence as indicated by the student's grade on the latest report card in the school subject in which the observation was made from 6 (*excellent*) to 1 (*insufficient*)[7], and (b) an observation of the student's subject-unspecific learning-related key competencies on an abbreviated version of the measure developed by Helm et al. (2012). The items read: "In my perception, the student (a) … can concentrate on one thing (e.g., restricts attention to the limited learning area and is not easily distracted from learning, can concentrate on one thing for a long time if necessary), (b) … has creative ideas (e.g., makes own suggestions for new solutions, shows imagination when designing and solving tasks, brings creative ideas into the classroom), (c) … works and learns independently (e.g., works on tasks independently and can acquire knowledge independently, starts working on tasks quickly and has his/her materials ready), (d) … applies learning strategies (e.g., knows how to proceed in order to learn something and applies suitable strategies, can observe and evaluate his/her own learning paths and progress)".

[7] The grading scale in Germany ranges from 1 (*very good*) to 6 (*unsatisfactory*). To improve understanding for our international readership, we have recoded the scale so that low student grade values stand for high competencies and high values for low competencies.

Ratings were given on a five-point Likert-scales from 1 (*strongly disagree*) to 5 (*strongly agree*). The reliability was Cronbach's α = .86.

Regarding interrater reliability, results from our second pilot test (see above) revealed an ICC of .99 (ranging from .85 to .98 across videos), showing high agreement between different raters based on the average ratings of student behavior.

Procedure

Observations were conducted in schools from different districts in Berlin, Germany. Prior to the investigation, all observers underwent training consisting of three blocks of 90 minutes each, in which they learned how to systematically observe social interactions and acquired background knowledge on agency and communion of teacher's interpersonal behavior in the circumplex space. They were further trained to systematically observe both teacher and student behaviors in various videos using our circumplex scale. Schools participating in our study were asked to allow one teacher and two randomly selected students taught by that teacher to be observed over three 45-minute school hours by an external observer. The observers chose three consecutive lessons in the respective school subject. Observations of daily occurring school subjects (e.g., German) were carried out on three consecutive days while the observations in a subject taught only twice a week could extend over a period of up to ten school days. Observers were instructed to fill out the questionnaire after each lesson. After the third and final observation, observers filled out the final questionnaire by accumulating their observations from all three lessons, indicated students' and the teacher's observed genders, and gathered information about students' grades in the observed school subject. In Germany, conducting systematic observations in schools is routine for university students completing teacher educational programs. Thus, school principals, teachers, students and parents know that not only teachers but also student-teacher visit schools and occasionally gather observational data on students. All participating teachers

gave consent to the observations being carried out in their lessons. In order to use the collected data for scientific purposes, permission was also obtained from the school authorities (School Senator of Berlin). The approval was subject to the condition that no personal data was collected in order to preserve full anonymity of the observed teachers and students.

Statistical Analysis

For all analyses, we used the statistical software R 4.0.5 (R Core Team, 2021). We conducted a structural analysis combining exploratory and confirmatory approaches (see recommendations by Hopwood & Donnellan, 2010) to test the model fit of the measure in the two-dimensional circumplex space. A detailed description of the procedure (see Note S2.2) as well as the R-script for our analyses can be found in the Supplemental Material.

After items were discarded (the detailed item selection procedure is reported in Note S2.2 in the Supplementary Material) that did not empirically align with the theoretical octant or had insufficient interpersonal content (Gurtman, 1991), we computed scale means for each octant and evaluated their confirmatory circular model fit. We used the R-package "CircE" (Grassi et al., 2010) which is a R- implementation of Browne's Circular Stochastic Process Model (Browne, 1992) and examines the expected correlational pattern between octants for a circular fit. The correlation between two octants of a circumplex is defined as the cosine difference between the angles of the two octants ($r_{ij} = cos\ (\theta_i - \theta_j)$) and this correlational structure can be approximated by a Fourier series function (Browne, 1992). We first specified an unconstrained model (M1). We expanded this stepwise by constraining equal spacing (M2) which assumes an even distribution of the variables around the circle. Next, we constrained an equal radius which signifies an equal VL (M3). Lastly, our fully constrained model (M4) relied on both equal spacing and equal radius. For model fit evaluations, χ^2 as well as the Comparative Fit Index (CFI) > .90, Goodness of Fit Index (GFI) > .90, Adjusted Goodness of

Fit Index (AGFI) > .85, and the Root Mean Square Error of Approximation (RMSEA) < .13 were considered (Gurtman & Pincus, 2003; Rogoza et al., 2021)[8].

For our main analysis, we tested whether the teacher's interpersonal behavior was complementary to the student's communion and competence. To estimate the correlation of the teacher behavior octant scales with our external variables (student communion, grades, and learning-related key competencies), we applied SSM (Gurtman, 1992; Zimmermann & Wright, 2017) which tests whether the correlational pattern of the respective external variable with the octants conforms a cosine curve. We used the corresponding R-package "circumplex" for SSM analysis. This package supplies 95% bootstrapped confidence intervals (with 2000 bootstrap resamples) allowing us to draw inferential conclusions.

The association of an external variable with the octant scale i can be expressed with the following formula (Gurtman, 1992):

Let r_i be the construct's correlation with the octant scale i, e the elevation of the curve, α the amplitude, θ_i the octants angle, and δ the angular displacement of the curve.

$$r_i = e + a * cos\,(\theta_i - \delta) \quad (2.1)$$

The elevation represents the average correlation of the external variable with the teacher behavior circumplex. The amplitude substantiates how much the correlation of the construct with the circumplex differs across octants. High amplitudes indicated that correlations between the constructs and each octant greatly differ, whereas a low amplitude

[8] The cutoff for RMSEA values deviates from the established standards (RMSEA < .08; Hu & Bentler, 1999) because RMSEA values in circumplex models can be biased due to the high correlations between octant variables. Hence, it is recommended (Gurtman & Pincus, 2003; Rogoza et al., 2021) that RMSEA values <.13 indicate adequate model fit if other fit indices suggest acceptable fit.

would indicate that correlations are very similar between the construct and each octant. Thus, the amplitude represents the effect size of the association with the circumplex (amplitudes around .10, .16, and .23 can be conceived as small, average, or large effects; Zimmermann & Wright, 2017). The angular displacement describes the peak of the cosine curve and expresses which octant(s) are most highly associated with the external variable (for further details, see Gurtman & Pincus, 2003; Zimmermann & Wright, 2017). Thus, the displacement specifies the angular orientation of the correlational profile on the circumplex space (degree) and specifies in which octant(s) the correlational profile lies. Additionally, the correlational profile can be described by its value on the two dimensions of agency and communion, therefore its cartesian coordinates in the circumplex space. Additionally, R^2 assesses whether the correlational structure of the external variable with the circumplex octants follows the expected cosine curve and thus measures interpersonal prototypicality. Prototypicality is met for values higher than .70 (Rogoza et al., 2021).

The percentage of missing data ranged from 0% for all teacher behavior items and student learning-related key competencies, 0-4% for items on student communion, and 25% for school students' grades. Results of Little's MCAR test (Little, 1988) suggested that there was no systematic pattern of missing data, $\chi^2(82) = 79.71$, $p = .551$. For the SSM analyses, missing data was handled using listwise deletion since the corresponding R-package only provides listwise or pairwise deletion.

Transparency and Openness

All study materials as well as the R analysis script can be retrieved from https://osf.io/qmjxy/.

Results

Fit to the Structural Model

The item selection procedure (for details, see Note S2.3 in the supplement) revealed that in both samples (first pilot and main study) all criteria were best met with 22 selected items (13 items were discarded). Each interpersonal teacher behavior octant was represented by two or three items, obtaining a parsimonious and internally consistent solution (Cronbach's $\alpha > .64$; Spearman-Brown-Coefficients > .60).

After item selection, scale means were computed. Means, standard deviations, and intercorrelations of the octants can be found in Table 2.1. Overall, the octant scale means indicated that teachers exhibited more high communal behavior ("helping- guiding", "directing", "participating-tolerating", "understanding-interested") compared to low communal behavior ("demanding-strict", "admonishing", "ignoring-resigning", "indeterminate-waiting").

Table 2.1

Means, Standard Deviations, Internal Consistency, and Correlations of the Interpersonal Teacher Behavior Scales (Octants)

Variable	*M*	*SD*	α	1	2	3	4	5	6	7
1. Helping-guiding	3.84	0.81	.64	-						
2. Directing	3.46	1.10	.85	.33**	-					
3. Demanding-strict	3.07	1.15	.82	-.10	.37**	-				
4. Admonishing	2.69	1.09	.60[a]	-.40**	.02	.52**	-			
5. Ignoring-resigning	1.85	1.05	.79[a]	-.57**	-.36**	.06	.36**	-		
6. Indeterminate-waiting	2.78	1.19	.85	-.26*	-.45**	-.36**	.06	.45**	-	
7. Participating-tolerating	3.19	1.05	.78	.30**	-.21	-.56**	-.56**	-.14	.32**	-
8. Understanding-interested	3.45	1.09	.69	.51**	.02	-.22	-.50**	-.42**	-.29**	.32**

Note. [a]For two-item measures, Spearman-Brown coefficients were computed. In all other cases Cronbach's α was used.

*$p < .05$. **$p < .01$.

Next, the intercorrelations of the octant scales were used to assess model fit of the circumplex measurement model. The loose circular scale layout (M1, see Table 2.2) achieved a good fit. Model fit did not significantly decline after constraining equal spacing in M2 ($\Delta\chi^2$ = 13.21, Δdf = 7, p = .067), equal radius in M3 ($\Delta\chi^2$ = 6.62, Δdf = 7, p = .469) and both equal radius and equal spacing at the same time in M4 ($\Delta\chi^2$ = 18.77, Δdf = 14, p = .173). Figure S2.2 (supplement) depicts the structure of the circumplex for observed teacher behavior. Altogether, the configuration of interpersonal teacher behavior scales yielded a

quasi-circumplex (Guttman, 1954) that was very similar to the ordering proposed by our theoretical model (see Figure 2.1) and showed that the scales were systematically interrelated according to the expected correlational pattern of circumplex models (i.e., adjacent octants being more closely related than octants being further apart).

Table 2.2

Fit of the Interpersonal Circumplex for Teacher Behavior to Circular Models

		χ^2	df	RMSEA (90% CI)	CFI	GFI	AGFI
M1	Unconstrained	17.25	10	.097 (.000 - .172)	.965	.977	.917
M2	Equal spacing	30.46*	17	.101 (.037 -.159)	.936	.959	.913
M3	Equal radius	23.87	17	.072 (.000 -.135)	.967	.978	.953
M4	Equal radius & equal spacing	36.02	24	.081 (.000 -.132)	.943	.962	.943

Note. All models were tested with $k = 1$, $k = 2$, and $k = 3$ β_k parameters for the Fourier series correlation function. For $k = 3$ parameters, the best model fits were shown. RMSEA = Root-Mean-Square Error of Approximation; CI = Confidence Interval; CFI = Comparative Fit Index; GFI = Goodness of Fit Index; AGFI = Adjusted Goodness of Fit Index.

*$p < .05$.

Analysis of Complementarity in Teacher Behavior and Student Behaviors and Competence

Means, standard deviations, and intercorrelations of the student variables can be found in Table 2.3. Grades and learning-related key competencies were highly correlated constructs (r = .80).

Table 2.3

Means, Standard Deviations, and Correlations of Student's Grades, Learning-Related Key Competencies, and Communion

Variable	*M*	*SD*	1	2	3	4	5	6
1. Grades[a]	4.47	1.19	-					
2. Learning-related key competencies	3.21	1.07	.80**	-				
3. Sincere[b]	3.70	1.20	.46**	.48**	-			
4. Cooperative[b]	3.73	1.30	.46**	.54**	.73**	-		
5. Polite and respectful[b]	3.90	1.20	.50**	.55**	.70**	.71**	-	
6. Cold and reserved[b]	1.91	1.13	-.27*	-.31**	-.68**	-.57**	-.53**	-
7. Hostile[b]	1.54	1.00	-.44**	-.36**	-.48**	-.48**	-.60**	.55**

Note. [a]Grades: 6 = "excellent" to 1 = "insufficient". [b]Single-item measures were used for all analyses.

*p < .05. **p < .01.

Table 2.4 depicts the circular parameters. In the following, we report the correlational profiles of teacher interpersonal behavior with either student competencies (Hypothesis 1) or student communion (Hypothesis 2). Each correlational profile is characterized by its angular orientation in the circumplex space pointing to the interpersonal teacher behavior octant that

is most highly associated with the respective student variable. Since each octant is characterized by a blend of agency and communion, we examined the association of the student variable with teacher agency and communion simultaneously.

Complementarity Regarding Student Competence

We used correlation-based SSM to assess whether teacher agency was complementary to student competence. We hypothesized that the lower the teacher's agency was, the higher the student's competence would be (Hypothesis 1). These relationships should become evident in the angular orientation of the correlational profile for the two student competence measures (grades, learning related key-competencies) located between the octants "indeterminate-waiting" and "participating-tolerating" (see Figure 2.1). This implies that the summary profile should be placed orthogonally to the communion axis, entailing that student competence is uncorrelated with teacher communion. Supporting this hypothesis, results revealed that the teacher behavior octant "participating-tolerating" was most strongly associated with students' grades and learning-related key competencies, placing the correlational profile at δ = 310.5°, 95% CI [288.4, 333.6], and δ = 318.8°, 95% CI [293.2, 340.9]. This indicates that for both measures of student competence there was a negative correlation with teachers' agentic behavior (grade: Agency = -.40, 95% CI [-.55, -.22]; learning-related key competencies: Agency = -.39, 95% CI [-.57, -.20]), supporting Hypothesis 1. The $R^2 > .95$ indicated that the correlational patterns of both student competence variables with the interpersonal circumplex had sufficient fit to the cosine curve (Rogoza et al., 2021). This means that correlations were high for octants that are adjacent to the octant "participating-tolerating" teacher behavior and that correlations decreased for octants that were further apart from the "participating-tolerating" octant. The corresponding correlational patterns are visualized in Figure S2.3 in the Supplementary Material. The amplitudes indicated with .53 for grades and .59 for learning-related key competencies that the correlations highly differed across octants

indicating large effect sizes for both relationships with the interpersonal circumplex (Zimmermann & Wright, 2017).

Further, the correlational profiles were not perfectly orthogonal to the teacher communion axis. In fact, the correlational profiles were also significantly associated with teacher communion axis indicating that the higher the students' competence was, the more communal teachers behaved (grade: Communion = .34, 95% CI [.16, .52]; learning-related key competencies: Communion = .45, 95% CI [.23, .65]). Figure 2.3 displays the correlational profile plot for students' grades and learning-related key competencies.

Table 2.4

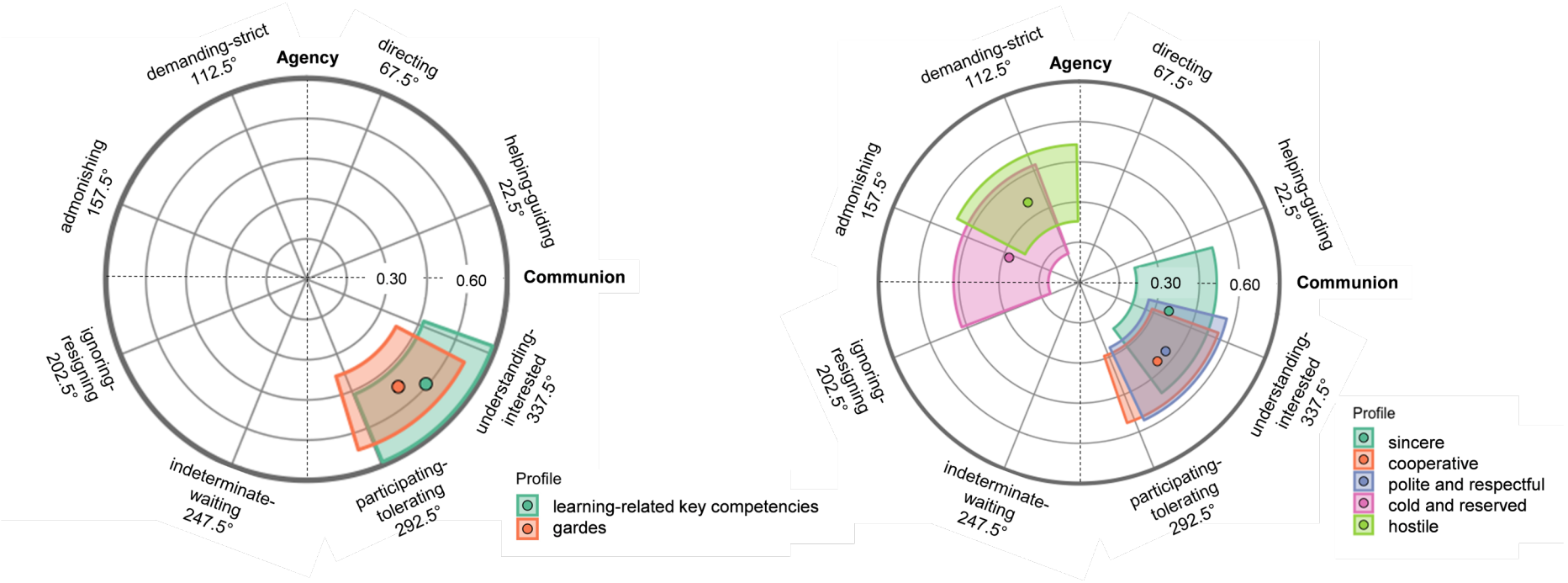
Correlation-Based SSM-Parameters of Student Agency (Grades and Learning-Related Key Competencies), and Student Communion with 95% Bootstrapped CIs

Profile	Elevation	Communion	Agency	Amplitude	Displacement	Fit
			Student Competence			
Grade	-0.01 (-0.08, 0.05)	0.34 (0.16, 0.52)	-0.40 (-0.55, -0.22)	0.53 (0.39, 0.67)	310.5 (288.4, 333.6)	.950
Learning-related key competencies	0.04 (-0.02, 0.10)	0.45 (0.23, 0.65)	-0.39 (-0.57, -0.20)	0.59 (0.46, 0.74)	318.8 (293.2, 340.9)	.956
			Student Communion			
Sincere	0.02 (-0.04, 0.08)	0.34 (0.16, 0.50)	-0.11 (-0.30, 0.09)	0.35 (0.21, 0.51)	342.4 (306.8, 14.7)	.907
Cooperative	0.05 (-0.01, 0.10)	0.29 (0.12, 0.45)	-0.29 (-0.44, -0.13)	0.41 (0.29, 0.55)	314.9 (288.9, 340.2)	.969
Polite and respectful	0.02 (-0.03, 0.07)	0.32 (0.14, 0.49)	-0.26 (-0.41, -0.09)	0.41 (0.27, 0.57)	321.6 (295.3, 346.3)	.965
Cold and reserved	-0.01 (-0.07, 0.05)	-0.26 (-0.46, -0.05)	0.09 (-0.10, 0.26)	0.28 (0.11, 0.47)	160.5 (110.4, 200.8)	.913
Hostile	0.01 (-0.05, 0.07)	-0.19 (-0.39, -0.01)	0.30 (0.15, 0.43)	0.35 (0.23, 0.51)	122.7 (91.0, 152.4)	.958

Note. Confidence intervals (CI) are in parentheses.

Figure 2.3

Projecting Students' Competence (Grades and Learning-Related Key Competencies) (Left), and Students' Communion (Right) on Teachers' Interpersonal Behavior



Note. The scale ranges from $r = 0$ (at the center) to $r = 0.75$ (at the circumference). The plot was computed using the R-package "Circumplex" (Zimmermann & Wright, 2017).

Complementarity Regarding Student Communion

In the next step we used correlation-based SSM to test whether teacher communion was complementary to student communion (Hypothesis 2). This relationship should become evident in the angular locations of the correlational profiles for the measures of high student communion located between the octants "helping-guiding" and "understanding-interested" (see Figure 2.1), and in the correlational profiles for the measures of low student communion located between the octants "admonishing" and "ignoring- resigning " (see Figure 2.1). Also, the correlational profiles should be placed orthogonally to the agency axis, entailing that student communion is uncorrelated with teacher agency. We analyzed all items measuring high or low student communion separately to test whether there were differences in the association with teacher behavior according to the valence of the student behavior. Table 2.4 depicts the SSM parameters and Figure 2.3 the correlational profile plots for student communion. For the items indicating high communal behaviors (sincere, cooperative, polite, and respectful student behavior), the correlational profiles were placed in the teacher behavior octant "understanding-interested" (sincere: $\delta = 342.2°$, 95% CI [306.8, 14.7]; cooperative: $\delta = 314.9°$, 95% CI [288.9, 340.2]; polite and respectful: $\delta = 321.6°$, 95% CI [295.3, 346.3]), indicating that understanding-interested teacher behavior was most strongly associated with high communal student behavior. For the items indicating low communal behaviors (cold and reserved, hostile student behavior), as expected, the inverted association with teacher behavior was found: both profiles had a negative correlation with teacher communion, placing the correlational profiles for cold and reserved student behavior at $\delta = 160.5°$, 95% CI [110.4, 200.8] in the octant "admonishing" and for hostile student behavior at $\delta = 122.7°$, 95% CI [191.0, 152.4] in the octant "demanding-strict". Supporting Hypothesis 2 for all student communion variables, the confidence intervals for the relation with the communion axis did not contain zero (see Table 2.4) indicating a significant relation between teacher and student communion. In all cases, amplitudes > .28 indicated high differentiations in correlations

across the octants suggesting large effect sizes for the relationship between student and teacher communal behaviors (Zimmermann & Wright, 2017). The correlational pattern was in line with the circumplex structure indicating sufficient fit to the cosine curve (as seen in Figure S2.3 in the Supplementary Material) as supported by the $R^2 > .90$ (Rogoza et al., 2021).

The correlational profiles of sincere as well as cold and reserved student behavior were not significantly correlated with teacher agency (see Table 2.4), supporting the assumption that correlational profiles for student communion were orthogonal to the teacher agency axis. However, for some communal behaviors (cooperative, polite and respectful, hostile) correlational profiles were significantly correlated with teacher agency, such that profiles were not orthogonal to the teacher agency axis. In particular, correlations with teacher agency (see Table 2.4) indicated that teachers' agency was lower toward cooperative, polite and respectful students (cooperative: Agency = -.29, 95% CI [-.44, -.13]; polite and respectful: Agency = -.26, 95% CI [-.41, -.09]) and higher toward hostile students (hostile: Agency = .30, 95% CI [.15, .43]).

Additional Analyses

We conducted several additional analyses to ensure the robustness of our results. First, we employed additional analyses accounting for the nested data structure (students nested in teachers). Second, we accounted for control variables to test that results were independent of teacher and student genders as well as school type. Since the SSM-package (Zimmermann & Wright, 2017) does not allow to account for nested data or to incorporate control variables, we decomposed the octant scales into teacher agency and communion scores for each student. [9]

[9] Octant scale scores can be decomposed by computing the sum of the octant scale scores weighted by the sine (for agency) or cosine (for communion) of the theoretical

We then conducted linear regression analyses predicting student variables with teacher agency and communion while computing cluster-robust standard error to account for nested data (Model 1). In a second analysis, we added teacher and student genders as well as school type as control variables (Model 2). Results are displayed in Table S2.2 in the Supplementary Material. Relevant deviations from our SSM-analysis findings were found only for cold and reserved student behavior in association with teacher communion: teacher communion was only marginally significantly associated (B = -0.30, SE = 0.17, p = .072) with cold and reserved student behavior when cluster-robust standard errors were computed in Model 1. However, direction and strength of the association remained the same as the SSM-analysis. For all other student communion variables, the associations with teacher agency and teacher communion were in line with the SSM-analyses. Deviations in the angular orientation of the correlational profiles, i.e., the location in the circumplex, were small ($\Delta\theta \leq 8.6°$) after accounting for the nested data structure and control variable, indicating the teacher behavior octants most strongly associated with the respective student variable did not change compared to the SSM-results. Considering the associations with the control variables, students from primary schools obtained higher observer ratings for their learning-related key competencies (B = 0.42, SE = 0.15, p = .006) and cooperative behavior (B = 0.71, SE = 0.25, p = .004), and lower ratings regarding cold and reserved behavior (B = -0.56, SE = 0.20, p = .005). Further, when taught by a female teacher, students obtained higher observer ratings on sincere (B = 0.79, SE = 0.26, p = .002), cooperative (B = 0.42, SE = 0.21, p = .043), as well as polite and respectful behavior (B = 0.42, SE = 0.20, p = .035). Additionally, girls obtained higher observer ratings on sincere (B = 0.61, SE = 0.26, p = .018), cooperative (B = 0.47, SE = 0.23,

circumplex position (for more information see Gurtman, 2009). The corresponding formulae can be found in the Supplementary Material (see note in Table S2.2).

p = .044), as well as polite and respectful behavior (B = 0.48, SE = 0.23, p = .035). All remaining associations were not significant.

Discussion

In heterogenous classrooms it is of crucial importance for student learning that teachers adapt their agency, i.e., the extent to which they guide and monitor a student, to the individual learner's competence level (Decristan, & Dumont, 2021). In our study we observed dyadic teacher-student interactions to find out the extent to which teachers adjust their agency to student competence, according to the complementarity principle described in Interpersonal Theory (Leary, 1957; Sadler et al., 2009). The assessment of interpersonal behavior via the Interpersonal Circumplex (Gurtman, 2009; Horowitz & Strack, 2011; Kiesler, 1996) accounts for the fact that agency in teacher behavior means something different to the student depending on whether it is accompanied by high or low teacher communion. The same holds for teacher communion that can either be combined with high or low teacher agency. To account for that interdependency, we modeled teacher behavior in an interpersonal circumplex and used Structural Summary Method to analyze complementarity between teacher and student while accounting for teacher agency and communion simultaneously.

Complementarity of Teacher Agency

In our first research hypothesis, we expected teacher agency to be complementary to student competence. In line with this assumption, the teacher's agency in dyadic interactions was related to the student's subject-specific (grades) and subject-unspecific learning-related key competencies. The higher the student's competencies were, the less agency the teacher displayed toward him or her. This complementarity between teacher agency and student competence has been referred to as adaptive teaching and implies that the teacher dynamically adjusts their instructional strategies and learning support to meet the varying prerequisites and learning behaviors of the student (Bernard et al., 2019; Corno, 2008). While a student who does not yet have well-developed subject-specific or subject-unspecific competencies can be

assumed to profit if the teacher provides much guidance, a student with well-developed competencies should benefit from more degrees of freedom. It is important to keep in mind that adaptive teaching is a dynamic process in which teacher behavior and student competence influence each other in many dyadic interactions over time. Hence, adaptive teaching is a fluid, reciprocal process in which the teacher continuously calibrates their degree of agency to the student's needs and learning behaviors (Van De Pol et al., 2010). The teacher may initially exhibit strong agency to support a student with lower competencies, then gradually withdraw agency as the student takes on more responsibility and agency in their own learning. This process strengthens the student's ability self-concept, encourages motivation, and consequently supports competence gains over time. However, our data is only a snapshot: we measured the strength of teacher agency given a certain student competence level, which does not fully reflect the reciprocal influence processes occurring over time.

Further, we found that not only teacher agency but also teacher communion was related to the student's competence level: the higher the students' competence the more communion was shown by the teacher. As students profit from high communal teacher behavior (see meta-analyses Roorda et al., 2011; Roorda, Jak, et al., 2017), this can be a risk factor especially for low-achieving students. Low-achieving students are particularly dependent on a warm and sensitive relationship to their teacher, hence, teachers behaving less communal toward them may even exacerbate existing disadvantages for low achieving students (see OECD, 2019). This mechanism, also known as the "Matthew-effect" (Ceci & Papierno, 2005; for review, see Pfost et al., 2014), highlights the cycle in which students starting from lower competence levels build up their competencies at a slower rate than students starting at higher levels. Our finding that higher teacher communion corresponds to higher student competence is in accordance with findings on teacher-student relationship quality: teachers report less conflict and child dependency as well as more closeness in relationships with high-achieving students compared to relationships with low-achieving

students (see meta-analysis Nurmi, 2012). Further, a longitudinal investigation conducted by Hajovsky et al. (2017) revealed that student competence predicted teacher-student relationship quality but not vice versa: students with higher math achievement were involved in a closer and less conflictual relationship with their teacher at a later point in time. Our findings align with previous studies, suggesting that students who most need high-quality relationships with their teachers—specifically, those with low competencies—are often the least likely to experience them.

Complementarity of Teacher Communion

Our second research hypothesis stated that within the teacher-student dyad, teacher communion is complementary to student communion. As expected, high teacher communion was related to high communal student behaviors (sincere, cooperative, polite, respectful) and low teacher communion was associated with low communal student behaviors (hostile, cold and reserved). These findings are in line with the results of Pennings et al. (2014, 2018) and of Thijs et al. (2011) who also observed complementarity in teacher-student interactions on the communion-dimension. While our findings suggest that socially competent students showing communal behavior toward their teacher are likely to be treated in a warm and affective manner by their teacher, they also imply that students who have not yet learned to engage in positive, interpersonal behaviors are faced with lower communion in their teacher's behavior. This can result in a downward spiral of cold and negative teacher-student interactions for students with problematic behaviors in particular, creating a dysfunctional teacher-student relationship (e.g., Bosman et al., 2022; Roorda, Spilt, et al., 2017). In teacher education, teachers should be trained to engage in professional behavior even in challenging interactions with a student. When faced with cold or even hostile student behavior, they should refrain from responding with low communion and instead act anti-complementary by responding with neutral, or even friendly behavior. As described by the complementarity principle, such positive teacher behavior should make warm and affective behaviors more

likely even among students with problematic behaviors. A study by Pennings et al. (2018) found that the majority of teachers (69 %), but not all of them, managed to refrain from responding hostile when confronted with student hostility. Thus, not all teachers are equipped with the resources (e.g., knowing which teacher behavior is dysfunctional; being able to regulate one's negative feelings toward a student) that help them overcome dysfunctional, complementary reactions toward misbehaving students. It should be noted, however, that suppressing a spontaneous negative psychological response by acting anti-complementary can cause distress (Kiesler, 1996; T. J. G. Tracey, 2004) and create an emotional burden for the teacher (e.g., Taxer & Frenzel, 2015). This is a factor which should be considered in future research endeavors.

We did not find exact orthogonality of each correlational profile on student communion to the teacher agency axis. Teacher communion and teacher agency are related to student communion - an interplay which can indicate a disadvantage for students who have not yet learned to behave communally. Students behaving in a non-communal, hostile manner are met with teachers expressing higher agency, a potentially demotivating experience when mismatched with a student's competence level (Bernard et al., 2019; Hardy et al., 2019). This finding is in line with the results of Roorda et al. (2013) who found a negative association between teacher agency and student communion. It seems that teachers try to control a student's unfavorable social behaviors by directing and monitoring them more than would be appropriate to best support their motivation and learning. It is conceivable that if a teacher, for whatever reason, treats a student with strong agency, the student will feel restricted in their autonomy and react with negative, oppositional behaviors.

Using the Advantages of the Circumplex Model to Analyze Complementarity

We used Structural Summary Method to fully exploit the potential of a circumplex model (Gurtman, 1992; Zimmermann & Wright, 2017). Our circumplex measure of interpersonal teacher behavior comprised eight scales. The measure showed excellent fit to

our model requiring items to conform to the circumplex structure. We translated the theoretical understanding that (1) the dimensions of agency and communion only occur in combination with each other, and that (2) the circumplex implies a certain structure within interpersonal teacher behavior scales, into our methodological approach. Hence, we acknowledged that any interpersonal behavior is to a certain degree, a combination of both agency and communion.

Previous studies investigating complementarity in teacher-student interactions using circumplex measures of interpersonal teacher behaviors (Pennings et al., 2014, 2018; Pennings & Hollenstein, 2020) focused primarily on a descriptive analysis and a graphical depiction of the interdependence between teacher and student behavior. They restricted their statistical analysis to the data provided by the orthogonal axis agency and communion. By doing so, as the authors explain themselves (Pennings et al., 2018, p. 55), they were not able to examine whether the relationship of teacher and student behavior aligned with the structural model proposed by the Interpersonal Circumplex (Gurtman & Balakrishnan,1998). By describing teacher behavior as a blend of agency and communion and applying SSM, we were able to complement this line of research and exploit the full potential of the structural model of the circumplex to investigate complementarity in teacher student-dyads. Going beyond the circumplex approach of Pennings et al. (2014, 2018), we were able to identify and inferentially test which interpersonal teacher behavior octants were most strongly associated with the student's competence and communal behaviors. In this way, we were not only able to explore relations between teacher agency and student competence, but also between teacher and student communion, teacher agency and student communion, and vice versa. Via this analytical method we discovered that lower teacher communion was associated with lower competence levels in the student and that teacher agency was related to the student's communion. Our findings highlight the vulnerability of certain groups of students to be embedded in low qualitative relationships to their teachers, especially those deemed "at risk"

based on factors such as low achievement and low social skills (Hannover et al., 2022; Roorda et al., 2014). Future studies may want to investigate whether the same complementary tendencies can be observed in teachers interacting with students from low socioeconomic backgrounds or ethnic minority families (e.g., Fiske, 2018).

Generalizability of our Findings

While existing studies investigated complementarity in either kindergarteners (Roorda et al., 2013; Roorda, Spilt et al, 2017; Thijs et al., 2011) or secondary school students (Mainhard et al., 2012; Pennings et al., 2014; 2018), we analyzed complementarity in both primary and secondary school students and thus in an age group not previously studied. Children build attachment relationships with their nonparental care providers (Pianta & Steinberg, 1992) in kindergarten (see meta-analysis Ahnert et al., 2006) and school (e.g., L. Li et al., 2022; Verschueren, 2015). However, as children grow older, the importance of the teacher as an attachment figure decreases (Verschueren & Koomen, 2012), and teacher-student relationship quality declines in its warmth and closeness (e.g., B. A. Collins et al., 2017; Horn et al., 2021; Wu & Hughes, 2015). Against this background, we wanted to add to the current state of research by examining complementarity in teacher-student dyads in primary and secondary schools and thus in a broader age group of students. Our additional analyses revealed that the associations of teacher interpersonal behavior with the student's competence and communion did not change after controlling for the school type (primary vs. secondary). Taken together, our findings suggest that the complementarity principle holds irrespective of students' class level, as is predicted by Interpersonal Theory (Carson, 1969; Leary, 1957).

A strength of our study was that we were able to include a broad spectrum of schools from a city with several million inhabitants, as each of the 39 observers visited a different school. Schools were located in neighborhoods that varied in regard to their ethnic composition and families' socioeconomic status. Thus, our sample of children and adolescents

was highly diverse and reflective of the large heterogeneity of students attending primary and secondary schools in Germany. This suggests that the generalizability of our findings is not limited by a selective sample.

Limitations

We are aware that our study has limitations that should be considered in future studies. First, we used students' grades as proxies for their subject-specific competencies to test complementarity of teacher agency to student competence. Though students' subject-unspecific competencies were also considered, future studies should use standardized tests instead of grades to measure student subject-specific competence as grades may be biased by, for example, student gender (e.g., Hofer, 2015) or migration background (e.g., Bonefeld & Dickhäuser, 2018). Although we consider it an innovation of our study to have operationalized the student's agency via his or her scholastic competence, it would have been an interesting addition to also have applied the scale by Roorda et al. (2013) and Thijs et al. (2011) to observe the students' agentic behavior (initiative, dominance). We would have expected positive correlations between our competence measure and Roorda et al.'s and Thijs et al.'s agency measure.

Second, because direct observations are a very time-consuming method, only one observer per classroom was used. Although our first pilot test revealed that there was high interrater agreement regarding the items' interpersonal content and all 39 raters of our study went through extensive training, we were not able to calculate interrater reliability. Though rater bias (Hoyt & Kerns, 1999) might have impacted the results, we were able to minimize strong dependencies with rater subjective attitudes by using a high number of raters. Additionally, in our second pilot study, we investigated the interrater reliability among our observers of the video sequences on teacher-student interactions. Considering the mean of ratings, we had excellent interrater agreement with ICCs ranging from .92 to .99 for teacher interpersonal behavior and ICCs ranging from .85 to .98 for student behavior (Cicchetti et al.,

2006). All values were above or comparable to the agreement across raters reported by Thijs et al. (2011, p. 38), Roorda et al. (2013, p. 148), and by Roorda, Spilt et al. (2017, p. 79). Thus, we found these interrater reliability values to be acceptable.

Third, we had the teachers' and the students' behavior assessed by the same person, raising the concern of common method bias (Podsakoff et al., 2003). To mitigate any issues, we used different operationalizations of teacher vs. student communion/agency to reduce such bias. Raters were instructed to observe teacher communion and agency on our circumplex measure, student communion on a communal behavior scale, and student competence on a scale capturing learning-related key competencies. It is therefore unlikely that the observers' assessment of teacher agency/ communion was directly influenced by their assessment of student competence/ communion. Further, although observers were not instructed about the complementarity principle, it cannot be ruled out that they expected to see complementary tendencies in teacher and student. This potential bias should also be mitigated by the fact that we used different operationalizations of teacher and student behaviors.

Lastly, due to our cross-sectional design we cannot draw conclusions about the sequence of teacher-student interactions. A teacher's interpersonal behavior can be both a reaction to a student's preceding actions or an antecedent of a student's subsequent behavior. While the observations did span three measurement points, only data aggregated across the three observations was available for analysis.

Practical Implications

The present study indicates that interpersonal theory and the complementarity principle (Carson, 1969; Leary, 1957) can be used to describe and predict teacher interpersonal behaviors in dyadic interactions based on a student's communion and competence. Educators and teachers can benefit from our findings by gaining a more nuanced understanding of how teacher behavior is influenced by student characteristics. An influence which can be to the detriment of students who have not yet learned to behave in a communal

manner or who have rather poor scholastic competencies. Our findings suggest that high-achieving students receive more warmth (communion) as compared to low-achieving students. Teachers may unintentionally show less warmth towards low-achieving students because they themselves feel little joy in instructing a student who has seemingly lower potential. Some teachers may mistakenly believe that they can motivate a low-achieving student through less communal behavior. Regardless of the teacher's intentions, negative effects on student motivation and performance outcomes (Roorda et al., 2011; Roorda, Jak, et al., 2017), as well as quality of the teacher-student relationship are to be expected (Kreutzmann et al., 2024; Pianta et al., 2003). Educators should be mindful of this dynamic and strive to offer supportive warmth, in particular to students with lower academic competence. After all, it is precisely these students for whom a high-quality relationship with the teacher can be an important resource. In this way, a vicious circle can be avoided in which negatively colored interactions with the teacher further reduce the student's motivation and learning success.

Professional teacher behavior is characterized by a high degree of warmth and sensitivity (high communion), as this is known to benefit student motivation and performance and fosters a positive relationship between the teacher and the student (Roorda et al., 2011; Roorda, Jak, et al., 2017; Pianta, 1992). Moreover, to respond to individual differences in students' learning prerequisites and behaviors, professional teacher behavior is complementary in its agency to the student's competence (Bernard et al., 2019). Our results can inform practitioners and researchers in school psychology that interpersonal teacher behavior is always a blend of agency and communion: investigating the dimensions separately can thus be insufficient to identify advantageous and disadvantageous interpersonal teacher behaviors. Our newly developed circumplex-observation instrument can be used as a self-reflection feedback tool by teachers and as an observation tool by school psychologists to identify both supportive and problematic teacher-student interactions. To more effectively

support disadvantaged students (with regard to their scholastic competence or social skills), special attention should be given to the quality of interpersonal teacher behavior in dyadic interactions ensuring that all students receive the necessary warmth and adaptive guidance to foster their academic growth.

Supplementary Material for the Article:

A Circumplex Approach to Identify Complementarity in Dyadic Teacher Behaviors Depending on Student Communion and Competence

Note S2.1

Pilot Tests for the Observational Measures

In a first pilot study, we tested whether the developed items for teacher behavior comprise the theoretically intended blend of agency and communion. Sixty-six trained university students that were enrolled in a teacher education master program indicated on an 8-point-scales[10] ranging from 1 (*not at all communal/ agentic*) to 8 (*very communal/ agentic*) for each of the 35 items how communal and how agentic the teacher behavior described by the item was in their perception. Prior to the rating, students underwent a 60-minute training about circumplex models on teacher behavior using the dimensions agency and communion. The ratings were used to compute the angular position of each item (see Equation S2.1 in Note S2.2). We then compared the empirically determined angle (see Equation S2.1 in Note S2.2) with the ideal angle interval ($\pm$ 22.5°) from the theoretical octant model and additionally evaluated the VL (see Equation S.2 in Note S2.2). All results from our pilot test can be found in Table S2.1 and were used for item selection for our main study.

For a second pilot test, we trained 95 university teacher enrolled in a teacher education bachelor program (in the following: observers) in the use of the observational measures for teacher and student behavior through video-based exercises and examined whether they assessed teachers' and students' l behavior similarly (interrater reliability). We used eight different videos that were provided to us from the Qualitäts- und Unterstützungs-Agentur Landesinstitut für Schule (QUA-LiS NRW; Federal Quality and Support Agency for Schools in Northrhine-Westphalia, n.d.). In total, observers were equally and randomly distributed across the eight videos (video-length: M = 7.50 minutes, Range [3.43, 9.44]). Observers were asked to describe the teacher's interpersonal behavior towards the child shown in the video on

[10] We recoded all variables ranging from -1 (*not at all communal/ agentic)* to 1 (*very communal/ agentic)*.

the items of our circumplex instrument on five-point Likert-scales from 1 (*strongly disagree*) to 5 (*strongly agree*). Additionally, observers were asked to describe the student's behavior (communion and learning-related key competencies; Helm et al., 2012; Scherzinger et al., 2021).

Note S2.2

Statistical Analysis Procedure for Item Selection

To investigate whether our observational measure met the circular properties, we conducted a structural analysis to test the model fit of the items in the two-dimensional circumplex space. Following the recommendations of Hopwood and Donnellan (2010), we combined exploratory and confirmatory approaches for the analysis. For all analyses, we used the statistical software R 4.0.5 (R Core Team, 2021).

A measure that captures a circumplex model geometrically comprises ordered variables equally distributed across a circle perimeter (Gurtman & Pincus, 2003). Each item is represented through its polar coordinates in the two-dimensional space and can be evaluated against their circular properties: (a) the *projection angle* captures each item's interpersonal content through the underlying octant facet, (b) the *vector length* (VL; distance from the center of the coordinate system) provides information about each item's interpersonal content (Wiggins & Broughton, 1991). Taking the distance along the x-axis (*communion*) and the distance along the y-axis (*agency*), the projection angle θ_i and the vector length (VL) of each item *i* is computed as follows (Gurtman, 1991):

$$\theta_i = tan^{-1}\left(\frac{\text{agency}_i}{\text{communion}_i}\right) * \frac{180}{\pi} \tag{S2.1}$$

From the Pythagorean theorem follows:

$$VL_i = \sqrt{\text{agency}_i{}^2 + \text{communion}_i{}^2} \quad \text{(S2.2)}$$

For item selection we followed the common iterative procedure (I. Jacobs & Scholl, 2016; see also Trobst, 2000). First, to determine the empirical location of each item we performed a principal component analysis (PCA) extracting two orthogonal factors which represent agency and communion as axes in the two-dimensional space. Then, the correlations with these two factors, e.g., the factor loadings, express the magnitude of agency and communion within each item and thus can operate as polar coordinates to map each item onto the two-dimensional circumplex space (Wiggins & Broughton, 1991). The PCA can ensure the theoretically conceptualized orthogonality, but not the position of the axes. Due to the complexity of structural requirements in regards to the circumplex correlational structure, axes' position can dramatically differ from the theoretical structure (e.g., the plot of circumplex seems to be shifted) (McCrae et al., 1996). A solution to this problem is the Procrustes rotation which closely maps the factor structure to the theorized target structure with a least-squares best fit (McCrae & Costa Jr, 1989; Schönemann, 1966).

Second, to apply Procrustes rotation to our extracted factor loadings, we created a matrix of ideal factor loadings by item-wise calculating cosine (for ideal loadings with the communion axes) and sine (for ideal loadings with the agency axes) of the theoretically ideal angle of the scale. We then used the R-package “EFA.dimensions” (B. P. O’Connor, 2022) to map the 2 x 35 matrix with extracted factor loadings from the two-factorial PCA onto the 2 x 35 matrix with theoretical ideal factor loadings. Then, the Tucker-Wrigley-Neuhaus coefficient of factor congruence was used to evaluate the similarity of the two factor loadings matrices (Guadagnoli & Velicer, 1991).

Third, we used the rotated factor loadings as representatives of agency and communion to calculate the angular location as well as the vector length.

Item Selection

We discarded items that proved empirically not to be located in the octant that was proposed by the theoretical model or that did not have a sufficient interpersonal content (Gurtman, 1991): angles should not exceed $\pm$ 22.5° around the hypothesized scale position and the vector length should be larger than .30 (Gurtman, 1991). Additionally, items should sufficiently cover the octant space and the internal consistency of the scale should be acceptable.[11] The exploratory analysis was used to iteratively discard and select items until all criteria were best met.

Note S2.3

Results of the Item Selection

To locate each item onto the circumplex space, we performed a PCA at the item level and extracted two orthogonal factors representing agency and communion as circumplex axes. Both axes explained nearly equal variance proportions (Communion: 25 %; Agency: 22 %) in teacher behavior. Angles and VL for each item are depicted in Table S2.1. The item selection procedure revealed that in both samples (pilot study 1 and main study) all criteria were best met with 22 selected items (13 items were discarded), of which, after selection was completed, 20 items obtained perfect alignment, with the remaining 2 items showing only minor angular deviances. Each octant was represented by two or three items, obtaining a parsimonious and internally consistent solution (α > .64; Spearman-Brown-Coefficients > .60). All selected items showed a satisfactory VL. A plot of the selected items can be found in Figure S2.1.

[11] We follow the same criteria for item selection as Jacobs and Scholl (2016).

Table S2.1

Item Label, Translation (English) form the German Original, Ideal Angle as well as Angel and Vector Length (VL) from the Pilot Test and the Study Before (Pre) and After (Post) the Item Selection Procedure

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
		Helping-guiding						
HG1	**The teacher willingly shows the student step by step how to solve a problem when difficulties arise.**	22.5 [0; 45]	49.587	0.725	355.489	0.647	358.050	0.697
HG2	**The teacher helps the student to identify misconceptions and to find the solution on his/her own.**	22.5 [0; 45]	12.752	0.571	2.574	0.705	3.742	0.749
HG3	The teacher makes sure for the student that help is available for solving tasks (e.g., help cards).	22.5 [0; 45]	33.602	0.663	63.129	0.534	-	-
HG4	**When transitioning to a new learning activity, the teacher helps the student to master this transition.**	22.5 [0; 45]	30.384	0.744	35.816	0.519	38.352	0.526

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
		Directing						
D1	**When setting tasks, the teacher always checks that the student has understood what he/she has to do.**	67.5 [45; 90]	65.470	0.676	68.584	0.567	67.796	0.675
D2	**The teacher often explains the solution of a problem step by step to the student.**	67.5 [45; 90]	44.590	0.662	59.707	0.728	62.885	0.799
D3	**The teacher always gives the student clear and step-by-step instructions when he/she should work on which tasks in class.**	67.5 [45; 90]	86.048	0.648	63.745	0.450	61.736	0.598
		Demanding-strict						
DS1	**The teacher often directly says to the student something like that now is the time to pay attention.**	112.5 [90; 135]	111.945	0.604	108.853	0.761	114.515	0.751
DS2	The teacher often says to the student something lke that he/she should hurry up to finish an activity in class.	112.5 [90; 135]	146.586	0.706	110.236	0.816	-	-

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
DS3	**The teacher makes sure that the student strictly follows the instructions in class.**	112.5 [90; 135]	109.697	0.684	107.208	0.684	107.878	0.663
DS4	The teacher expects the student to complete tasks exactly as given.	112.5 [90; 135]	126.323	0.827	133.903	0.569	-	-
DS5	**The teacher often demands from the student to actively participate in class.**	112.5 [90; 135]	118.217	0.523	109.798	0.790	114.810	0.761
		Admonishing						
A1	**The teacher explicitly tells the student that the set tasks must be completed without objections.**	157.5 [135; 180]	150.527	0.768	150.466	0.647	155.233	0.621
A2	The teacher makes it clear to the student that the given tasks must be completed, otherwise negative consequences will follow.	157.5 [135; 180]	147.455	0.874	124.859	0.546	-	-

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
A3	The teacher imposes negative consequences because of the student's work behavior.	157.5 [135; 180]	155.300	0.910	111.955	0.506	-	-
A4	**In class, the teacher does not give the student too much freedom of actions in class.**	157.5 [135; 180]	135.370	0.660	151.589	0.765	151.185	0.780
		Ignoring-resigning						
IR1	**The teacher moves from one learning activity to the next without paying particular attention to how the student is coping.**	202.5 [180; 225]	184.288	0.833	195.659	0.749	198.149	0.778
IR2	The teacher teaches the lesson according to the plan without being dissuaded by the student from doing so.	202.5 [180; 225]	139.823	0.898	187.446	0.551	-	-
IR3	**The teacher seems to have given up trying to influence the student's work behavior.**	202.5 [180; 225]	228.625	1.123	197.579	0.604	202.342	0.674
IR4	The teacher does not pay much attention to the student.	202.5 [180; 225]	214.504	0.945	230.039	0.787	-	-

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
		Indeterminate-waiting						
IW1	The teacher does not provide the student with any materials or tasks specially prepared for him/her.	247.5 [225; 270]	206.385	0.662	216.116	0.706	-	-
IW2	**The teacher lets the student work in class without planning much ahead for him/her or interfering too much.**	247.5 [225; 270]	271.895	0.775	237.189	0.738	244.322	0.715
IW3	**The teacher lets the student run along in class.**	247.5 [225; 270]	236.433	0.952	231.932	0.777	234.059	0.767
IW4	**The teacher rarely interferes when the student is working on tasks.**	247.5 [225; 270]	245.156	0.637	243.022	0.740	247.397	0.737
IW5	The teacher usually only reacts to the student if he/she has questions on his/her own or cannot get along.	247.5 [225; 270]	214.856	0.519	228.819	0.798	-	-
		Participating-tolerating						

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
PT1	When the teacher assigns tasks, the student gets to choose tasks in which he/she learns something new.	292.5 [270; 315]	317.238	0.625	2.861	0.544	-	-
PT2	**The teacher allows the student to shape his/her own learning process without giving precise instructions.**	292.5 [270; 315]	295.064	0.836	317.901	0.669	319.624	0.691
PT3	The teacher provides a lot of freedom in learning to the student.	292.5 [270; 315]	300.569	0.639	327.485	0.753	-	-
PT4	**The teacher observes the student's work behavior and willingly lets them have their way.**	292.5 [270; 315]	280.755	0.620	292.232	0.786	297.569	0.798
PT5	**If the student tries his/her own approaches of learning in class, the teacher willingly allows this.**	292.5 [270; 315]	320.397	0.729	298.099	0.662	303.830	0.648
	Understanding-interested							

Table S2.1 (continued).

Label	Item	Ideal angle [lower bound; upper bound]	Angle pilot test	VL pilot test	Angle study (pre-selection)	VL study (pre-selection)	Angle study (post-selection)	VL study (post-selection)
UI1	**The teacher always listens patiently and with interest to the student when he/she contributes something in class.**	337.5 [315; 360]	336.623	0.810	338.711	0.556	346.279	0.562
UI2	The teacher makes sure that the student can find something of his/her interest in the work materials.	337.5 [315; 360]	7.320	0.696	346.395	0.723	-	-
UI3	To convey the learning content to the student, the teacher often tries to make references to his/her interests.	337.5 [315; 360]	14.541	0.738	351.106	0.738	-	-
UI4	**The teacher endeavors to respond to the interests expressed by the student and to include him/her into classroom activities.**	337.5 [315; 360]	6.197	0.676	346.829	0.804	347.215	0.797
UI5	**The teacher asks the student what new tasks or questions he/she is interested in and what he/she would like to work on.**	337.5 [315; 360]	343.516	0.694	353.217	0.715	351.341	0.668

Note. All angles are given in degree. **Bold** Items are selected.

Table S2.2

Results from Linear Regression Analysis Predicting Student Competence and Communion

	Student Competence				Student Communion									
	Grade		Learning-related key competencies		Sincere		Cooperative		Polite and respectful		Cold and reserved		Hostile	
	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2	M1	M2
	Est. (SE)	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*	*Est. (SE)*
Intercept	**4.30** (0.13)	**3.95** (0.35)	**2.92** (0.15)	**2.38** (0.19)	**3.37** (0.17)	**2.33** (0.33)	**3.56** (0.20)	**2.59** (0.27)	**3.66** (0.18)	**2.92** (0.28)	**2.09** (0.19)	**2.69** (0.34)	**1.64** (0.13)	**2.07** (0.22)
Agency[a]	**-0.61** (0.15)	**-0.62** (0.14)	**-0.40** (0.15)	**-0.50** (0.15)	-0.17 (0.20)	-0.30 (0.23)	**-0.56** (0.16)	**-0.63** (0.17)	**-0.49** (0.14)	**-0.53** (0.16)	0.13 (0.19)	0.15 (0.22)	**0.47** (0.11)	**0.49** (0.12)
Communion[b]	**0.44** (0.12)	**0.46** (0.15)	**0.56** (0.11)	**0.63** (0.11)	**0.50** (0.15)	**0.62** (0.13)	**0.46** (0.17)	**0.52** (0.16)	**0.51** (0.13)	**0.59** (0.12)	-0.30 (0.17)	**-0.41** (0.15)	**-0.30** (0.11)	**-0.42** (0.09)
School Type[c]		0.00 (0.24)		**0.42** (0.15)		0.31 (0.22)		**0.71** (0.25)		0.42 (0.22)		**-0.56** (0.20)		-0.24 (0.24)
Teacher Gender[d]		0.32 (0.24)		0.26 (0.18)		**0.79** (0.26)		**0.42** (0.21)		**0.42** (0.20)		-0.13 (0.34)		-0.27 (0.25)
Student Gender[e]		0.33 (0.29)		0.16 (0.18)		**0.61** (0.26)		**0.47** (0.23)		**0.48** (0.23)		-0.37 (0.24)		-0.06 (0.20)
θ	305.8°	306.6°	324.5°	321.6°	341.2°	333.8°	309.4°	309.4°	316.2°	318.1°	156.6°	159.9°	122.6°	130.6°

Note. All analyses we conducted using cluster-robust standard errors with the R-package "miceadds" (Robitzsch et al., 2021). [a] Agency is computed according to the following formula $\frac{1}{4}\sum_{i=1}^{8}(\sin(\varphi_i)S_i)$, where S_i denotes the individual octant scale sore, φ_i denotes the theoretical

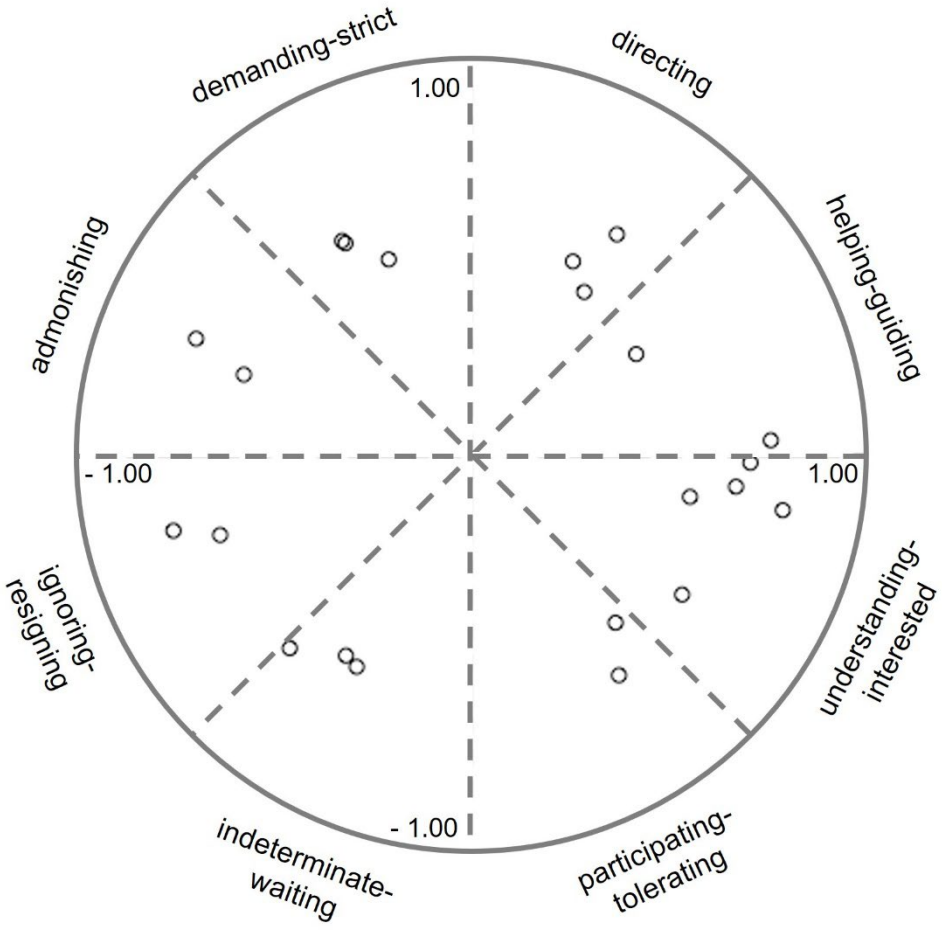
Table S2.2 (continued).

angular location of the scale. [b] Communion is computed according to $\frac{1}{4}\sum_{i=1}^{8}(\cos(\varphi_i)S_i)$. [c] 0 = Secondary school, 1 = Primary school. [d] 0 = Male teacher, 1 = Female teacher. [e] 0 = Boy, 1 = Girl. θ can be derived from the regression estimates according to $tan^{-1}\left(\frac{Est_{\text{agency}}}{Est_{\text{communion}}}\right) * \frac{180}{\pi}$.

Bold estimates indicate $p < .05$.

Figure S2.1

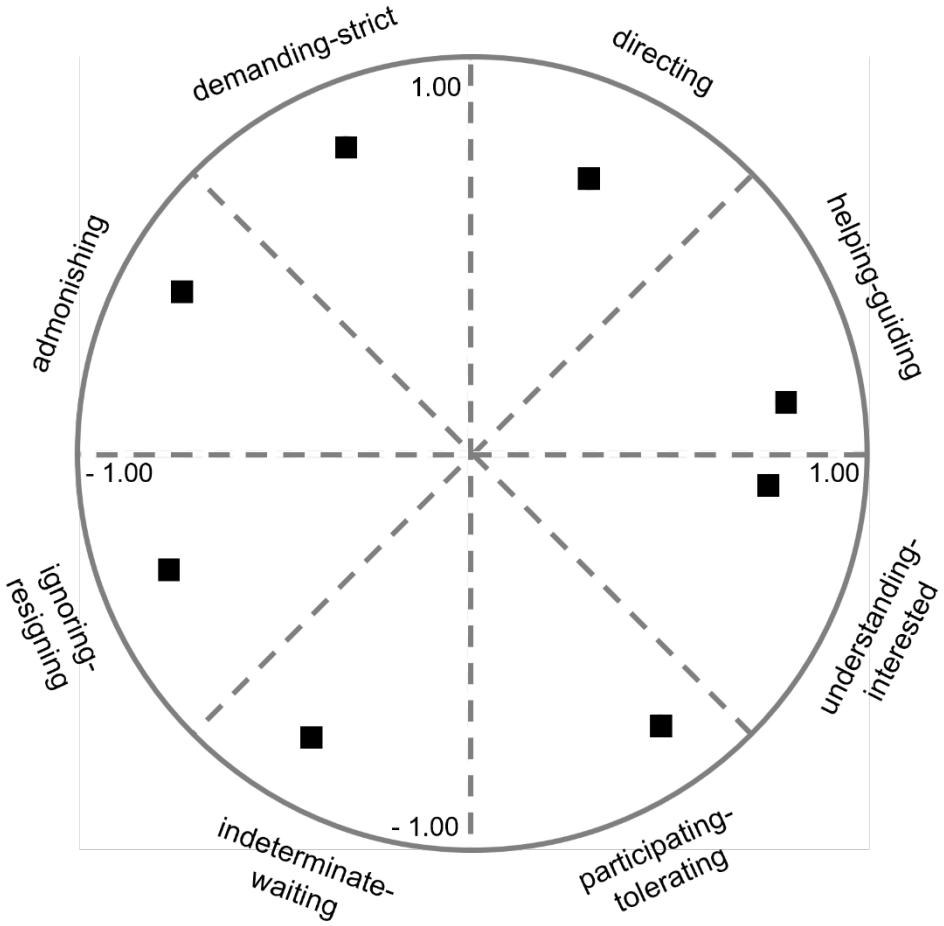
Plot of the Final Item Selection



Note. The location is computed using Procrustes-rotated factor loadings (McCrae & Costa Jr, 1989). The Tucker-Wrigley-Neuhaus coefficient was at 97.6%, which expressed a high congruence between the target and Procrustes-rotated loadings (Guadagnoli & Velicer, 1991). Dashed lines denote the theoretical octant bounds.

Figure S2.2

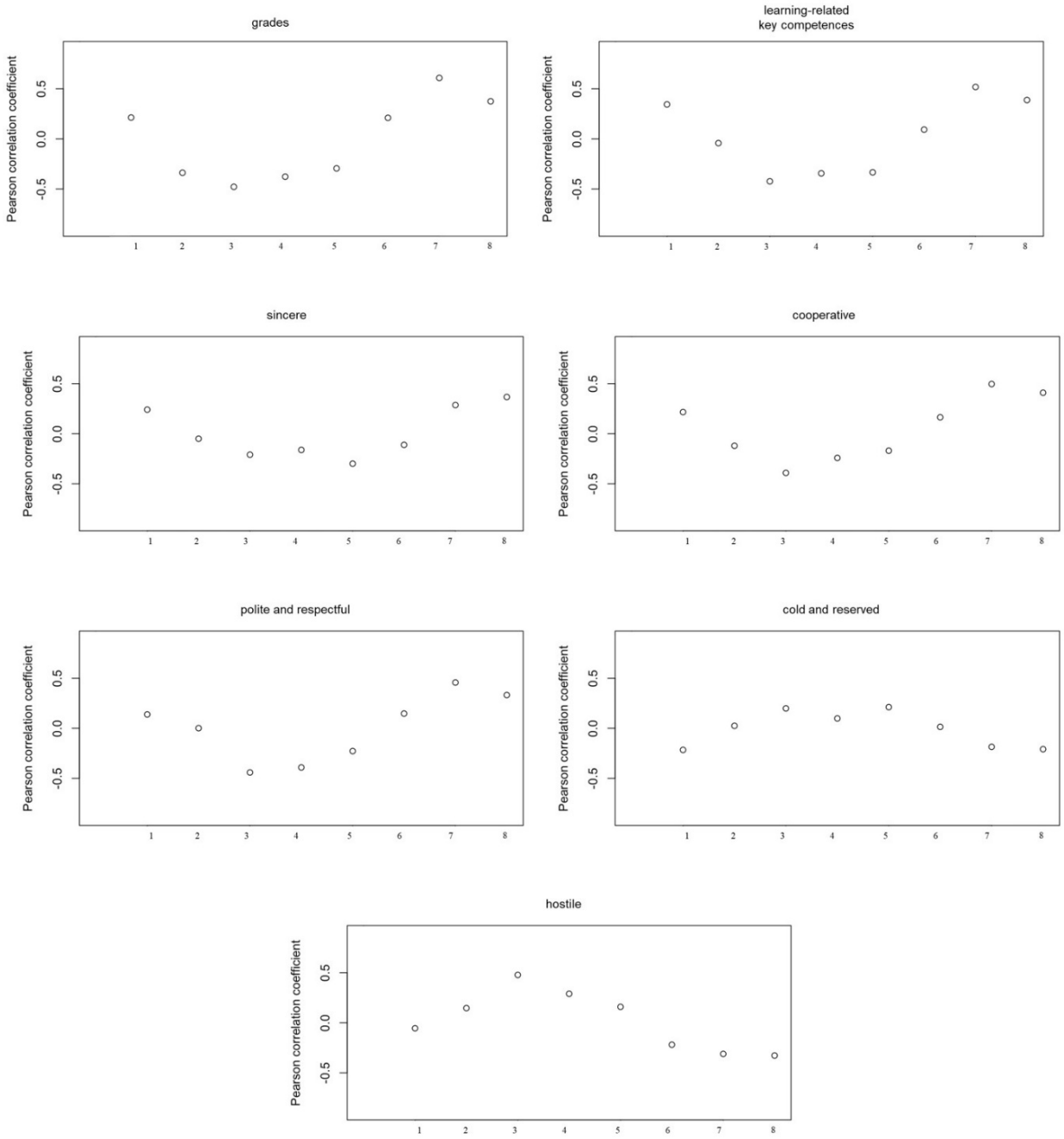
Estimated Circular Position of the Octant Variables from the Observation Instrument for Teacher Interpersonal Behavior



Note. Dashed lines denote the theoretical octant bounds.

Figure S2.3

Correlational Patterns Between Teacher Interpersonal Behavior Octants and Student Competence and Communion



Note. 1. helping- guiding, 2. directing, 3. demanding- strict, 4. admonishing, 5. ignoring- resigning, 6. indeterminate- waiting, 7. participating- tolerating, 8. understanding- interested.

CHAPTER 3 – Study 2: Teaching Anxiety in Mathematics. Associations with Teacher Agency and Communion in Teacher-Student Dyadic Interactions.

Note. This is the first author's version of a paper under review at the time. It may differ from the final published version due to revisions made during the editorial and peer review process, and it should not be cited as the final version.

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CRediT authorship contribution statement

MF: conceptualization, methodology, formal analysis, investigation, data curation, visualization, writing- original draft; BH: funding acquisition, conceptualization, supervision, writing- review & editing.

Teaching Anxiety in Mathematics. Associations with Teacher Agency and Communion in Teacher-Student Dyadic Interactions

Abstract

This study investigates how elementary school teachers' anxiety to teach mathematics plays out in their interpersonal behavior in dyadic teacher-student interactions. Building on Interpersonal Theory, we describe teachers' behavior on two fundamental dimensions: communion (warmth, sensitivity) and agency (direction, guidance). Data was collected from 161 elementary school teachers (129 female) who described their interpersonal behavior toward individual students of their class (2,235 teacher-student dyads). Using multilevel structural equation modeling, we found that teaching anxiety in mathematics was associated with low communion in teachers' interpersonal behavior. It seems, anxiety to teach mathematics hinders high quality teacher-student interactions. Interestingly, while both male and female teachers who were anxious to teach mathematics displayed low communal behavior, anxiety was associated with low agency in men but moderately strong agency in women. These findings suggest that men and women cope differently with their anxiety to teach mathematics. To prevent teachers from engaging in low communal interpersonal behaviors, we discuss how they can be supported to better cope with their anxiety to teach mathematics.

Keywords. Interpersonal Behavior; Agency; Communion; Mathematics Anxiety; Gender; Student-Teacher-Relationship

While extensive research documents that many school students are anxious about math (Barroso et al., 2021; Ma, 1999; Namkung et al., 2019), comparatively little attention has been given to anxiety teachers may experience when teaching math. Math teaching anxiety refers to the apprehension and stress teachers feel when preparing for and delivering mathematical instruction and thus denotes the manifestation of math anxiety in the teaching profession (Hadley & Dorward, 2011; F. Liu, 2016; Peker, 2009). Recent studies revealed that math anxiety is notably prevalent among elementary school teachers (Artemenko et al., 2021; Hughes et al., 2019; Mizala et al., 2015). While teachers may develop more effective coping mechanisms over time, research consistently indicates that math related anxiety persists throughout their careers (Gresham, 2018; Hughes et al., 2019). Further, prior research has shown that math related anxiety in the teacher can adversely affect student emotional experiences (McLean et al., 2023) and even learning outcomes (Beilock et al., 2010; Hadley & Dorward, 2011; Ramirez, Hooper, et al., 2018; Schaeffer et al., 2021) .

How Anxiety to Teach Math Plays out in Classroom Dynamics

Several potential pathways have been suggested through which teachers' math related anxiety might influence classroom dynamics. Math-anxious teachers often display lower teaching self-efficacy (Gonzalez-DeHass et al., 2017; Gresham, 2009), are less well organized (Sinclair & Ryan, 1987), and have lower problem-solving skills when teaching math (Akinsola, 2008). Also, teachers how are anxious when teaching math adopt more traditional teaching approaches, like teacher-oriented rather than student-oriented practices. Violating established standards for math education (for Germany, see Kultusministerkonferenz [German Conference of Education Ministers], 2022; for the US, see National Council of Teachers of Mathematics, 2000), they often avoid procedures such as open-ended problem solving, peer collaboration, and student-led discovery of mathematical ideas (Bush, 1989; Hadley & Dorward, 2011; Hughes et al., 2019). As a result, they inhibit students' active engagement

with mathematical content and are viewed by students as endorsing a fixed mindset toward learning math (Ramirez, Hooper, et al., 2018).

However, we are not aware of any research investigating how the teacher's math related anxiety relates to the quality of his or her interpersonal behavior in student-teacher interactions. Teachers do not only have to deliver high quality instruction and manage the class, they also should invite every student to engage in a high-quality interpersonal dyadic relationship with them, providing emotional support in stressful situations and learning assistance adapted to the individual student's needs (Hamre & Pianta, 2001; Klieme, 2018). In our study we therefore investigated how the teacher's anxiety to teach math relates to their interpersonal behavior in student-teacher relationships.

Math Teaching Anxiety in Elementary School Teachers

Emotions, such as math anxiety, are typically defined as multicomponent changes in an individual's psychophysical system in response to certain stimuli (Scherer & Moors, 2019; Shuman & Scherer, 2014), involving affective, cognitive, physiological, motivational, and expressive-behavioral elements (Moors et al., 2013; Pekrun et al., 2023; Scherer et al., 2001). We focus specifically on math teaching anxiety—a subconstruct of general math anxiety—which refers to the anxiety teachers experience specifically in the context of preparing for and delivering math instruction (Hadley & Dorward, 2011; F. Liu, 2016; Peker, 2009). Of particular concern is the high prevalence of math related anxiety among elementary school teachers (Artemenko et al., 2021; Mizala et al., 2015), who are responsible for children's foundational mathematical education. The high prevalence may be partly explained the prior experience with the subject (Brady & Bowd, 2005) and by educational policies in many countries, including Germany, where elementary school teachers are required to study and teach math regardless of their personal subject preferences (Porsch, 2017).

Teacher Behavior in an Interpersonal Circumplex

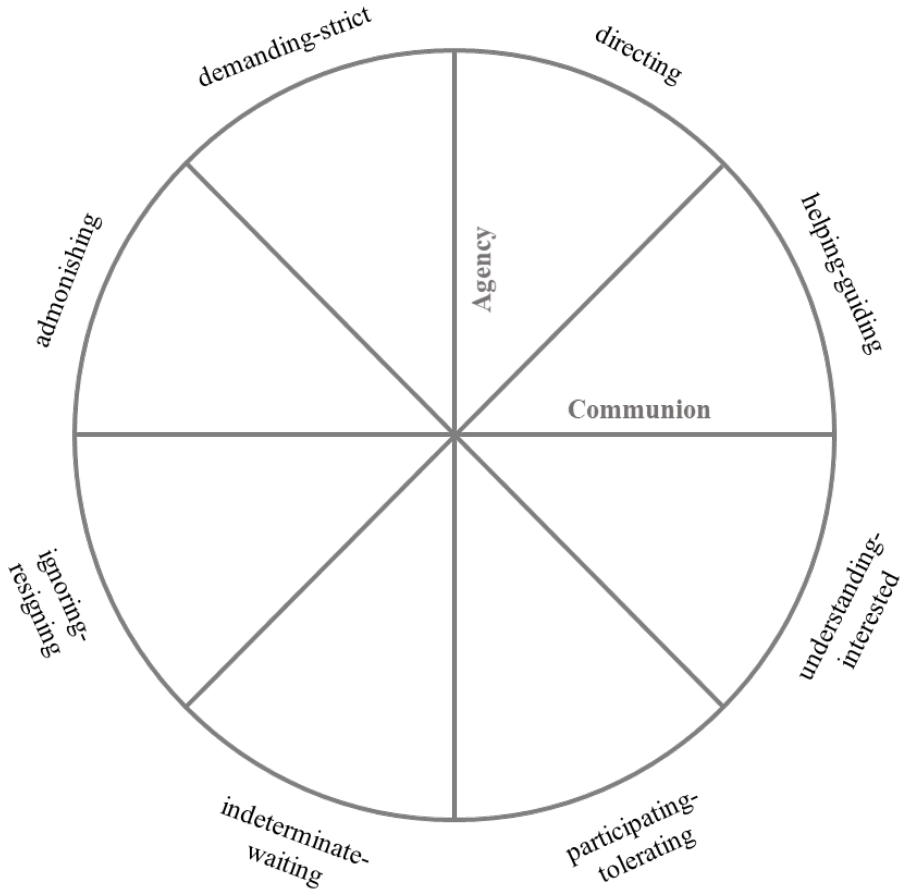
We aim to illuminate how math teaching anxiety translates into teachers' interpersonal behaviors in student-teacher dyads. Building on Interpersonal Theory (Horowitz & Strack, 2011; Leary, 1957), we describe dyadic teacher behaviors (Horowitz & Strack, 2011; Leary, 1957) along the dimensions of communion and agency. Communion reflects the affective quality of interpersonal behavior —warmth, sensitivity, and emotional support (Horowitz & Strack, 2011). It pertains to teacher behaviors that ensure closeness and emotional support for a student. Agency describes behaviors aimed at goal achievement, such as dominance, guidance, and control (Horowitz & Strack, 2011). It pertains to teacher behaviors such as instructing and directing a student and monitoring their learning progress. Teachers can cultivate a positive teacher-student relationship by employing a high degree of communion (for second-order meta-analysis, see Emslander et al., 2025), while withdrawing from overly strong agency to foster the student's autonomy (Aelterman & Vansteenkiste, 2023; Koeppen et al., 2025).

The interpersonal circumplex model (Gurtman & Balakrishnan, 1998) provides a framework for measuring these dimensions, partitioning the interpersonal space into eight distinct behavioral octants (Kreutzmann et al., 2024; Wubbels et al., 1993), each characterized by varying degrees of agency and communion (see Figure 3.1). Thus, a teacher's behavior towards a student can be described as a profile across these octants. Because the octants are distributed around the circle, the profile can be mathematically summarized into two overall scores—one for agency and one for communion—by combining the octant scores based on their positions in the circle. The two scores can then be plotted as coordinates in the circular space, forming a vector that visually represents the teacher's interpersonal behavior profile (vector-method, see Gurtman & Pincus, 2003; Wiggins et al., 1989). The vector-based approach can also be used to examine how external factors—such as a teacher's math teaching anxiety—relate to interpersonal behavior. By analyzing how math teaching anxiety is

associated with a teacher's agency and communion scores, we mapped these associations into the circular space (Gurtman & Pincus, 2003).

Figure 3.1

The Circumplex Model of Dyadic Interpersonal Teacher Behavior



We examined teacher interpersonal behavior at both the student and class level, acknowledging that variance can stem from characteristics of either the individual student or the teacher. As regards effects on the student level, research shows that teachers' interpersonal behavior varies considerably between students of their classes, as teachers calibrate their behavior according to individual student characteristics (Frühauf et al., 2025; Kreutzmann et al., 2024; Roorda, Spilt, et al., 2017). As regards the class level, research shows that a relevant proportion of variance in interpersonal behavior can be attributed to interpersonal teaching styles (Pennings et al., 2018) or teaching-related beliefs (Kreutzmann et al., 2024).

How Math Teaching Anxiety Relates to Teacher Interpersonal Behavior

We hypothesized that math teaching anxiety will be associated with teacher behaviors low in communion. Appraisal theories (Frenzel et al., 2020; Moors et al., 2013) suggest that anxiety arises when attainment of the personal goal to appear competent while delivering an effective and cognitively stimulating math lesson is at stake. Importantly, anxiety in turn may disrupt the teacher's capacity to engage in positive interpersonal behaviors, such as displaying warmth and responding sensitively to a student's needs (Gable & Impett, 2012). Hence, we hypothesized that teachers with math teaching anxiety struggle to engage in a positive, supportive relationship with a student, evident in math teaching anxiety negatively relating to teacher communion in the interpersonal circumplex.

Regarding agency, it is more difficult to make a directional prediction regarding its relationship with math teaching anxiety. Generally, anxiety is typically related to behavioral tendencies of avoidance (Carver, 2001). Consistently, research has shown that general math anxiety is associated with avoidance behaviors (Choe et al., 2019; Hembree, 1990). In the case of math teaching anxiety, these avoidance behaviors might manifest in teachers steering clear of situations where they feel their mathematical competence is challenged—such as avoiding certain student questions, hesitating to engage in more complex teaching strategies, or inhibiting an in-depth discussion of math content with the students (Akinsola, 2008; Bush, 1989). These avoidance behaviors can be reflected in lower levels of teacher agency, as the teacher refrains from taking the initiative or from engaging actively in the teaching process, leading to a more passive role in the classroom. However, other study results suggest that math-anxious teachers may adopt rigid, highly structured approaches to teaching, thus preventing thorough student engagement (Bush, 1989; Hughes et al., 2019). Such behaviors may indicate that the teacher tries to maintain control and to circumvent situations where their lack of expertise could become apparent. These inconsistencies are also evident in research on subject-unspecific anxiety, where some studies have found an association with low teacher

agency (Donker et al., 2020), while others report a link to high agency (Kreutzmann et al., 2024). Against the background of these inconsistent findings, we refrained from specifying a directional hypothesis to examine the relationship between teacher math teaching anxiety and agency in interactions with students.

The Case of Gender

Women are disproportionately strongly affected by math anxiety (Vos et al., 2023), with female elementary school teachers reporting particularly high levels (Artemenko et al., 2021). Math remains associated with gender-related stereotypes favoring men (Nosek et al., 2002), and the stereotype persists among teachers, too (Makarova & Herzog, 2015; Robinson-Cimpian et al., 2014; Tiedemann, 2002). Additionally, societal norms shape how men and women display emotions, with the expression of fear and anxiety being less socially acceptable for men (Brody & Hall, 2008; Timmers et al., 1998). As a result, math teaching anxiety may play out differently in male and female teachers' interpersonal behaviors.

The Present Investigation

The current study examines how female and male elementary school teachers' math teaching anxiety manifests in their interpersonal behavior during teacher-student interactions. Specifically, we investigated this relationship along the two fundamental dimensions of interpersonal behavior (Horowitz & Strack, 2011; Leary, 1957): agency and communion. Based on appraisal theories (Frenzel et al., 2020; Moors et al., 2013), we hypothesized that math teaching anxiety is negatively associated with teacher communion (*Hypothesis 1*). We further predicted math teaching anxiety to be systematically related to teacher agency (*Hypothesis 2*), without being able to predict the direction of the association. Additionally, considering documented gender differences in math anxiety (Artemenko et al., 2021) and emotional expression (Timmers et al., 1998), we explore whether these relationships differ between male and female teachers.

Method

Sample and Procedure

We asked a total of 161 (129 female) German math teachers to describe their interpersonal behavior towards the individual students of their respective class from grades 1 to 6 (on average 13.8 (*SD* = 6.1) students per teacher), resulting in 2,235 dyadic behavior descriptions (towards 927 girls, 1060 boys, and 4 students identifying as diverse; 247 missing values). Teacher age was recorded in five categories: 27.3% of teachers were under 29 years old, 31.1% were between 30 and 39, 21.7% between 40 and 49, 17.4% between 50 and 59, and 2.5% were older than 60 years of age. Most teachers had a teaching experience below 10 years (44 % below 5 years, 25.8 % between 5-9, 16.4 % between 10-19, 7.5 % between 20-29, and 6.3 % more than 30 years of teaching experience). About 16 % of the sample were at the beginning of their professional career, where teachers teach under supervision and have to pass examinations (so-called *Referendariat*). In the city studied, elementary school comprises grades 1 to 6. Our teachers taught the following grade levels: $n_{grade\_1} = 1$, $n_{grade\_2} = 2$, $n_{grade\_3} = 49$, $n_{grade\_4} = 39$, $n_{grade\_5} = 20$, $n_{grade\_5} = 20$, $n_{grade\_6} = 14$ (36 mixed-year grades or missing values).

Data for this study were collected as part of a research project funded by the German Research Foundation (anonymized) and approved by both the School Authorities (anonymized) and authors' institutional ethics committee (anonymized). To encourage participation, teachers were offered a monetary incentive of 100 Euros and the option to receive a summary of the main study results. Initially, all participating teachers were asked to describe their behavior toward the entire class. However, during the recruitment process, as it was difficult to reach the required number of participants, the procedure was adjusted, and a subset of teachers (31 %) was asked to select only ten students from their classroom while ensuring student diversity across various characteristics. To rule out that the change in procedure affected results, we included the procedure as a control variable (*Study Sample*).

To control for the potential impact of student math competencies, we assessed their grades in math via teacher report. As grades can be biased (Bonefeld & Dickhäuser, 2018; Hofer, 2015), in a subsample of 41 classes we assessed students' math competencies with their parents' informed consent. Of the 2,235 students to which teachers' behavioral descriptions pertained, 736 students (32 %) were tested using a standardized achievement test.

Measures

Interpersonal Behavior

Teachers described their interpersonal behavior towards each student with the 18-item version of the Questionnaire on Dyadic Interpersonal Teacher Behavior (DITeB; Kreutzmann et al., 2024). Each of the items is located in one of the eight facets of the teacher interpersonal behavior circumplex (see Figure 3.1). For instance, the octant ignoring-resigning was assessed with items such as: "I teach the learning content according to plan, without letting [unique identifier] get in the way." The full item set, including the German original items and the English translation can be found in the Appendix of this dissertation. Teachers indicated their agreement to each item on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). We computed scale means for each of the octant scales (McDonald's ω ranges from .64 to .84) which were then used for estimating teacher agency and communion (see Statistical Analysis).

Math Teaching Anxiety

We assessed math teaching anxiety using a 5-item scale from Ganley et al. (2019). On a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*) teachers indicated their agreement to items such as: "I worry about making mistakes while solving math problems in front of my class." The full item set can be found in the Supplement (see Note S3.1). The reliability was McDonald's ω = 83.

Students' Competence

As a proxy for students' competence, we assessed and inverted their school grade in math ranging from 6 (*excellent*) to 1 (*insufficient*). In addition, a subsample of 32 % of the students underwent a standardized math test (for grades 3 to 4: BEFKI 3-4; Schroeders et al., in preparation; for grades 5 to 7: BEFKI 5-7; Schroeders et al., 2020). The test consists of 16 multiple choice questions and assesses the student's numeric reasoning skills. The tests were scaled using a one-parameter logistic IRT model, estimated by the R-package eatModel (R Core Team, 2021; Weirich & Hecht, 2018). Weighted Likelihood Estimates (WLE; Warm, 1989) were used as estimates of student ability (WLE reliability was $r_{wle} = .76$).

Control Variables

We controlled for teaching experience (1 = less than five years, 2 = 5-9 years, 3 = 10-19 years, 4 = 20-29 years, 5 = more than 30 years), whether the teacher was still in the *Referendariat* (0 = no, 1 = yes) and the grade level of the respective class. Further, we accounted for whether teachers described their behaviors towards the entire class or only 10 selected children (Study Sample, see procedure).

Statistical Analysis

We used M*plus* version 8.8 (Muthén & Muthén, 2017) for all analyses if not stated differently. For goodness of fit evaluation, we used the common criteria: χ^2 statistic, the Comparative Fit Index (CFI; Bentler, 1990), the Root Mean Error of Approximation (RMSEA; Browne & Cudeck, 1992), and the Standardized Root Mean Square Residual (SRMR; Jöreskog & Sörbom, 1993). We applied the established cutoff-criteria, with CFI values above .90, as well as RMSEA and SRMR values below .08 as representing a reasonable fit (Hu & Bentler, 1999).

Testing the Structural Models

We examined the circular structure of our circumplex model for teacher interpersonal behavior using the circular stochastic process model (SPMC; Browne, 1992; Nagy et al., 2019), a confirmatory approach to test its latent (quasi-)circumplex structure. To investigate

gender differences in the relationship between teacher math teaching anxiety and interpersonal behavior, we assessed whether the model was invariant across teacher gender groups. Following established procedures (Etzel et al., 2021; Nagy et al., 2010), we conducted a multigroup SPMC analysis in *Mplus*, systematically constraining key model parameters to ensure comparability. Additionally, we tested for measurement invariance of the math teaching anxiety measure (Chen, 2007) to demonstrate that differences were not due to measurement bias. Full details on the procedure are provided in the Note S3.2 in the Supplement.

Multilevel Multiple-Group Analysis

We estimated interpersonal profiles to illustrate the association of teacher interpersonal behavior with their math teaching anxiety. In particular, we decomposed the eight descriptions of teacher behavior towards each student into agency and communion scores for each student, representing the core dimensions of the circumplex model (Gurtman & Pincus, 2003; Wiggins, 1991). These two variables can function as coordinates to locate the teacher's interpersonal behavior profile towards each student into the circumplex space (with agency representing the coordinate along the y-axis and communion representing the coordinate along the x-axis). The scores of agency and communion that summarize the behavior profile of a teacher towards each student *j* were calculated according to the following formulae (with $S_{i,j}$ being the individual value of the octant scale i, and $\hat{\theta}_i$ being the angular location of the scale estimated by the SPMC):

$$Agency_j = \frac{1}{4}\sum_{i=1}^{8}(sin\left(\hat{\theta}_i\right)S_{j,i}) \tag{3.1}$$

$$Communion_j = \frac{1}{4}\sum_{i=1}^{8}(cos\left(\hat{\theta}_i\right)S_{j,i}) \tag{3.2}$$

Thus, we are using the empirically estimated angular location, in contrast to the theoretically intended angle of each octant scale to calculate teacher agency and communion.

To test our hypotheses, we employed multilevel structural equation modeling (ML-SEM) in *Mplus*. This approach accounts for the hierarchical structure of our data, where student-specific descriptions of teacher behavior are nested within teachers (Raudenbush & Bryk, 2002). Multilevel modeling allows us to separate variance into two levels: the within-level (student-level) and the between-level (teacher-level), enabling a more precise examination of individual and group-level effects on the outcome variables. This decomposition was performed automatically in *Mplus* using the latent variable decomposition framework.

In our model, we included teacher agency and communion as outcome variables at both the student-level (within -level) and the teacher level (between-level). At the within-level, we predicted teacher agency and communion from students' math grades and test scores, with both math grades and test scores group-mean centered to ensure that student-level effects were not confounded by between-teacher differences. At the between-level, teacher math teaching anxiety was modeled as a latent variable to account for measurement error. We predicted teacher agency and communion from math teaching anxiety while controlling for teacher characteristics, including teaching experience, educational level (*Referendariat*), grade level taught, and study sample (see procedure). We estimated coefficients with Robust Maximum Likelihood (MLR) to account for non-normality and accounted for missing values using Full Information Maximum Likelihood (FIML) as model-based approach to missing data handling (Enders, 2010). The standardized path estimates (β_{AG} and β_{CO}) of predicting teachers agency and communion by teachers math teaching anxiety at the teacher level can be used to visualize the relationship as the endpoints of a vector in the interpersonal circumplex (Gurtman, 1992; Gurtman & Pincus, 2003).

$$\delta = \tan^{-1}\left(\frac{\beta_{AG}}{\beta_{CO}}\right) * \frac{180}{\pi} \tag{3.3}$$

$$VL = \sqrt{{\beta_{AG}}^2 + {\beta_{CO}}^2} \tag{3.4}$$

The angular orientation δ of the vector points to the type of behavior (octants) that is most strongly associated with teacher math teaching anxiety and the vector length (VL) indicates the strength of the association (Gurtman & Pincus, 2003). To investigate gender differences in the association between teacher agency and communion with math teaching anxiety, we conducted a multiple-group analysis in *Mplus*, estimating separate models for men and women and systematically comparing the model parameters. To test for significant gender differences in the associations, we constrained the paths between math teaching anxiety and teacher agency/communion to be equal across men and women and then compared the model fit to the unconstrained model. To determine whether these constraints significantly worsened model fit, we used the Satorra-Bentler scaled chi-square difference test (Satorra & Bentler, 2010). A significant chi-square difference indicated that the constrained path differed between women and men, suggesting a moderating effect of gender.

Transparency and Openness

M*plus* analysis syntaxes and the data can be retrieved from https://osf.io/dte3u/?view_only=881f2e29318042f1b76c41f85fdbe4e1.

Results

Descriptive Statistics

Means, standard deviations, and bivariate correlations of the teacher level variables can be found in Table 3.1. On average, teachers' interpersonal behavior was high in both communion (M = 1.08, SD = 0.55) and agency (M = 0.07, SD = 0.61), which corresponds to the interpersonal behavior octant "helping-guiding" (see Figure 3.1). Teachers had a rather low math teaching anxiety (M = 2.76, SD = 1.35). Strength of teaching anxiety was independent of teaching experience, educational level (*Referendariat*), or grade level taught. Men (M = 2.55, SD = 1.25) and women (M = 2.81, SD = 1.81) did not differ in their levels of math teaching anxiety, $t(159) = -1.0$, $p = .319$. There was a negative but insignificant relationship between teachers' math teaching anxiety on the one hand and students' math

grades (r = -.10, p = .204) and test scores (r = -.09, p = 574) on the other. Students' math grades and test scores were moderately correlated (r = .32, p = .044), which may indicate that math grades do not purely reflect standardized competencies and could be influenced by other, potentially biasing, factors (Bonefeld & Dickhäuser, 2018; Hofer, 2015).

Table 3.1

Means, Standard Deviations, and Correlations for all Study Variables

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Teacher Math Teaching Anxiety	2.76	1.35									
2. Teacher Agency (class mean)	0.07	0.61	.01								
3. Teacher Communion (class mean)	1.08	0.55	-.11	.00							
4. Teacher Gender (0 = men, 1 = women)	0.80	0.40	.08	.01	.06						
5. Student Math Grades (class mean)	4.57	0.50	-.10	-.16*	.07	-.01					
6. Student Test Score (class mean)	0.54	0.68	-.09	-.25	.15	-.07	.32*				
7. Teacher Teaching Experience	2.06	1.22	-.02	-.05	.05	.06	-.12	.20			
8. Teacher Educational Level (*Referendariat*)	0.22	0.42	-.01	.10	-.13	.01	-.14	-	-.43**		
9. Class School Grade	3.92	1.08	-.07	-.02	.01	-.14	-.16	.70**	.16	-.10	
10. Study Sample	0.26	0.44	-.08	-.02	.15	-.06	.26**	-	.28**	-.32**	-.01

Note. * $p < .05$. ** $p < .01$.

Fit to the Structural Models

First, we tested the fit of the interpersonal teacher behavior scale to the circumplex model (for more information, see Note S3.2). Model comparisons revealed that the SPMC model with $m = 3$ components in the Fourier series led to the best fit (χ^2 (10) = 50.03, $p <$ .001, RMSEA = .042, CFI = .966, SRMR = .044, see Table S3.2). Hence, we used scale positions estimated by the SPMC model with three components in the Fourier series to decompose the octant scale scores into agency and communion scores for each student according to Equations 3.1 and 3.2. Further, the teacher interpersonal behavior measure was invariant across gender (see Table S3.2), indicating that any observed differences were not due to variations in the measure's circular structure. Additionally, testing the invariance for our measure of math teaching anxiety, results indicated we achieved strict invariance (see Table S3.3), allowing us to draw valid conclusions about factor means in our analyses (Chen, 2007).

Multilevel Analysis

To assess the reliability of aggregated individual-level ratings (agency, communion), we computed intraclass correlations ICC(1) and ICC(2) (Bliese, 2000; Lüdtke et al., 2007). The ICC(1) indicated that approximately 19% of variance in teacher agency and 32% of variance in teacher communion could be attributed to the teacher level, demonstrating that the means of these variables varied meaningfully between teachers. The ICC(2) values were robust: .76 for teacher agency, and .87 for teacher communion. These values indicate the within-teacher agreement regarding the description of their behavior towards a student and support the reliability of aggregating these variables at the teacher level. Consequently, the necessary preconditions for multilevel modeling were satisfied (Bliese, 2000; Lüdtke et al., 2007). Table 3.2 shows the estimates from the full sample SEM. In line with Hypothesis 1, results indicate that math teaching anxiety significantly related to lower communion at the teacher level ($\beta = -.21$, $p = .030$), even after controlling for teaching experience, educational

level, class grade level, and study sample. Contrary to Hypothesis 2, there was no significant association between teacher agency and math teaching anxiety (β = -.07, p = .427). Results for the student level indicate that the higher a student's math grades (β = -.37, p < .001) and competence (β = -.23, p < .001) were, the less agency the teacher exhibited towards him or her. Additionally, student's math grades (β = 0.28, p < .001) related positively and student test scores (β = -.15, p < .001) related negatively to communion the teacher displayed towards the student.[12]

[12] We additionally explored whether teacher math teaching anxiety influenced the association between agency/ communion and student math grades and test scores, probing cross-level interactions. However, results indicated that math teaching anxiety did not moderate the relationship between teacher agency and communion with the students' math grades and test scores.

Table 3.2

Results From the SEM Predicting Teacher Agency and Communion in the Full Sample

	Teacher Agency			Teacher Communion		
	B (SE)	β	*p*	*B (SE)*	β	*p*
Intercept	0.09 (0.27)	0.17	.078	1.10 (0.21)	2.18	< .001***
Student Level (within)						
Math Grade	-0.40 (0.04)	-.37	< .001***	0.20 (0.03)	.28	< .001***
Test Score	-0.21 (0.03)	-.23	< .001***	-0.09 (0.03)	-.16	< .001***
Teacher Level (between)						
Math Teaching Anxiety	-0.04 (0.05)	-.07	.427	-0.11 (0.05)	-.21	.030*
Teaching Experience	-0.01 (0.05)	-.02	.848	-0.004 (0.04)	-.01	.923
Teacher Educational Level	0.15 (0.21)	.11	.230	-0.14 (0.11)	-.12	.200
Grade Level Class	-0.01 (0.06)	-0.02	.857	0.003 (0.05)	.01	.953
Study Sample	-0.003 (0.12)	-0.002	.982	0.12 (0.10)	.11	.208
Variance explained R^2						
Within		.28			.06	
Between		.02			.07	

Note. We specified covariances for: student grades and competence at student level, teacher agency and communion on student and teacher levels, teacher teaching experience and educational level (*Referendariat*) at teacher level. Model fit: $\chi^2(38) = 88.92$, $p < .001$, CFI = .959; RMSEA = .024; $SRMR_{within} = .000$, $SRMR_{between} = .075$.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Our multiple-group analysis revealed a significant relationship between teacher math teaching anxiety and lower communion at the teacher level (Table 3.3). This relationship was significant for men (β = -.32, p = .015) and marginally significant for women (β = -.20, p = .070), partly supporting Hypothesis 1. However, there was no gender difference in the strength of the association between math teaching anxiety and communion (SB-$\Delta\chi 2$ = 1.29, Δdf = 1, p = .256).

A significant gender difference was found regarding the relationship between teacher math teaching anxiety and agency. For men, math teaching anxiety was related to lower agency towards the class (β = -.30, p = .007), whereas for women math teaching anxiety was unrelated to the agency they displayed towards the class (β = -.02, p = .836). To provide deeper insight into these relationships, we mapped the associations within the interpersonal circumplex by converting the path estimates using Equations 3.3 and 3.4. Figure 3.2 depicts the association for men (δ = 223.2°, VL = 0.44) and women (δ = 185.7°, VL = 0.20) with 95% confidence interval ellipses. The vector lengths indicate that the association between math teaching anxiety and interpersonal behavior was weaker for women than for men. In female teachers, math teaching anxiety was most strongly associated with the behavior octants "ignoring-resigning" and "admonishing" of the interpersonal space (characterized by low communion and moderate agency). In contrast, male teachers' math teaching anxiety was most strongly associated with the behavior octants "ignoring-resigning" and "indeterminate-waiting" (characterized by both low communion and low agency). Multiple-group comparison revealed that the strength of the association between math teaching anxiety and agency significantly differed between men and women (SB-$\Delta\chi 2$ = 4.79, Δdf = 1, p = .029).

Table 3.3

Results From the Multiple-Group SEM Predicting Teacher Agency and Communion in Men and Women

	Men						Women					
	Teacher Agency			Teacher Communion			Teacher Agency			Teacher Communion		
	B (SE)	β	*p*	*B (SE)*	β	*p*	*B (SE)*	β	*p*	*B (SE)*	β	*p*
Intercept	0.24 (0.42)	.36	.574	0.64 (0.53)	1.13	.251	0.07 (0.31)	0.12	.835	1.18 (0.22)	2.45	< .001***
Student Level (within)												
Math Grade	-0.43 (0.08)	-.40	< .001***	0.20 (0.06)	.30	< .001***	-0.39 (0.04)	-.36	< .001***	0.20 (0.03)	.27	< .001***
Test Score	-0.18 (0.04)	-.22	< .001***	-0.06 (0.04)	-.12	.140	-0.22 (0.04)	-.24	< .001***	-0.11 (0.03)	-.17	< .001***
Teacher Level (between)												
Math Teaching Anxiety	-0.21 (0.08)	-.30	.007**	-0.19 (0.09)	-.32	.015*	-0.01 (0.06)	-.02	.836	-0.10 (0.05)	-.20	.070
Teaching Experience	0.16 (0.10)	.25	.149	-0.04 (0.11)	-.08	.677	-0.03 (0.06)	-.07	.591	0.01 (0.04)	.03	.782
Educational Level	0.80 (0.25)	.50	< .001***	-0.22 (0.22)	-.16	.343	0.01 (0.13)	.01	.930	-0.12 (0.13)	-.11	.332
Grade Level Class	-0.20 (0.10)	-.30	.031*	0.11 (0.12)	.20	.333	0.02 (0.07)	.05	.739	-0.01 (0.05)	-.03	.776
Study Sample	0.58 (0.19)	.40	< .001***	0.16 (0.22)	.13	.452	-0.10 (0.15)	-.08	.490	0.09 (0.10)	.09	.364
Variance explained R^2												
Within		.31			.06			.28			.06	
Between		.59			.19			.01			.06	

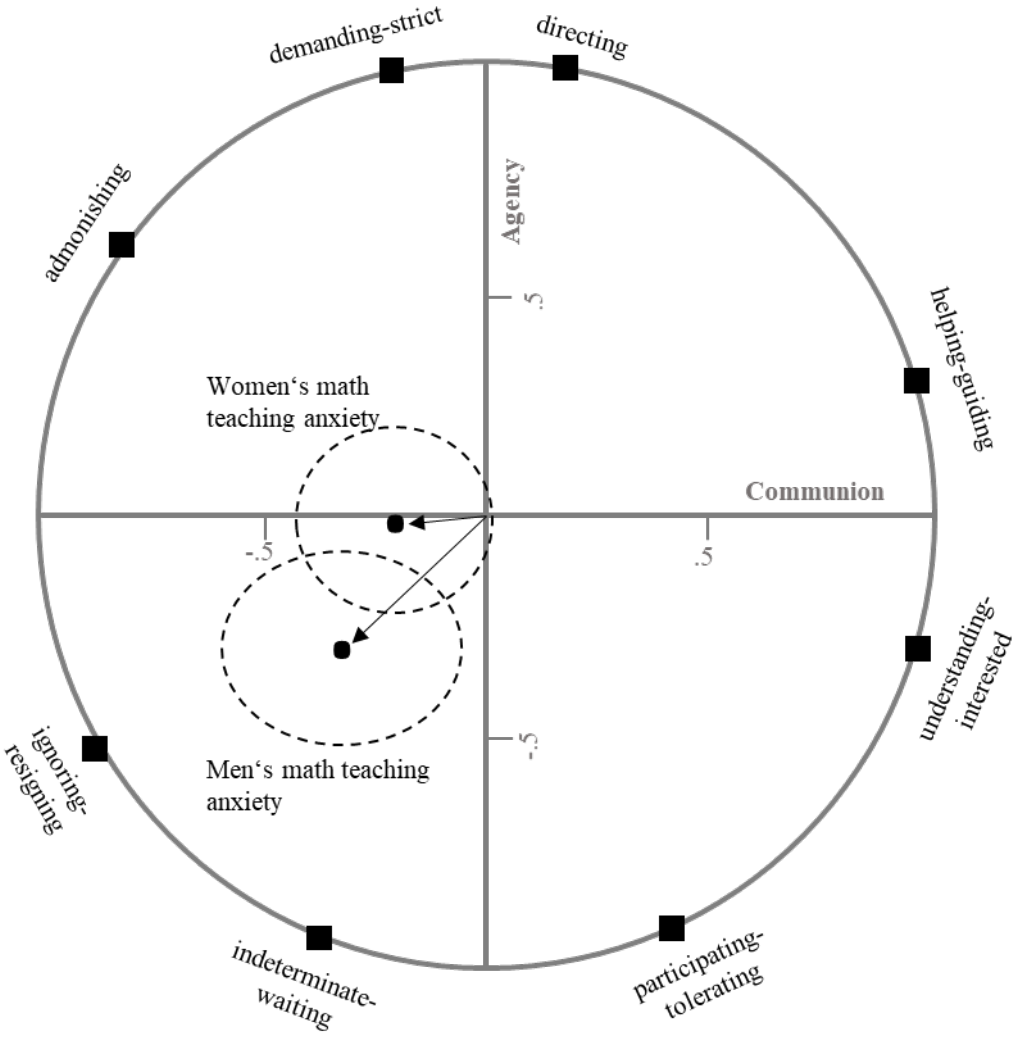
Table 3.3 (continued).

Note. We specified covariances for: student grades and test scores at student level, teacher agency and communion both levels, and teacher teaching experience and educational level (*Referendariat*) at teacher level. Model fit: $\chi^2(84) = 147.96$, $p < .001$, CFI = .952; RMSEA = .026; $SRMR_{within} = .000$, $SRMR_{between} = .060$.

* $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3.2

Profile Plot of the Association Between Math Teaching Anxiety and Men and Women Teacher Interpersonal Behaviors with 95%-Confidence-Interval-Ellipses



Discussion

This study investigated the relationship between math teaching anxiety and interpersonal behavior in elementary school teachers through the lens of Interpersonal Theory (Leary, 1957). Our findings indicate that generally, math teaching anxiety related to interpersonal teacher behavior low in communion. Further, a significant gender difference between men and women occurred regarding agency. In men, their math teaching anxiety related to interpersonal behavior that was both low in communion and agency (octants

"ignoring-resigning" and "indeterminate-waiting") whereas in women, their math teaching anxiety related to interpersonal behaviors low in communion (though only marginally significant) but moderate in agency (octants "admonishing" and ignoring-resigning").

We found that the more anxious elementary school teachers were to teach math the less warm and affectionate (communion) they interacted with the students of their class (admonishing, ignoring, resigning, indeterminate, waiting teacher behavior). According to appraisal theory (Frenzel et al., 2020), anxiety arises when individuals feel the attainment of important goals to be threatened—in this case the goal to appear as competent and effective while teaching math (Frenzel et al., 2020). Anxiety may interfere with teachers' ability to engage in positive interpersonal behaviors with their students (Gable & Impett, 2012). A contributing factor to this anxiety may be elementary school teachers' limited mathematical knowledge (Novak & Tassell, 2017), bad prior experience with the subject (Brady & Bowd, 2005), and the fact that many did not choose teaching careers with a focus on math, and consequently develop negative feelings towards the subject (Artemenko et al., 2021; Porsch, 2017).

The negative link between anxiety and communion we found in our sample carries important implications. Math teaching anxiety may hinder teachers to build warm and supportive relationships with their students (Hamre & Pianta, 2001). High quality teacher-student relationships are essential for students' academic achievement, motivation, and overall well-being (for second-order meta-analysis, see Emslander et al., 2025), and also for teachers' own well-being (Milatz et al., 2015; Spilt et al., 2011). This may also potentially account for the observed link between teacher anxiety and lower student performance in math (Beilock et al., 2010; Ramirez, Hooper, et al., 2018; Schaeffer et al., 2021)—a trend we also noted (albeit non-significant) in our descriptive results (see Table 3.1). Although the association between math teaching anxiety and communion was only marginally significant for women, we could not detect a significant gender difference in the strength of the relationship.

In contrast, our results revealed significant gender differences regarding agency. Male teachers who were anxious of teaching math engaged in emotionally unresponsive (low communion) and passive behaviors (low agency), corresponding to the octants "ignoring-resigning" and "indeterminate-waiting". In contrast, female teachers' anxiety of teaching math played out in emotionally unresponsive (low communion) but moderately agentic behaviors, reflected in the octants "admonishing" and "ignoring-resigning". While we did not find an overall association between math teaching anxiety and teacher agency, the gender specific patterns in the circumplex space show that math teaching anxiety is associated with low to moderate levels of agency, suggesting that anxious teachers adopt more passive and unstructured classroom practices. This finding is consistent with research showing that anxiety is typically associated with avoidance tendencies and withdrawal behaviors (Carver, 2001; Choe et al., 2019) and with research showing that teachers with math anxiety tend to avoid direct student engagement or minimize interaction altogether (Bush, 1989; Hughes et al., 2019). Unlike anger, which may elicit approach-oriented behaviors (Carver & Harmon-Jones, 2009), anxiety tends to result in inhibited action. In the context of teaching, this can translate into a reluctance to take on a directive role, hesitation to initiate or sustain in-depth mathematical conversations, avoidance of inviting student questions or facilitating open-end problem-solving discussions, and steering away from complex topics or student-led exploration, out of fear of being challenged or making mistakes in front of the class. This interpretation is in line with the findings of a study by Donker et al. (2020) according to which teachers' subject-unspecific anxiety negatively related to observations of teachers' moment-to-moment agency. Going beyond the study by Donker et al. (2020), we additionally observed a negative association between anxiety and communion. The authors speculate that they did not find this association due to the emotional labor teachers engage in, which could mask or compensate for the expected decline in communion. The association between teaching anxiety and low teacher agency can be further understood by considering that agency

in teaching is closely associated with mastery experiences and a sense of control over instructional processes (Donker et al., 2020, 2025). Teachers who are confident in their math teaching ability are more likely to exhibit higher levels of agency in the classroom.

The gender difference we found in how teacher math teaching anxiety relates to agency is particularly noteworthy. While we observed male teachers' anxiety to be associated with a broad withdrawal—low agency and low communion—female teachers' anxiety was linked to a more directive, moderately agentic, though still low communal behavior. It seems, when anxious female teachers remain more structured or directive in their teaching approach than their male counterparts. In the classroom context, this could mean that female teachers, despite their anxiety, still attempt to maintain control over classroom activities. This difference may be explained by gendered expectations surrounding math and teaching. With math being stereotyped as a masculine domain (Nosek et al., 2002; Steffens & Jelenec, 2011) and teachers being aware of that (Makarova & Herzog, 2015; Robinson-Cimpian et al., 2014; Tiedemann, 2002), this may lead to different pressures for male and female teachers. Female teachers may anticipate that these stereotypes are also held by their students (Cvencek et al., 2011; Hannover & Kessels, 2004; J. Steele, 2003), potentially leading female teachers to fear that their subject-specific expertise will be questioned. For female teachers, maintaining a moderate level of agency—even in the presence of anxiety—may function as a compensatory strategy (e.g., emotional labor; Taxer & Frenzel, 2015) to counteract these pervasive stereotypes. By preserving a more directive teaching stance, they may seek to reinforce their credibility and authority in the classroom. Further, professional norms discourage the expression of negative emotions such as anxiety, with female teachers being particularly constrained by these expectations (for a review, see Stark & Bettini, 2021). Maintaining a directive stance may therefore serve both to counteract gendered stereotypes and to conform to emotional display norms. This interpretation is supported by the lower vector length in the association between math teaching anxiety and agency for women, suggesting that women,

rather than withdrawing interpersonally, prioritize preserving a professional, authoritative classroom presence even under emotional strain. In contrast, male teachers experience less pressure to counteract math related gender stereotypes, as their mathematical competence is not challenged on the basis of gender. Consequently, when experiencing anxiety, they may feel more able to withdraw, resulting in a more pronounced reduction in both agency and communion. However, our interpretations remain speculative and the gender specific profiles we found in our study should be replicated in future research.

Limitations

Our study provides important insights into the relationship between teachers' math teaching anxiety and their interpersonal behavior; however, some limitations should be noted. First, the cross-sectional and correlational design of the study limits the ability to draw causal inferences. While we identified significant associations between math teaching anxiety and teacher interpersonal behavior, we cannot determine the directionality of the association, nor can we rule out the influence of unmeasured variables or underlying processes that may account for the observed patterns. Second, primary school teachers in Germany typically teach multiple subjects rather than focusing exclusively on math. Hence, when describing their interpersonal behavior toward individual students, teachers might have reflected on their general behavior towards a child, irrespective the school subject. Third, this study relied on teacher self-reports to assess both math teaching anxiety and interpersonal behaviors which can inflate the strength of associations due to shared method variance. Moreover, it may obscure important discrepancies between how teachers perceive and report their behavior and how students actually experience it, particularly in relation to emotional labor (Donker et al., 2020, 2021; Taxer & Frenzel, 2015). To address this limitation, future research should incorporate multiple informants—such as student reports or external observers of teacher interpersonal behavior (Frühauf et al., 2025)—to provide a more comprehensive and objective understanding of classroom dynamics.

Implications

The findings of this study have several important implications for both research and educational practice. First, the results suggest that elementary school teachers' anxiety to teach math is related to the interpersonal behavior they display toward students. This indicates that math anxiety may not only affect specific instructional practices but also influence the overall quality of teacher-student-interactions. By using Interpersonal Theory (Leary, 1957) as a guiding framework, this study offers a useful perspective for examining how teacher emotions—beyond math anxiety—may relate to their interactions with students and, ultimately, to student outcomes (Frenzel et al., 2021). Our study also points to the role of broader societal influences, such as gender-related stereotypes, in shaping emotional expression (Brody & Hall, 2008) and regulation (Gross, 2015) among teachers. In terms of practical implications, it is important for educators and teacher training programs to recognize that math teaching anxiety can affect how teachers relate to their students. Interventions should focus on (1) helping elementary school teachers reduce math anxiety and build greater confidence in teaching math, and (2) supporting their awareness of how emotional experiences may be reflected in their interpersonal behavior.

Supplementary Material to the article:

Teaching Anxiety in Mathematics

Associations with Teacher Agency and Communion in Teacher-Student Dyadic Interactions

Note S3.1

Overview of Study Items with English Translation (italics)

Math Teaching Anxiety (Ganley et al., 2019)[13]

1. Ich bin besorgt Fehler zu machen, wenn ich vor meiner Klasse schwierige Matheaufgaben löse.

   I worry about making mistakes while solving math problems in front of my class.

2. Ich wäre nervös, wenn ich Mathe in einer höheren Klassenstufe unterrichten sollte als ich bisher gewohnt bin.

   I would be nervous teaching math to students in a grade level any higher than I am used to teaching.

3. Ich würde mich unwohl fühlen, wenn eine andere Lehrkraft in meinem Matheunterricht hospitiert.

   I would feel uncomfortable if another teacher observed me teaching a math lesson.

4. Ich würde mich unwohl fühlen, wenn eine Schülerin oder ein Schüler mich darum bitten würde zu erklären, warum eine anspruchsvolle mathematische Lösungsstrategie funktioniert.

   I would feel uncomfortable if a student asked me to explain why an advanced math strategy works.

5. Es macht mich nervös, eine Matheaufgabe vor meiner Klasse zu lösen, wenn ich die Lösung nicht bereits vorher kenne.

[13] We omitted the item "I would be nervous teaching math to students in a grade level any higher than I am used to teach" that was originally part of the anxiety about teaching math scale from Ganley et al. (2019) because it reflects a behavioral manifestation of anxiety, rather than a purely emotional or cognitive component.

It makes me nervous to solve a math problem in front of my class if I haven't already figured out the solution.

Note S3.2

Testing the Structural Models

We examined the circular structure of our circumplex model for teacher interpersonal behavior utilizing the circular stochastic process model (SPMC; Browne, 1992). This confirmatory approach assesses whether the model exhibits a latent (quasi-)circumplex structure (Nagy et al., 2019). A circumplex model is characterized by (a) the angular location of each octant scale, and (b) the correlational relation among the octant scales, more precisely, adjacent octants being positively correlated, opposite octants being negatively corelated, and orthogonal octants being uncorrelated (Gurtman, 1991). The SPMC employs a Fourier series approximation (with one, two, or three Fourier components to define the function's shape) to estimate the empirical angular location ($\hat{\theta}_i$) of each octant scale i and to account for the expected correlational pattern of common scores (for more details, see Nagy et al., 2019).

Given our aim to explore gender differences in the relationship between teacher math teaching anxiety and their interpersonal behavior, we tested the invariance of our circumplex model across teacher gender groups. This step was necessary to ensure that any observed gender differences were not merely artifacts of variations in the circular structure of the teacher behavior measure. We followed the established procedure (Etzel et al., 2021; Nagy et al., 2010) by estimating a multigroup SPMC using the GROUPING command in *Mplus.*. We then progressively constrained (a) beta parameters (to ensure an identical correlation function shape across gender), (b) theta parameters (to confirm that octant scales had the same angular location across gender), (c) uniquenesses (to equate unique variances across gender), and (d)

scaling constants (to maintain consistent factor loadings for the observed octant variables across gender groups).

Further, to ensure valid comparisons between gender groups, we assessed measurement invariance for the anxiety about teaching math scale (Chen, 2007). Measurement invariance is a crucial prerequisite in group comparisons, as it ensures that the construct is being measured equivalently across groups, rather than reflecting systematic bias or differences in interpretation. Following van de Schoot et al. (2012), we estimated model parameters simultaneously for both gender groups and systematically tested (a) configural invariance (ensuring a consistent factor structure across gender), (b) metric invariance (confirming invariant factor loadings across gender), (c) scalar invariance (verifying equal item intercepts across gender), and (d) strict invariance (ensuring equal item uniqueness across gender). According to Cheung and Rensvold (2002), $|\Delta CFI| < .010$ indicates measurement invariance.

Table S3.1

Model Fit Comparison of the SPMC Models

	Goodness of fit						Model comparison			
Number of Fourier components	χ^2	df	*p*	RMSEA	CFI	SRMR	SB-$\Delta\chi^2$	Δdf	*p*	ΔCFI
m = 1	72.48	12	< .001	.048 [.037, .058]	.948	.037	-	-	-	-
m = 2	67.59	11	< .001	.048 [.037, .059]	.951	.038	19.59	1	< .001	.003
m = 3	50.03	10	< .001	.042 [.031, .054]	.966	.044	5.09	1	.024	.015

Note. χ^2 difference tests were adjusted using Satorra-Bentler scaling correction (SB; Santorra & Bentler, 2010). RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

Table S3.2

Invariance Test of the SPMC Model for Men and Women

	Goodness of fit						Model comparison			
Model	χ^2	df	*p*	RMSEA	CFI	SRMR	SB-$\Delta\chi^2$	Δdf	*p*	ΔCFI
Unconstrained	93.63	22	< .001	.054 [.043, .066]	.947	.040	-	-	-	-
Equal betas	78.11	24	< .001	.045 [.034, .056]	.960	.044	1.52	2	.468	-.013
Equal theta	83.63	31	< .001	.039 [.029, .049]	.961	.046	7.30	7	.399	-.001
Equal uniquenesses	94.77	39	< .001	.036 [.027, .045]	.959	.046	11.90	8	.156	.002
Equal scaling	99.11	47	< .001	.032 [.032, .040]	.962	.058	5.15	8	.741	-.003

Note. χ^2 difference tests were adjusted using Satorra-Bentler scaling correction (SB; Santorra & Bentler, 2010). RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

Table S3.3

Invariance Test of Math Anxiety, Self-Concept, and Perceived Teacher Expectation for Girls and Boys

	Goodness of fit						Model comparison			
Model	χ^2	df	*p*	RMSEA	CFI	SRMR	SB-$\Delta\chi^2$	Δdf	*p*	ΔCFI
Configural	16.90	10	.077	.025 [.000, .045]	.969	.053	-	-	-	-
Metric	20.96	15	.138	.019 [.000, .036]	.974	.078	4.27	5	.512	.005
Scalar	26.15	20	.161	.017 [.000, .032]	.973	.080	5.02	5	.414	.004
Strict	31.11	25	.185	.015 [.000, .030]	.973	.095	5.17	5	.395	.004

Note. χ^2 difference tests were adjusted using Satorra-Bentler scaling correction (SB; Santorra & Bentler, 2010). RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

CHAPTER 4 – Study 3: How Teacher Behavior in Student-Teacher Dyads Relates to Boys' and Girls' Mathematics Anxiety. An Investigation of Interpersonal Profiles

Note. This is the first author's version of a paper under review at the time. It may differ from the final published version due to revisions made during the editorial and peer review process, and it should not be cited as the final version.

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CRediT authorship contribution statement

MF: conceptualization, methodology, formal analysis, data curation, investigation, visualization, writing- original draft; JME: methodology, formal analysis, writing: review and editing; BH: conceptualization, funding acquisition, supervision, writing- review & editing.

How Teacher Behavior in Student-Teacher Dyads Relates to Boys' and Girls' Mathematics Anxiety. An Investigation of Interpersonal Profiles

Abstract

Mathematics anxiety impairs student learning, with girls being particularly strongly affected. Using interpersonal theory as a comprehensive theoretical framework, we investigated how teacher interpersonal behaviors– defined as blends of agency (guidance, control) and communion (warmth, sensitivity) in an interpersonal circumplex– relates to girls' and boys' math anxiety in student-teacher dyads and whether this relationship is indirectly associated through students' mathematics self-concept and students' perception of the teacher's expectation regarding their mathematics competence. We surveyed 42 (32 female) mathematics teachers and their 731 (362 female) primary school students. Teachers described their interpersonal teacher behavior towards every student of their class. We derived teacher agency and communion as underlying dimensions of teachers' interpersonal profiles from circumplex modeling. We used structural equation modeling to assess which profiles were most strongly associated with student-reported math anxiety in girls and boys and tested indirect associations. Teacher behavior that is characterized as a combination of high agency and low communion was associated with strong student math anxiety in the teacher-student dyad. Low teacher communion was significantly associated with their math anxiety in girls only. Indirect associations between teacher behavior and student math anxiety via self-concept and student teacher perception were found for agency in both boys and girls but for communion in girls only. Low teacher agency in dyadic interactions supports an anxiety-free approach to mathematics. High teacher communion is of particular importance for girls: They may be more dependent on it as they are chronically exposed to subtle stereotype threat in mathematics.

Keywords. Interpersonal Behavior; Mathematics Anxiety; Gender; Teacher Expectations; Self-Concept; Student-Teacher-Relationship

Introduction

Math anxiety is known to have detrimental effects on student learning. For instance, PISA 2022 data indicate that differences in math anxiety strength between countries account for approximately 25% of the variance in student math performance (OECD, 2023). The prevention of math anxiety is therefore crucial to support students in the acquisition of math skills (Barroso et al., 2021; Hembree, 1990). Research demonstrates that contextual factors significantly influence math anxiety, with teachers playing a crucial role through their ability to create supportive learning environments (Gunderson et al., 2012; Z. Wang et al., 2021). A comprehensive review by O'Hara et al. (2022) on the relationship between learning environment characteristics and student math anxiety identified several key aspects of teacher behavior that can either reduce or amplify student math anxiety: classroom activation, teacher use of fear, goal structure, teacher diagnostic skills, level of challenge, teacher support, and teacher punishment. Our study used a theoretical paradigm that effectively integrates the various aspects of teachers' behavior known to be associated with students' math anxiety by framing it along two basic dimensions of interpersonal behavior. Specifically, we relied on Interpersonal Theory (Horowitz & Strack, 2011; Leary, 1957) according to which any behavior in dyadic interactions can be described on two dimensions: communion (e.g., warmth, sensitiveness, empathy) and agency (e.g., direction, guidance, assertiveness). We described different profiles of teacher behavior consisting of varying combinations of agency and communion. We then used these profiles of interpersonal teacher behavior to (1) identify which profiles were most strongly related to student math anxiety, (2) whether interpersonal teacher behavior is indirectly associated with student math anxiety through student perceived teacher expectations and math self-concept, and (3) whether these relationships were different for boys versus girls.

O'Hara et al. (2022) noted that in most of the studies the relations between interpersonal teacher behavior and student math anxiety were analyzed by exclusively relying

on student report, an approach that can potentially inflate correlations between teacher and child characteristics. In our study we therefore related teacher-reported interpersonal teacher behavior to student-reported math anxiety. Additionally, prior studies typically described teacher behavior toward the entire class rather than individual students (O'Hara et al., 2022), not taking into account that a teacher's behavior varies greatly between individual students (Domen et al., 2020; Frühauf et al., 2025; Kreutzmann et al., 2024) and may relate to each students' emotional experience differently. Finally, the majority of studies included in the review investigated grade levels 9 to 12 (O'Hara et al., 2022). We seek to address these limitations in the present study by investigating primary school children and by relating the teacher's report of their interpersonal teacher behavior towards individual children in the teacher-child dyad to math anxiety reported by the respective girl or boy.

Math Anxiety in Girls and Boys

Math anxiety involves the feeling of fear, dread, apprehension, or tension when engaging with math (Ashcraft, 2002) and is reciprocally linked to competence deficits (Barroso et al., 2021). Math anxious individuals tend to avoid math (Choe et al., 2019) and show less engagement in math classes (Hembree, 1990; Ramirez, Shaw, et al., 2018). Math anxiety is already observed in primary school students (Ramirez et al., 2013; Vukovic et al., 2013), necessitating its early investigation, particularly in vulnerable groups like girls because the achievement-related gender stereotype favoring boys in math persist (Henschel, Jansen, et al., 2023; Nosek et al., 2002). Compared to boys, math is more closely associated with anxiety and negative attitudes in girls (Vos et al., 2023), regardless of their actual performance (Geary et al., 2023). Notably, despite gender differences in math achievement having mostly disappeared (Else-Quest et al., 2010), girls continue to experience higher levels of math anxiety.

Using the Interpersonal Circumplex to Describe Teachers' Behavior Profiles

We assumed that the two dimensions underlying any interpersonal behavior, communion and agency (Leary, 1957) matter for students developing math anxiety. Communion pertains to behavior qualities necessary for forming and maintaining social connections, such as warmth, friendliness, sensitivity, and meeting emotional needs – i.e., it refers to the affective quality of interpersonal teacher behavior. It can be assumed that warm and sensitive interpersonal teacher behavior decreases student math anxiety as such behaviors provide emotional reassurance in potentially distressing situations in the classroom (Goetz et al., 2021; Zee & Roorda, 2018). Agency describes behaviors geared towards goal achievement, including dominance, guidance, control, and competence (Horowitz & Strack, 2011; Leary, 1957) — i.e., it refers to instructional interpersonal teacher behavior: how well does the teacher guide and monitor the individual student's learning progress.

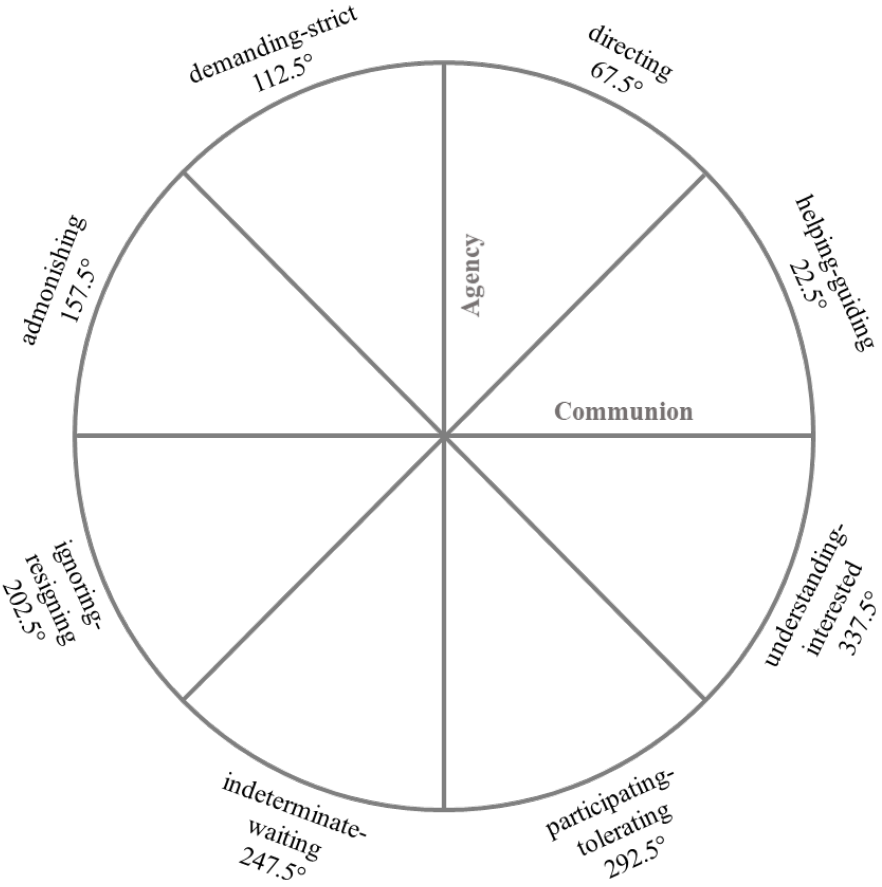
While the affective qualities of interpersonal teacher behavior have typically been investigated within the attachment theory paradigm (Ahnert et al., 2006; Pianta, 1999), instructional quality has been studied in research on teaching effectiveness (Alp Christ et al., 2022) and on adaptive teaching (Bernard et al., 2019). In our research we wanted to measure the two dimensions of interpersonal teacher behavior and their differential relations to student math anxiety simultaneously. This is important as a certain value on one of the two dimensions of interpersonal teacher behavior can have a differential effect on math anxiety, depending on which value it is combined with on the other dimension. For instance, strongly agentic interpersonal teacher behavior in combination with high communion can decrease math anxiety, but certainly not when combined with low communion.

To analyze both dimensions of interpersonal teacher behavior, we used an interpersonal circumplex (Gurtman & Balakrishnan, 1998) which acknowledges that every interpersonal behavior is best described as a blend of the two dimensions. As illustrated in Figure 4.1, the interpersonal circumplex partitions the two-dimensional space spanned by the agency and

communion dimensions into eight sections ("octants") and allowing us to examine how different blends of agency and communion relate to student math anxiety. The circumplex implies that adjacent octants (e.g., "demanding strict", "directing") are more closely related than octants that are further apart. Opposing octants (e.g., "demanding strict", "participating-tolerating") are assumed to be most dissimilar. The circumplex model suggests that individuals' interpersonal behavior patterns align with their structure (Gurtman & Balakrishnan, 1998). For instance, individuals who score highest on "demanding-strict" are likely to score high on "directing" and "admonishing", and to score lowest on "participating-tolerating". Most importantly, the circumplex can be used to summarize how external variables–here student math anxiety– relate to interpersonal profiles, in this case agency and communion of interpersonal teacher behavior (Gurtman, 1992). As will be described in more detail below, the relationship between interpersonal teacher behavior and student math anxiety can be represented by a vector whose angular orientation in the circumplex space indicates the behavioral octant most strongly associated with student math anxiety, while its length indicates the strength of the relationship (Gurtman & Pincus, 2003).

Figure 4.1

Theoretical Circumplex Model of Interpersonal Teacher Behavior



Interpersonal Teacher Behavior and Student Math Anxiety in Student-Teacher Dyads

We expected octants of interpersonal teacher behavior characterized by high communion and moderate to low agency to be associated most strongly with low student math anxiety ("understanding-interested" and "participating-tolerating", Figure 4.1). Accordingly, the opposite interpersonal teacher behavior, a combination of low communion and strong agency ("demanding-strict" and "admonishing", Figure 4.1) should be associated with high student math anxiety. This expectation is substantiated by the fact that a non-communally behaving teacher fails to provide emotional reassurance in stressful situations, such as when a student has problems understanding a math problem or when afraid of solving it on the blackboard in front of their peers (Goetz et al., 2021; Zee & Roorda, 2018). Further, our

expectation is substantiated by research showing that high teacher agency restricts the students' sense of autonomy and competence (Deci & Ryan, 2000), thwarting high quality forms of motivation, need-satisfaction, and positive affect (Aelterman & Vansteenkiste, 2023; Pekrun, 2006). More specific evidence for our assumption that interpersonal teacher behavior facets in the circumplex characterized by high communion and moderate or low agency relate to weak student math anxiety is provided by several previous studies investigating interpersonal teacher behavior and student math anxiety on the class level. We use the interpersonal circumplex to reappraise these scattered findings within an integrative framework. For instance, teacher sensitivity (Aldrup et al., 2020) and strong teacher support (Ahmed et al., 2010; Lazarides & Buchholz, 2019; H. Li et al., 2023), coincide with weak class-level math anxiety. In contrast, teaching practices involving fear, punishment, and competition are consistently related to strong student class-level math anxiety (Frenzel et al., 2007b; Putwain & Symes, 2011; Westphal et al., 2018). These findings are consistent with our expectation that facets of interpersonal teacher behavior characterized by high communion predict weak math anxiety in the teacher-student dyad. Further, clear and structured instruction (Frenzel et al., 2007b) and classroom activation (Lazarides & Buchholz, 2019) are associated with lower class-level math anxiety, while directly controlling behavior relates to stronger class-level math anxiety (Assor et al., 2005)—consistent with our expectation that facets of interpersonal teacher behavior characterized by weak or moderately strong agency predict weak math anxiety in the teacher-student dyad.

Student Perception of Teacher Behavior in Student-Teacher Dyads

In our study, we related teacher-reported interpersonal teacher behavior to student-reported math anxiety. To take the student's perception of the teacher into account, we additionally examined what the student thought of the teacher's expectation towards their math competence. A teacher's perception of a student's math ability has been found to be visible in their interpersonal teacher behavior towards the student (Eccles & Wigfield, 2020).

More specifically, we assumed that if a teacher has low expectations of a student, they are less likely to communicate in a warm and sensitive manner with the student (low communion) and be inclined to strongly direct and control the student's learning (high agency). The student in turn may interpret this interpersonal teacher behavior as a lack of acceptance and an indication that the teacher had little confidence in their abilities (Gentrup et al., 2020). We further measured the student's self-concept in math, which was found to be an important predictor of math anxiety (Pekrun, 2006; Pekrun et al., 2023).

The Present Investigation

This study aims to examine (1) the relationships between dyadic interpersonal teacher behavior and primary school students' math anxiety, and (2) whether there is an indirect association through students' cognitive appraisals (perceived teacher expectation, self-concept). We further explored whether the relationships between interpersonal teacher behavior and math anxiety differed between boys and girls. Using the interpersonal circumplex model (Leary, 1957), we investigated how interpersonal teacher behavior profiles relate to students' math anxiety in teacher-student dyads. Specifically, using a circumplex modeling approach, we first examined whether the structural assumptions of the circumplex model could be confirmed for dyadic interpersonal teacher behavior. In a next step, we summarized dyadic interpersonal teacher behavior profiles by deriving scores for the agency and communion axes and analyzed their relationship with students' math anxiety and appraisals. In doing so, it is possible to summarize these relationships in the form of vectors projected onto the dyadic interpersonal teacher behavior circumplex and identify the specific behavior patterns most strongly associated with students' math anxiety. We expected that both the affective and instructional qualities of interpersonal teacher behavior are important for the emergence of student math anxiety. Specifically, interpersonal teacher behavior characterized by low communion and high agency would show the strongest association with student math anxiety (*Hypothesis 1*). This hypothesis would be empirically supported by a significant

association between math anxiety and the interpersonal circumplex (Nagy et al., 2019) with an angular orientation of the corresponding vector that points in the direction of the "demanding-strict"/ "admonishing" behavior octants (Figure 4.1). We further assumed high agency and low communion in the teacher's behavior would be interpreted by the student as a sign of low expectations towards them in math and undermines their math-related self-concept, resulting in student experiencing higher math anxiety. Hence, student perception of the teacher's expectation should explain the indirect relationship between student math anxiety and teacher agency (*Hypothesis 2a*)/ teacher communion (*Hypothesis 2b*). Further, student math self-concept should account for the indirect relationship between student math anxiety on the one hand and teacher agency (*Hypothesis 3a*) /teacher communion (*Hypothesis 3b*) on the other. All analyses were also carried out separately for girls and boys for exploratory purposes.

Method

Sample and Procedure

We surveyed 42 (32 female) math teachers (age: 43.2 years, *SD* = 12.7; teaching experience: 13.4 years, *SD* = 11.2) and their respective classes from grades 3-6 from 13 primary schools in [location anonymized]. Teachers described their behavior towards each student in their classroom (on average 22.9 (*SD* = 2.4) students per teacher), resulting in 957 dyadic interpersonal teacher behavior descriptions. Of the students, 731 (mean age 10.1 years, *SD* = 1.3) completed the classroom survey after their parents provided informed consent, with 362 students identifying as female (48.7%), 379 as male (51.0%), and two as diverse. As a proxy for determining whether children had a migration background, we asked them to indicate the language(s) they were raised with. Of all children, 59.1% were raised exclusively with German. The remaining 40.9% of the students were raised with either German and another language, or exclusively with a non-German language during their early childhood, suggesting that they were from immigrant families.

Data collection was part of a research project funded by the German Research foundation [anonymized]. Approval was obtained by both the School authorities [anonymized] and the Ethics Committee [anonymized]. Participating was incentivized with 50 Euros per school class and 100 Euros for each teacher.

Measures

Interpersonal Teacher Behavior

Teachers described their interpersonal behavior towards each student on the 18-item version of the Questionnaire on Dyadic Interpersonal Teacher Behavior (DITeB; Kreutzmann et al., 2024). Each octant (Figure 4.1) is represented by two to three items (e.g., for "helping-guiding": "If [unique identifier] has difficulties solving a task, I am happy to show them step by step how to solve the problem."; for full item set, see Appendix). Teachers described their behavior towards each student one after another on 7-point Likert scales (1 = *strongly disagree,* 7 = *strongly agree*). We computed scale means for each of the octant scales (McDonald's ω ranges from .65 to .86) from which we derived scores on the agency and communion dimensions for each dyad (see Statistical Analysis).

Student Math Anxiety

Students reported their math anxiety on an 8-item-scale adapted from Henschel and Roick (2020; e.g., "I am nervous when my math teacher asks me something in math class."; 1 = *strongly disagree* to 4 = *strongly agree*; reliability McDonald's ω = .89). All items are in the Supplement (Note S4.1).

Student Perceived Teacher Expectation

We used 5 items from a scale by Gärtner (2010; e.g., “My math teacher has a lot of confidence in me during my math lessons.”; 1 = strongly disagree to 4 = strongly agree; reliability McDonald’s ω =.89). All items are in the Supplement (Note S4.1)

Student Math Self-Concept

We used a 3-item subscale from the German version (Arens et al., 2011) of the Self-Description Questionnaire-I (Marsh, 1990; "Math is easy for me."; 1 = *strongly disagree* to 4 = *strongly agree*; reliability McDonald's ω = .91). All items are in the Supplement (Note S4.1).

Covariates

As students' age and math competence may impact students' math anxiety and interpersonal teacher behavior (Barroso et al., 2021), these variables were included as covariates in all models. We assessed math competence (numeric reasoning skills) with standardized tests (for grades 3 to 4: BEFKI 3-4; Schroeders et al., in preparation; for grades 5 to 7: BEFKI 5-7; Schroeders et al., 2020). Children had to answer 16 questions by choosing one of four possible options. To solve the test, 3rd and 4th graders were given 18 minutes while 5th and 6th graders had 14 minutes to complete the task. The tests were scaled using a one-parameter logistic IRT model, estimated by the R-package eatModel (R Core Team, 2021; Weirich & Hecht, 2018). We calculated Weighted Likelihood Estimates (WLE; Warm, 1989) as estimates of student ability (WLE reliability was r_{wle} = .76). Further, to account for students' overall emotional experience in school, we controlled for general school satisfaction (Stanat et al., 2018; 3 items, e.g. “I enjoy going to school”, 4-pont Likert-scale; α = .81).

Statistical Analysis

We used M*plus* 8.8 (Muthén & Muthén, 2017) for all analyses if not stated differently. We accounted for the nested data structure by estimating cluster-robust standard errors (for additional information see Note S4.3).

Circumplex Structure

We used the circular stochastic process model (SPMC; Browne, 1992; Nagy et al., 2019) to examine the fit of the interpersonal teacher behavior measure. The latent SPMC, rooted in the structural equation modeling (SEM) framework (Etzel et al., 2021, 2023, 2024; Nagy et al., 2019), accounts for the fallibility of observed scale scores and relaxes the strict

assumption of perfectly equidistant scale positions around the circumplex (i.e., a quasi-circumplex Guttman, 1954). The central parameters estimated by the SPMC are (1) the shape of the circumplex' underlying correlation function, (2) the proportion of variance attributable to profile levels and profile patterns, (3) the angular locations of the octant scales around the circle ($\hat{\theta}_i$), and (4) the scales' communalities (i.e., the proportion of their variance shared with the latent circumplex; $\hat{h}_i$).

Relationships between Interpersonal Teacher Behavior and Math Anxiety

For the main analyses, we first derived agency and communion axis scores from the eight interpersonal teacher behavior subscales (Gurtman & Pincus, 2003). Axis scores are derived as linear combinations of the eight interpersonal teacher behavior scale scores using the sine ($\text{Agency}_j = \frac{1}{4}\sum_{i=1}^{8}(\sin(\hat{\theta}_i)S_{j,i})$) and cosine ($\text{Communion}_j = \frac{1}{4}\sum_{i=1}^{8}(\cos(\hat{\theta}_i)S_{j,i})$) of the estimated angular locations from the fitted SPMC models ($\hat{\theta}_i$) as weights. The two scores represent the dyads' cartesian coordinates in the circumplex space, summarizing a teacher's interpersonal profile towards the student. Using SEM, we modeled agency and communion on student math anxiety (Model 1), and then added student perceived teacher expectation and self-concept to test indirect associations (Model 2). Student math anxiety, perceived teacher expectation, and self-concept were incorporated as latent variables (Figure S4.1). We used Robust Maximum Likelihood (MLR) to account for non- normality and handled missing values via full information maximum likelihood (FIML). The standardized path estimates (β_{AG} and β_{CO}) of Model 1 can be used to visualize the relationship between interpersonal teacher behavior and math anxiety as the endpoints of a vector in the interpersonal circumplex. The angular orientation of the vector ($\delta = \tan^{-1}\left(\frac{\beta_{AG}}{\beta_{CO}}\right) * \frac{180}{\pi}$) corresponds to the octant most highly correlated with math anxiety and the vector length ($\text{VL} = \sqrt{{\beta_{AG}}^2 + {\beta_{CO}}^2}$) indicates the strength of the association (Gurtman & Pincus, 2003).

For potential gender differences in the association of interpersonal teacher behavior with math anxiety, we employed multiple-group analysis.

Transparency and Openness

The study materials, analysis syntaxes, and data are available at https://osf.io/pcfbk/?view_only=659c3ab0dd4e450e8f70221d12dd18f9.

Results

Fit to the Structural Models

First, we tested the interpersonal teacher behavior scale's fit to the circumplex model. Table S4.3 shows that the model with $m = 2$ components in the Fourier series yielded the best fit, $\chi^2(11) = 32.77$, $p < .001$, RMSEA = .046, CFI = .958, SRMR = .049. The configuration of interpersonal teacher behavior octants yielded a quasi-circumplex that was very similar to the theoretical model (Table 4.1, Fisher's A* > 92, Fisher et al., 1985).

Table 4.1

Results of the SPMC Model

	θ_{target}	$\hat{\theta}$ (SE)	$\lvert\Delta\hat{\theta}\rvert$	A^*	$\hat{h}$
1. Helping- guiding	22.5°	17.64° (9.21°)	4.86°	.97	.63
2. Directing	67.5°	80.20° (4.43°)	12.70°	.93	.79
3. Demanding- strict	112.5°	102.19° (5.55°)	10.31°	.94	.77
4. Admonishing	157.5°	142.99° (5.52°)	14.51°	.92	.77
5. Ignoring- resigning	202.5°	211.05° (6.61°)	8.55°	.95	.73
6. Indeterminate- waiting	247.5°	248.53° (4.32°)	1.03°	.99	.82
7. Participating- tolerating	292.5°	294.65° (4.44°)	2.15°	.99	.79
8. Understanding- interested	337.5°	342.68° (8.92°)	5.18°	.97	.65

Note. Parameters were derived from the SPMC model with $m = 2$ Fourier series components. θ_{target} = Target scale position according to the theoretical model. $\hat{\theta}$ = Estimated scale position. SE = Standard error. Fisher's $A^* = 1 - \lvert\Delta\hat{\theta}\rvert/180$ (Fisher et al., 1985). $\hat{h}$ = Estimated

communality. $\hat{h}$ adheres to $\hat{h}_i = \sqrt{\frac{1}{(1+u_i)}}$,with u_i being the estimated unique variance of each octant indicator (Nagy et al., 2009).

The interpersonal teacher behavior measure was invariant for girls and boys (Note S4.2 and Table S4.4). Additionally, regarding the student measures (math anxiety, perceived teacher expectation, self-concept). we achieved metric invariance (Table S4.5) as prerequisite of comparing regression weights between gender groups (Chen, 2007).

Since student perceived teacher expectation and self-concept were highly correlated (r = .84, Table S4.1), we employed one- and two-factor CFAs to assess whether both constructs were empirically separable. Results revealed that, that the two-factor model, $\chi^2(19) = 50.73$, p <.001, RMSEA = .048, CFI = .984, SRMR = .026, fitted the data better than the one-factor solution (SB-$\Delta\chi^2$ = 125.37, $\Delta df = 1$, $p < .001$). We therefore proceeded with the two-factor solution.

Interpersonal Teacher Behavior and Math Anxiety

Descriptive statistics are provided in the Supplement (Table S4.1 for full sample, Table S4.2 for boys and girls). Figure 4.2 visualizes the relationships as a projection of math anxiety onto the circumplex, placing the summary vector for the association at 95.19° ("demanding-strict") with VL = 0.10. Supporting Hypothesis 1, student math anxiety was most strongly associated with "demanding- strict" interpersonal teacher behavior (high agency combined with moderately low communion), which was additionally supported by the correlation pattern in Figure S4.2. The standardized estimates (Table 4.2) indicated that, after controlling for student age, math competence, and school satisfaction, student math anxiety was stronger the higher the teacher agency (β = .11, p = .011). As expected, teacher's dyadic communion was negatively associated with student math anxiety. However, this association was not significant (β = -.01, p =.891).

Figure 4.2

Profile Plot for Full-Sample (top) as well as Girls' and Boys' (bottom) Math Anxiety

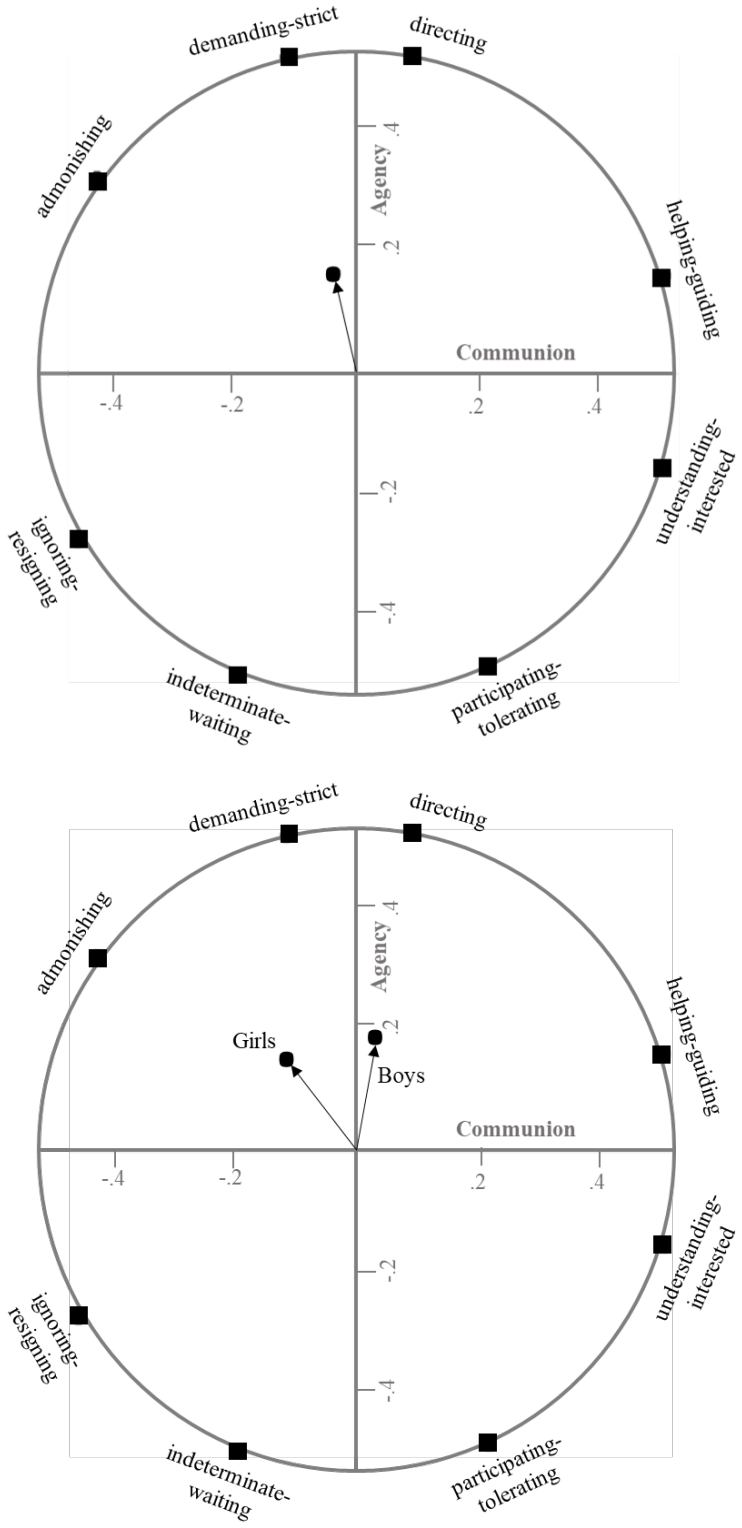


Table 4.2

Results from the SEM Predicting Student MA and Multiple-Group Analysis Predicting Girls' and Boys' Math Anxiety (MA)

	Full Sample MA			*Multiple-Group Analysis*					
				Girls' MA			Boys' MA		
	Est. (SE)	*Std. Est*	*p*	*Est. (SE)*	*Std. Est*	*p*	*Est. (SE)*	*Std. Est*	*p*
Math Competence	-0.17 (0.02)	-.38	< .001***	-0.10 (0.03)	-.20	< .001***	-0.16 (0.03)	-.39	< .001***
Age	0.05 (0.02)	.10	.028*	0.05 (0.03)	.10	.131	0.05 (0.02)	.11	.058
School Satisfaction	-0.17 (0.04)	-.20	< .001***	-0.21 (0.05)	-.24	< .001***	-0.14 (0.04)	-20	< .001***
Agency	0.06 (0.02)	.11	.011*	0.12 (0.03)	.24	< .001***	0.06 (0.02)	.13	.003**
Communion	0.00 (0.03)	-.01	.891	-0.14 (0.05)	-.16	.007**	0.03 (0.04)	.03	.503
R^2	0.23		< .001***	0.26		< .001***	0.25		< .001***

Note. $N = 957$, $n_{girls} = 362$, $n_{boys} = 379$. Model fit of the full sample analysis: $\chi^2(53) = 172.93$, $p < .001$, CFI = .950; RMSEA = .049; SRMR = .033, and multiple-group analysis: $\chi2(120) = 255.21$, $p < .001$, CFI = .937; RMSEA = .056; SRMR = .048.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Next, we explored gender differences. Multiple-group analysis revealed that the math anxiety of girls was most predominantly associated with the octant "admonishing", placing the summary vector at 123.69° with VL = 0.18 (Figure 4.2). For boys, the summary vector pointed to 77.01° with VL = 0.13, showing that boys' math anxiety was most strongly associated with the octants "demanding-strict" and "directing". Regarding the estimates, girls' math anxiety was positively associated with teacher agency ($\beta = .24$, $p < .001$) and negatively related to teacher communion ($\beta = -.16$, $p = .007$). For boys, math anxiety was also positively associated with teacher agency ($\beta = .13$, $p = .003$) but unrelated to teacher communion ($\beta = .03$, $p = .503$). Results further showed a significant gender difference in estimates for teacher communion (SB-$\Delta\chi^2 = 516$, $\Delta df = 1$, $p = .023$, $\Delta CFI = .002$) but not for teacher agency (SB-$\Delta\chi^2 = 2.78$, $\Delta df = 1$, $p = .095$, $\Delta CFI = .000$).

Testing Indirect Associations with Teacher Expectation and Self-Concept

Finally, we investigated the indirect associations of interpersonal teacher behavior and student math anxiety through student perceived teacher expectation and self-concept. We tested the indirect associations through student perceived teacher expectation (Model 2a) and student self-concept (Model 2b).[14] We used bias-corrected bootstrap analysis with 20,000 resamples to estimate confidence intervals of the indirect effects (MacKinnon et al., 2004). Table S4.6 and Table S4.8 show path estimates, while Table S4.7 and Table S4.9 display the estimates of indirect associations for both full sample and multiple-group analyses.

[14] Further, in Model 2c we included both student perceived teacher expectations and self-concept simultaneously to account for their mutual influence. Compared to Models 2a and 2b, the associations through perceived teacher expectation disappeared when both variables were included together. This is most likely because the two variables are highly correlated and similarly related to the outcome, meaning that neither adds incremental predictive power beyond the other.

Supporting Hypotheses 2a and 3a, teacher agency was associated with student math anxiety through student perceived teacher expectation (Model 2a; β = .04, 95%-CI = [0.06; 0.15]) and student self-concept (Model 2b; β = .06, 95%-CI = [0.08; 0.18]). Contrary to Hypotheses 2b and 3b, there were no indirect associations between student math anxiety and teacher communion.

Regarding gender specific analyses, indirect associations suggested that the paths between teacher agency/communion and girls' math anxiety were indirectly associated through girls' perceived teacher expectation (for agency: β = .04, 95%-CI = [0.04; 0.15], for communion: β = -.07, 95%-CI = [-0.14; -0.03]) and self-concept (for agency: β = .15, 95%-CI = [0.08; 0.21], for communion: β = -.10, 95%-CI = [-0.15; 0.04]), supporting Hypotheses 2a, 2b, 3a and 3b. Regarding boys' math anxiety, only the relation between teacher agency and math anxiety was indirectly associated through perceived teacher expectation (β = .13, 95%-CI = [0.07; 0.20]) and self-concept (β = .12, 95%-CI = [0.03; 0.08]), supporting Hypotheses 2a and 3a. As in the full sample analyses, no indirect associations occurred between teacher communion and boys' math anxiety.

Discussion

We investigated the relationship between math anxiety and dyadic interpersonal teacher behavior from an integrative perspective based on the Interpersonal Theory (Horowitz & Strack, 2011). By using an interpersonal circumplex model (Gurtman & Balakrishnan, 1998), we were able to simultaneously take teacher agency and teacher communion into account and examine how specific configurations of interpersonal teacher behavior were associated with math anxiety. We incorporated students' cognitive appraisals, to explain the associations between interpersonal teacher behavior and math anxiety. Going beyond previous studies, we investigated interpersonal teacher behavior at of the teacher-child dyad level and had interpersonal teacher behavior and math anxiety described by teachers and students, respectively.

What Configuration of Interpersonal Teacher Behavior Relates to Student Math Anxiety and Appraisals?

Student math anxiety was significantly associated with higher teacher agency and showed a negative trend with communion. Thus, consistent with our expectations, "demanding-strict" interpersonal teacher behavior showed the strongest association with math anxiety primary school students. This aligns with previous research showing that highly agentic and low communal interpersonal teacher behavior, such as using fear appeals, punishment, and competition, is associated with higher math anxiety at the class level (Frenzel et al., 2007b; Putwain & Symes, 2011; Westphal et al., 2018). The investigation of interpersonal teacher behavior in teacher-student dyads allowed us to account for interindividual differences in teacher's behavior. Our results indicate that when high teacher agency is paired with low affection (communion), it creates a negative and maladaptive learning environment (Goetz et al., 2021; Zee & Roorda, 2018). In this setting, students are denied emotional reassurance and support in stressful situations, while their sense of autonomy and competence is undermined (Aelterman & Vansteenkiste, 2023), most likely increasing their math anxiety. As expected, the strongest association with math anxiety was found for high agentic interpersonal teacher behavior, implying in the circular structure of the circumplex that low math anxiety was related to low agentic interpersonal teacher behavior. Thus, a teacher engaging in low agentic behaviors in the teacher-student dyad, the students will experience a greater sense of autonomy and competence, fostering positive affect when engaging in math. This interpretation is further supported by the indirect associations between interpersonal teacher behavior and math anxiety. Strong teacher agency, regardless of how much guidance and control a particular student (still) needs, makes it difficult for the student to be agentic and master the learning situation through their own capabilities, This, in turn, diminishes their self-concept and increase math anxiety (Goetz et al., 2010, 2020). Additionally, students may perceive close teacher guidance as indication of low expectations

of their math competence (Gentrup et al., 2020) which is also related to higher math anxiety (Hollenstein et al., 2023). While the association between math anxiety and teacher communion showed the expected negative direction without reaching significance in the overall sample, our gender-specific analyses revealed differential patterns in how communion relates to boy's and girl's math anxiety.

The Role of Gender

Boys' math anxiety was only related to teacher agency (strongest association for "demanding-strict") whereas girls' math anxiety had a positive association with teacher agency and a negative association with teacher communion ("admonishing"). Girls seem particularly affected in their math anxiety by low communion, aligning with research on teacher-student relationship quality according to which girls' math achievement, as compared to boys', is particularly dependent on a non-conflictual and close relationship with the teacher (McCormick & O'Connor, 2015; Valiente et al., 2019). This may be due to the gender-related stereotype that assume girls are less capable of doing math (Nosek et al., 2002). Being aware of this stereotype, girls can be affected in their math learning (known as stereotype threat, C. M. Steele, 1997). As a results they may feel uncertain about their own math abilities (Henschel, Jansen, et al., 2023). An "optimistic teacher-student relationship" (C. M. Steele, 1997, p. 624) in which girls are promoted and reassured in their competence can buffer the learning impairment induced by stereotype threat (S. Liu et al., 2021). Consistent with this interpretation, our results regarding indirect associations between interpersonal teacher behavior and math anxiety suggest that when the teacher shows warm and affectionate behavior in dyadic interactions with a girl (high communion) and offers her opportunities to act agentic herself (low agency), the girl is reassured of her own competence (self-concept) and assumes the teacher to think highly of her competence.

In contrast to our findings for girls, teacher communion was neither related to boys' perception of teacher expectations nor to their self-concept. Research has consistently shown

that boys tend to be involved in less close and more conflictual relationships with their teachers (Hajovsky et al., 2017; Kang et al., 2023), and perceive lower levels of support compared to girls (Arens & Niepel, 2019; Lietaert et al., 2015). Hence, boys might be less inclined than girls to infer their teacher's expectations on their teacher's behavior and make their self-concept contingent upon that behavior (Buckingham et al., 2012; Crocker et al., 2006).

Limitations

Some limitations of our study must be noted. First, the cross-sectional design prevents us from inferring causality. As interpersonal behavior is often reciprocal (Sadler et al., 2009), future research should utilize longitudinal or experimental designs to investigate how interpersonal teacher behavior influences students' math anxiety and vice versa. Second, primary school teachers in Germany typically teach multiple subjects and not only math. When describing their interpersonal teacher behavior towards the individual child, teachers therefore probably reflected on their general behavior rather than subject-specific interactions. However, we consider it unlikely that a teacher's behavior towards a child will vary significantly depending on the school subject. To address this limitation and account for the influence of the student's general, subject-unspecific emotional experiences at school, we controlled for their school satisfaction. Third, most of the teachers in our sample were women (76%) which aligns with the gender distribution amongst primary school teachers in Germany (Statistisches Bundesamt [German Federal Statistical Office], 2023). We were thus unable to investigate whether the interpersonal teacher behavior of male teachers would have produced different results. For instance, boys' math anxiety may have been less dependent on teacher communion because boys are less likely engage in an attachment relationship with a female (rather than a male) teacher (Ahnert et al., 2006). Fourth, we had a strong intercorrelation between student-perceived teacher expectations and self-concept, likely due to assessing both at the student level using similarly worded items (Note S4.1). The substantial overlap between

the measures may have influenced the results of models incorporating both variables simultaneously, as their high correlation and similar relationship with the outcome limit each variable's incremental predictive power.

Conclusion

The findings of this study highlight the importance of interpersonal teacher behavior in the development of math anxiety in primary school students (O'Hara et al., 2022). We provided evidence that dyadic interpersonal teacher behavior (Leary, 1957) is systematically related to students' emotions and anteceding appraisals (Mainhard et al., 2018; Pekrun, 2006). By using the Interpersonal Circumplex (Gurtman & Balakrishnan, 1998) we go beyond previous findings by showing that when investigating the teachers behavior as a core aspect of the learning environment in the emergence of student emotions (Pekrun, 2006), it is insufficient to solely focus on its instructional (agency) or its affective quality (communion). Instead, our results emphasize that interpersonal teacher behavior should be conceptualized as a combination of both teacher agency and communion. Our findings suggest that teachers can help to reduce math anxiety in their students by moderating their agency in dyadic encounters. Lower agency may foster an autonomy-supportive environment, allowing student become agents of their own learning (Aelterman & Vansteenkiste, 2023). Additionally, teachers should be especially mindful of providing reassurance to girls, who may be particularly reliant on communal dyadic interactions.

Supplementary Material for the Article:

How Teacher Behavior in Student-Teacher Dyads Relates to Boys' and Girls' Mathematics Anxiety.

An Investigation of Interpersonal Profiles

Note S4.1

Overview of Study Items with English Translation (italics)

Student Math Anxiety (adapted from Henschel & Roick, 2020)[15]

1. Ich mache mir Sorgen, dass die Aufgaben in meinem Mathebuch zu schwer für mich sind.

   I worry that the problems in my math book are too difficult for me.

2. Ich mache mir Sorgen, dass ich meine Mathe-Hausaufgaben nicht lösen kann.

   I worry that I cannot complete my math homework.

3. Ich mache mir Sorgen, dass mich die Lehrerin/der Lehrer im Matheunterricht aufruft.

   I worry that the teacher asks me something in math class.

4. Ich mache mir Sorgen, dass mir in einem Mathetest die Zeit nicht reicht.

   I worry that I do not have enough time in a math test.

5. Ich bin nervös, wenn ich in Mathe eine Hausaufgabe bekomme.

   I am nervous when I get a homework assignment in math.

6. Ich bin nervös, wenn ich weiß, dass ich in der nächsten Stunde Mathe haben werde.

   I am nervous when I know that I will have math in the next lesson.

7. Ich bin nervös, wenn mich mein/e Mathelehrer/in im Unterricht aufruft.

   I am nervous when my math teacher asks me something in math class.

[15] The math anxiety scale originally differentiates between cognitive ("worry") and affective ("nervousness") components of math anxiety. Confirmatory factor analysis (CFA) revealed that, compared to the one-factor model (χ^2 (12) = 12.92, p = .375, RMSEA = .010, CFI = 1.00, SRMR = .013), the two-factor solution (χ^2 (16) = 81.50, p < .001, RMSEA = .076, CFI = .965, SRMR = .031) led to a decrease in model fit (SB-$\Delta\chi^2$ = 69.12, Δdf = 4, p < .001, ΔCFI = .035); hence, we used a general factor of math anxiety for all following analyses.

8. Ich bin nervös, wenn ich am nächsten Tag einen Mathetest schreiben werde.

   I am nervous when I have to take a math test the next day.

Student Perceived Teacher Expectation (adapted from Gärtner, 2010)

1. Mein Mathelehrer/ Meine Mathelehrerin traut mir in Mathe viel zu.

   My math teacher has a lot of confidence in me during my math lessons.

2. Mein Mathelehrer/ Meine Mathelehrerin traut mir in Mathe zu, dass ich Aufgaben auch ohne Hilfe lösen kann.

   My math teacher believes that I can solve math problems without help.

3. Mein Mathelehrer/ Meine Mathelehrerin denkt, dass ich in Mathe schnell lerne.

   My math teacher thinks that I learn quickly during my math lessons.

4. Mein Mathelehrer/ Meine Mathelehrerin denkt, dass mir Mathe leichtfällt.

   My math teacher thinks that math is easy for me.

5. Mein Mathelehrer/ Meine Mathelehrerin denkt, ich kann auch sehr schwere Matheaufgaben lösen.

   My math teacher thinks that I can solve very difficult math problems.

Student Self-Concept (adapted from Arens et al., 2011)

1. Mathe fällt mir leicht.

   Math is easy for me.

2. In Mathe lerne ich schnell.

   In math I learn quickly.

3. In Mathe bin ich gut.

   I am good at math.

Note S4.2

Invariance Test of the SPMC and Student Measures

Since we wanted to investigate gender differences in the association of student math anxiety with the teacher behavior circumplex, we tested whether our circumplex model was invariant across student gender groups to rule out that gender differences were due to differences in the circular structure of the teacher behavior measure. We followed the established procedure (Etzel et al., 2021; Nagy et al., 2010) by estimating a multigroup SPMC using the GROUPING command in Mplus and stepwise constraining (a) equal beta-parameters (e.g., constraining the shape of the correlation function to be equal across gender), (b) equal theta-parameters (e.g., constraining octant scales to have the same angular location across gender), (c) equal uniquenesses (e.g., constraining the unique variances for octant scales across gender), and (d) equal scaling constants (e.g., constraining common factor to enter with the same weight into the observed octant variable for both gender groups). Additionally, we tested measurement invariance as a prerequisite to ensure comparability (Chen, 2007) of the student measures (math anxiety, self-concept, and perceived teacher expectation). Following van de Schoot et al. (2012) by estimating model parameters simultaneously for both gender groups and stepwise testing (a) configural invariance (e.g., constraining an equal factor pattern across gender), (b) metric invariance (e.g., constraining invariant factor loadings across gender), (c) scalar invariance (e.g., constraining equal item intercepts across gender), and (d) strict invariance (e.g., constraining equal item uniqueness across gender). According to Cheung and Rensvold (2002), $|\Delta CFI| < .010$ indicates measurement invariance. We applied χ^2-difference test with Satorra-Bentler scaling correction (Satorra & Bentler, 2010) for model fit comparison. The results of the invariance tests can be found in Table S4.3 for the SPMC and Table S4.4 for the student measures.

Note S4.3

Additional Information on Standard Error Estimation

For some estimated models, the M*plus* software produced a warning stating that the standard errors of the models may not be trustworthy due to the models having more parameters than the number of clusters. In such cases, we conducted two robustness checks by (1) estimating standard errors without cluster correction, and (2) estimating standard errors using 20,000 bootstraps that is recommended in case of small cluster sizes (Cameron et al., 2008). Both models were compared to the model with cluster-robust SE (TYPE = COMPLEX). In all cases, only small change in standard errors occurred that were not relevant to the central results of the study and therefore, we proceeded with the initial models. All robustness check models can be found in the OSF: https://osf.io/pcfbk/?view_only=659c3ab0dd4e450e8f70221d12dd18f9.

Table S4.1

Means, Standard Deviations, and Correlations for All Study Variables

Variable	*M* (*SD*)	ICC	1	2	3	4	5	6	7
1. Student Math Anxiety[a]	2.18 (0.64)	.17							
2. Student Self-concept[a]	2.85 (0.81)	.02	-.58***						
3. Student Perceived Teacher Expectation[a]	2.96 (0.62)	.03	-.50***	.84***					
4. Student Age	10.07(1.33)	.68	.04	-.14***	-.15***				
5. Student Math Competence	0.57 (1.37)	.20	-.39***	.34***	.26***	.21***			
6. Student School Satisfaction	2.91(0.77)	.08	-.33***	.25***	.33***	-.15***	-.04		
7. Teacher Agency	0.22 (1.31)	.23	.28***	-.27***	-.27***	-.09**	-.38***	-.13**	
8. Teacher Communion	1.35 (0.74)	.35	-.04	.03	.05	.15***	.05	.08*	.08*

Note. M and *SD* are used to represent mean and standard deviation, respectively. ICC = Intraclass Correlation Coefficient. [a]Latent means were computed.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table S4.2

Means, Standard deviations, and Correlations for Girls (Above the Diagonal) and Boys (Below the Diagonal)

Variable	M_{girls} (*SD*)	M_{boys} (*SD*)	1	2	3	4	5	6	7	8
1. Student Math Anxiety[a]	2.36 (0.68)	1.99 (0.53)		-.59***	-.49***	.05	-.32***	-.31***	.34***	-.20***
2. Student Self-concept[a]	2.65 (0.79)	3.08 (0.76)	-.50***		.80***	-.06	.38***	.30***	-.33***	.21***
3. Student Perceived Teacher Expectation[a]	2.87 (0.65)	3.06 (0.57)	-.49***	.86***		-.12*	.30***	.39***	-.26***	.23***
4. Student Age	10.06 (1.31)	10.10 (1.35)	.05	-.21***	-.17**		.18**	-.11*	-.08	-.08
5. Student Math Competence	0.40 (1.27)	0.79 (1.43)	-.40***	.26***	.20***	.23***		.04	-.44***	.11*
6. Student School Satisfaction	2.96 (0.74)	2.88 (0.79)	-.21***	.26***	.32***	-.19***	-.08		-.08	.11*
7. Teacher Agency	0.05 (1.31)	0.31 (1.32)	.30***	-.30**	-.34***	-.11*	-.39***	-.16**		.00
8. Teacher Communion	1.53 (0.70)	1.23 (0.69)	.00	-.04	-.02	.18***	.08	.01	-.15**	

Note. M and *SD* are used to represent mean and standard deviation, respectively. [a]Latent means were computed.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table S4.3

Model Fit Comparison of the SPMC Models

	Goodness of Fit					
Number of Fourier components	χ^2	df	*p*	RMSEA	CFI	SRMR
m = 1	43.09	12	< .001	.052 [.036, .070]	.940	.040
m = 2	32.77	11	< .001	.046 [.028, .064]	.958	.049
m = 3	30.06	10	< .001	.046 [.028, .065]	.961	.062

Note. RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

Table S4.4

Invariance Test of the SPMC Model for Girls and Boys

	Goodness of fit						Model comparison			
Model	χ^2	df	*p*	RMSEA	CFI	SRMR	SB-$\Delta\chi^2$	Δdf	*p*	ΔCFI
Unconstrained	47.92	22	.001	.057 [.035, .079]	.960	.048	-	-	-	-
Equal betas	47.83	24	.003	.052 [.030, .073]	.963	.047	0.26	2	.878	.003
Equal theta	54.97	31	.005	.046 [.025, .065]	.963	.053	5.77	7	.567	.000
Equal uniquenesses	62.13	39	.011	.040 [.020, .058]	.964	.059	6.56	8	.585	.001
Equal scaling	68.83	47	.021	.036 [.014, 0.053]	.966	.074	5.13	8	.744	.002

Note. χ^2 difference tests were adjusted using Satorra-Bentler scaling correction (SB; Santorra & Bentler, 2010). RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

Table S4.5

Invariance Test of Math Anxiety, Self-Concept, and Perceived Teacher Expectation for Girls and Boys

	Goodness of Fit						Model Comparison			
Model	χ^2	df	*p*	RMSEA	CFI	SRMR	SB-$\Delta\chi^2$	Δdf	*p*	ΔCFI
Configural	363.71	198	< .001	.048 [.040, .056]	.946	.041	-	-	-	-
Metric	385.60	214	< .001	.047 [.040, .055]	.963	.056	23.06	16	.112	-.017
Scalar	491.53	230	< .001	.056 [.049, .063]	.943	.089	159.85	16	< .001	.020
Strict	506.14	246	< .001	.054 [.048, .061]	.943	.094	19.40	16	.248	.000

Note. χ^2 difference tests were adjusted using Satorra-Bentler scaling correction (SB; Santorra & Bentler, 2010). RMSEA = Root-Mean-Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residuals.

Table S4.6

Results from the Model of Teacher Agency and Communion on Student Math Anxiety via Self-Concept and Perceived Teacher Expectation

Type	*Est. (SE)*	*Std. Est*	*p*
Model 2a (via perceived teacher expectation)			
Component (a, b)			
Agency → Perceived Teacher Expectation	-0.13 (0.02)	-.27	< .001***
Communion → Perceived Teacher Expectation	0.03 (0.04)	.03	.493
Perceived Teacher Expectation → Math Anxiety	-0.39 (0.05)	-.38	< .001***
Direct Effects (c′)			
Agency → Math Anxiety	0.03 (0.02)	.06	.171
Communion → Math Anxiety	0.01 (0.03)	.01	.823
Model 2b (via self-concept)			
Component (a, b)			
Agency → Self-concept	-0.17 (0.03)	-.27	< .001***
Communion → Self-concept	0.01 (0.05)	.00	.917
Self-concept → Math Anxiety	-0.36 (0.04)	-.46	< .001***

Table S4.6 (continued).

Type	*Est. (SE)*	*Std. Est*	*p*
Direct Effects (c′)			
Agency → Math Anxiety	0.03 (0.02)	.05	.207
Communion → Math Anxiety	0.00 (0.03)	.00	.994
Model 2c (via perceived teacher expectation & self-concept)			
Component (a, b)			
Agency → Perceived Teacher Expectation	-0.13 (0.02)	-.27	< .001***
Communion → Perceived Teacher Expectation	0.03 (0.04)	.03	.523
Perceived Teacher Expectation → Math Anxiety	-0.03 (0.09)	-.03	.723
Agency → Self-concept	-0.17 (0.03)	-.28	< .001***
Communion → Self-concept	0.00 (0.03)	.00	.929
Self-concept → Math Anxiety	-0.34 (0.07)	-.44	< .001***
Direct Effects (c′)			
Agency → Math Anxiety	0.02 (0.02)	.06	.201
Communion → Math Anxiety	0.00 (0.03)	.00	.997

Table S4.6 (continued).

Note. $N = 957$. Paths were controlled for student math competence, school satisfaction and age. We additionally specified covariances for: erceived teacher expectation with self-concept, math competence with self-concept, perceived teacher expectation age and agency, age with self-concept and perceived teacher expectation. Model perceived teacher expectation: $\chi 2\ (118) = 344.69$, $p < .001$, RMSEA = .045, CFI = .944, SRMR = .055; Model self-concept: $\chi 2\ (87) = 247.11$, $p < .001$, RMSEA = .044, CFI = .958, SRMR = .045; Model perceived teacher expectation & self-concept: $\chi 2\ (166) = 469.78$, $p < .001$, RMSEA = .044, CFI = .948, SRMR = .055.

$^{*}\ p < .05$, $^{**}\ p < .01$, $^{***}\ p < .001$.

Table S4.7

Indirect Effects from the Model of Teacher Agency and Communion on Student Math Anxiety via Self-Concept and Perceived Teacher Expectation

	Est. (SE)	*Std. Est*	Bc-Bootstrapped 95% CI
Model 2a (via perceived teacher expectation)			
Agency →Perceived Teacher Expectation →Math Anxiety	**0.04 (0.01)**	**.10**	**[0.06; 0.15]**
Communion→ Perceived Teacher Expectation →Math Anxiety	-0.01 (0.02)	.06	[-0.05; 0.02]
Model 2b (via self-concept)			
Agency → Self-concept→ Math Anxiety	**0.06 (0.01)**	**.12**	**[0.08; 0.18]**
Communion → Self-concept → Math Anxiety	0.00 (0.02)	.00	[-0.04; 0.04]
Model 2c (via perceived teacher expectation & self-concept)			
Agency→ Perceived Teacher Expectation → Math Anxiety	0.00 (0.01)	.00	[-0.05; 0.05]
Communion→ Perceived Teacher Expectation →Math Anxiety	0.00 (0.00)	.00	[-0.01; 0.01]
Agency → Self-concept→ Math Anxiety	**0.07 (0.02)**	**.13**	**[0.08; 0.20]**
Communion → Self-concept → Math Anxiety	0.00 (0.02)	.00	[-0.04; 0.04]

Note. We used bias-corrected 20,000-bootstrap analysis to estimate confidence intervals of the indirect effects (MacKinnon et al., 2004). Significant associations are **bolded**.

Table S4.8

Results from Multiple-Group Model of Teacher Agency and Communion on Student Math Anxiety via Self-Concept and Perceived Teacher Expectation

	Girls			Boys		
Type	*Est. (SE)*	*Std. Est*	*p*	*Est. (SE)*	*Std. Est*	*p*
			Model 2a (via perceived teacher expectation)			
Component (a, b)						
Agency → Perceived Teacher Expectation	-0.12 (0.03)	-.27	< .001***	-0.16 (0.03)	-.35	< .001***
Communion → Perceived Teacher Expectation	0.19 (0.05)	.23	< .001***	0.07 (0.05)	-.08	.177
Perceived Teacher Expectation → Math Anxiety	-0.34 (0.08)	-.32	< .001***	-0.34 (0.07)	-.37	< .001***
Direct Effects (c′)						
Agency → Math Anxiety	0.09 (0.03)	.20	.002**	0.02 (0.02)	.05	.281
Communion → Math Anxiety	-0.09 (0.06)	-.10	.114	0.02 (0.04)	.02	.690
			Model 2b (via self-concept)			
Component (a, b)						
Agency → Self-concept	-0.20 (0.04)	-.32	< .001***	-0.19 (0.04)	-.32	< .001***

Table S4.8 (continued).

	Girls			Boys		
Type	*Est. (SE)*	*Std. Est.*	*p*	*Est. (SE)*	*Std. Est.*	*p*
Communion → Self-concept	0.25 (0.06)	.22	< .001***	-0.10 (0.07)	-.09	.161
Self-concept → Math Anxiety	-0.35 (0.05)	-.45	< .001***	-0.27 (0.05)	-.37	< .001***
Direct Effects (c′)						
Agency → Math Anxiety	0.07 (0.03)	.16	.014*	0.03 (0.02)	.06	.130
Communion → Math Anxiety	-0.07 (0.05)	-.08	.140	0.01 (0.04)	.02	.742
Model 2c (via perceived teacher expectation & self-concept)						
Component (a, b)						
Agency → Perceived Teacher Expectation	-0.13 (0.03)	-.29	< .001***	-0.17 (0.03)	-.36	< .001***
Communion → Perceived Teacher Expectation	0.17 (0.05)	.20	< .001***	-0.06 (0.05)	-.07	.166
Perceived Teacher Expectation → Math Anxiety	0.12 (0.14)	.11	.369	-0.20 (0.12)	-.22	.081
Agency → Self-concept	-0.21 (0.04)	-.34	< .001***	-0.20 (0.03)	-.34	< .001***
Communion → Self-concept	0.24 (0.07)	.21	< .001***	-0.10 (0.07)	-.09	.140
Self-concept → Math Anxiety	-0.41 (0.09)	-.52	< .001***	-0.14 (0.09)	-.18	.159

Table S4.8 (continued).

	Girls			Boys		
Type	*Est. (SE)*	*Std. Est.*	*p*	*Est. (SE)*	*Std. Est.*	*p*
Direct Effects (c')						
Agency → Math Anxiety	0.08 (0.03)	.17	.009**	0.02 (0.02)	.05	.242
Communion → Math Anxiety	-0.07 (0.05)	-.08	.152	0.02 (0.04)	.03	.580

Note. $N = 741$, $n_{girls} = 362$, $n_{boys} = 379$. Paths were controlled for student math competence, school satisfaction and age. We additionally specified covariances for: perceived teacher expectation with self-concept, math competence with self-concept, perceived teacher expectation age and agency, age with self-concept and perceived teacher expectation. Model perceived teacher expectation: $\chi2$ (258) = 506.76, $p < .001$, RMSEA = .051, CFI = .934, SRMR = .066; Model self-concept: $\chi2$ (192) = 364.09, $p < .001$, RMSEA = .049, CFI = .951, SRMR = .055; Model perceived teacher expectation & self-concept: $\chi2$ (366) = 719.54, $p < .001$, RMSEA = .053, CFI = .936, SRMR = .073.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Table S4.9

Indirect Effects from Multiple-Group Model of Teacher Agency and Communion on Student Math Anxiety via Self-Concept and Perceived Teacher Expectation

	Girls			Boys		
	Est. (SE)	*Std. Est*	Bc-Bootstrapped 95% CI	*Est. (SE)*	*Std. Est*	Bc-Bootstrapped 95% CI
Model 2a (via perceived teacher expectation)						
Agency → Perceived Teacher Expectation → Math Anxiety	**0.04 (0.01)**	**.08**	**[0.04; 0.15]**	**0.06 (0.02)**	**.13**	**[0.07; 0.20]**
Communion → Perceived Teacher Expectation → Math Anxiety	**-0.06 (0.02)**	**-.07**	**[-0.14; -0.03]**	0.02 (0.02)	.03	[-0.01; 0.08]
Model 2b (via self-concept)						
Agency → Self-concept→ Math anxiety	**0.07 (0.02)**	**.15**	**[0.08; 0.21]**	**0.05 (0.02)**	**.12**	**[0.03; 0.08]**
Communion → Self-concept → Math anxiety	**-0.09 (0.03)**	**-.10**	**[-0.15; -0.04]**	0.03 (0.02)	.03	[-0.01; 0.07]

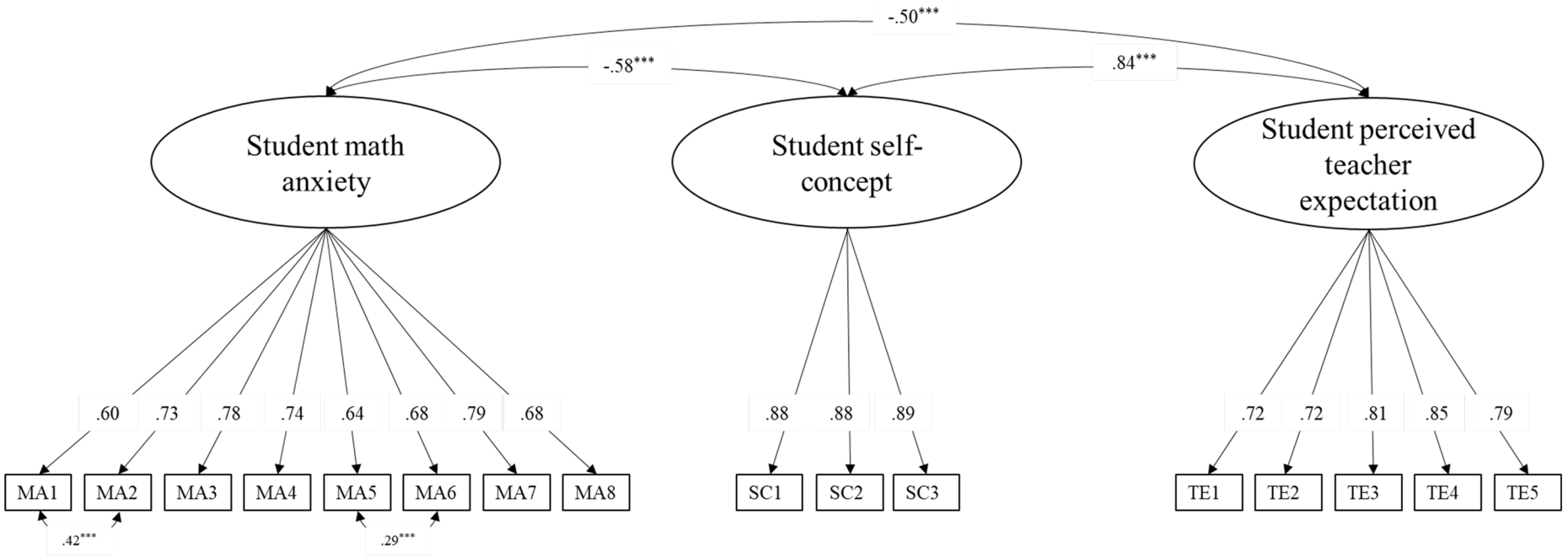
Table S4.9 (continued)

	Girls			Boys		
	Est. (SE)	*Std. Est*	Bc-Bootstrapped 95% CI	*Est. (SE)*	*Std. Est*	Bc-Bootstrapped 95% CI
Model 2c (via perceived teacher expectation & self-concept)						
Agency → Perceived Teacher Expectation → Math Anxiety	-0.01 (0.02)	-.03	[-0.12; 0.03]	0.03 (0.02)	.08	[-0.02; 0.17]
Communion → Perceived Teacher Expectation → Math Anxiety	0.02 (0.03)	.02	[-0.02; 0.10]	0.01 (0.02)	.02	[-0.004; 0.08]
Agency → Self-concept→ Math Anxiety	**0.09 (0.03)**	**.18**	**[0.09; 0.30]**	0.03 (0.02)	.06	[-0.03; 0.18]
Communion → Self-concept → Math Anxiety	**-0.10 (0.04)**	**-.11**	**[-0.22; -0.05]**	0.01 (0.02)	.02	[-0.005; 0.08]

Note. We used bias-corrected 20,000-bootstrap analysis to estimate confidence intervals of the indirect effects. Significant associations are **bolded**.

Figure S4.1

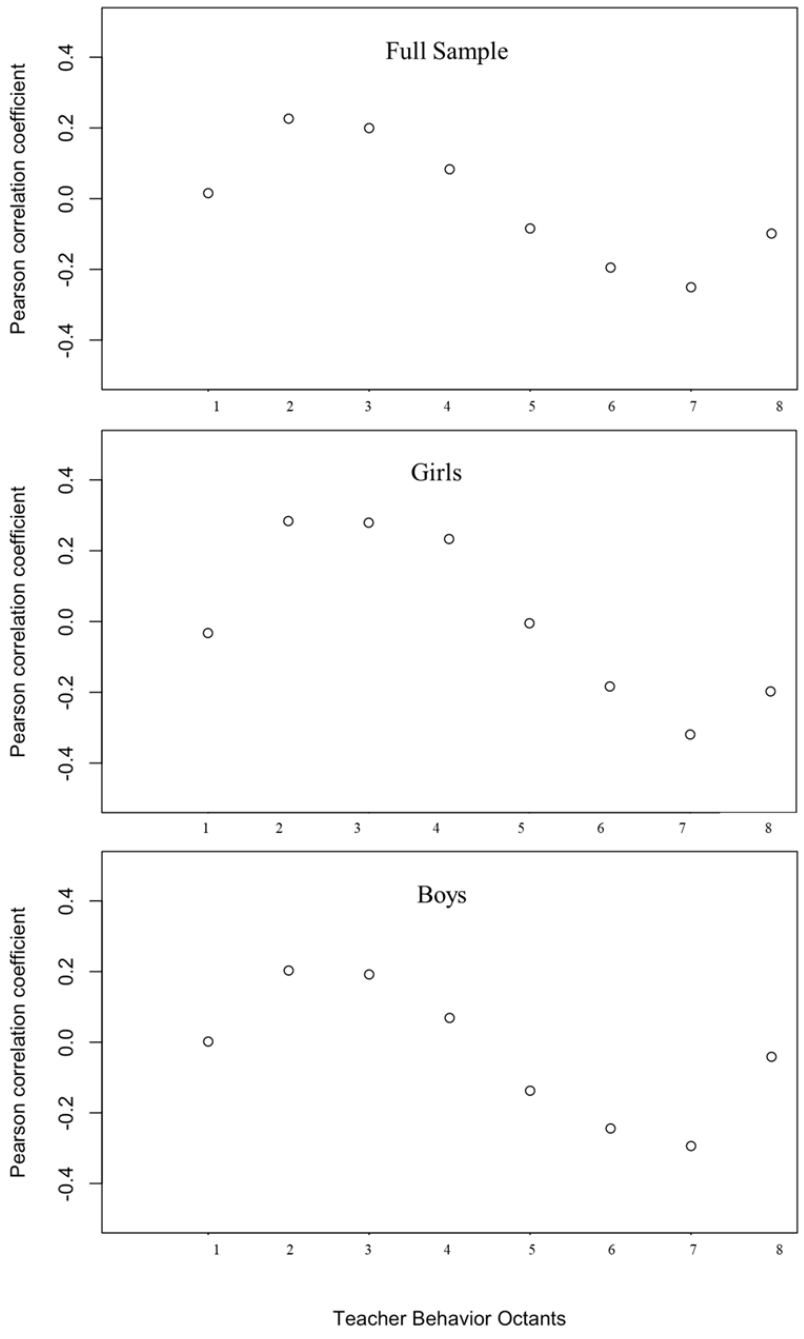
Measurement Model of Student Math Anxiety, Self-Concept, and Perceived Teacher Expectation



Note. For model estimation, we freed few and only theoretically plausible parameters (allowing errors for semantically similar items within one construct to covary) according to the modification indices (Sörbom, 1989). Model fit: $\chi 2$ (99) = 272.10, $p < .001$, RMSEA = .049, CFI = .964, SRMR = .034.

Figure S4.2

Correlational Patterns Between Interpersonal Teacher Behavior Octants and Student Math Anxiety



Note. 1. helping- guiding, 2. directing, 3. demanding- strict, 4. admonishing, 5. ignoring- resigning, 6. indeterminate- waiting, 7. participating- tolerating, 8. understanding- interested.

CHAPTER 5 – General Discussion

The current dissertation aims to shed light on the interpersonal processes in dyadic interactions between teachers and students. More specifically, it utilizes Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) and the propositions of the Interpersonal Circumplex (Gurtman & Balakrishnan, 1998; Gurtman & Pincus, 2003) to describe dyadic interpersonal teacher behavior on the dimensions of agency and communion (see Figure 1.2). This is used to examine (1) how dyadic interpersonal teacher behavior relates to students' behaviors and scholastic competencies (RQ1), and (2) how teachers' and students' math anxiety relates to dyadic interpersonal teacher behavior (RQ2). For that, three empirical studies were presented. In the following, the results of these studies are summarized and the research questions are discussed. Further, implications for theory and practice are derived, and strengths, limitations, and directions for future research are outlined.

Summary of the Results

Study 1 investigated whether dyadic interpersonal teacher behavior was complementary to students' communal behavior and scholastic competencies. The observational study integrated the complementary principle (Carson, 1969; Sadler et al., 2009), which assumes complementary patterns in teacher and student behaviors (reciprocity regarding agency, sameness regarding communion), with adaptive teaching propositions (Bernard et al., 2019; Hardy et al., 2019; S. A. Parsons et al., 2018) suggesting that teacher agency should also align with student competence levels. We expected reciprocity between teacher agency and students' scholastic competencies, with higher student competencies associated with lower teacher agency. Teacher and student communion were expected to correspond, with high communal student behaviors relating to high teacher communion and low communal behaviors relating to low teacher communion. Results showed that students' scholastic competencies (learning-related competencies and grades) as well as communal behaviors were substantially associated with teacher interpersonal behavior. More specifically, students' scholastic competencies were most strongly associated with teacher

behavior low in agency and moderately high in communion ("participating-tolerating"), supporting the expected negative relationship between teacher agency and student competencies while revealing a positive association between student scholastic competencies and teacher communion through the combined examination of agency and communion dimensions. Further, teacher communion was complementary to student communion: high communal student behaviors were most strongly associated with high communal teacher behavior ("helping-guiding" and "understanding-interested"), while low communal student behaviors were associated with low communal teacher behavior ("admonishing" and "ignoring-resigning"). Further, high student communion was associated with lower teacher agency, whereas lower student communion was associated with higher teacher agency.

Study 2 examined how primary school teachers' math teaching anxiety relates to their interpersonal behavior in dyadic interactions. Building on teacher emotion research (Frenzel et al., 2021), appraisals and action tendencies of teacher emotions (Fredrickson, 2001; Frenzel, 2014; Frenzel et al., 2020; Gable & Impett, 2012), we hypothesized that math teaching anxiety is negatively associated with teacher communion and did not specify a direction in the association with teacher agency due to conflicting evidence. Results indicated that math teaching anxiety was significantly associated with interpersonal teacher behavior low in communion. When exploring potential gender differences, we found a significant difference regarding agency. In male teachers, math teaching anxiety related most strongly to interpersonal behavior low in both communion and agency ("ignoring-resigning" and "indeterminate-waiting"). In female teachers, math teaching anxiety related most strongly to interpersonal behaviors low in communion (marginally significant) but moderate in agency ("admonishing" and "ignoring-resigning").

Study 3 investigated the relationship between dyadic interpersonal teacher behavior and students' math anxiety. Based on control-value theory (Pekrun, 2006; Pekrun et al., 2023) and previous findings on the relationship between aspects of teacher behavior and student

math anxiety (O'Hara et al., 2022), we expected interpersonal teacher behavior characterized by low communion and high agency to show the strongest association with student math anxiety. Further, we assumed students' perception of the teacher's expectations towards them and their math-related self-concept to mediate this relationship. Results suggest that teacher behavior high in agency is related to student math anxiety. Again, we explored gender differences and found a significant difference regarding communion: boys' math anxiety was associated with high teacher agency and moderate teacher communion ("demanding-strict"), whereas girls' math anxiety was most strongly associated with high teacher agency and low teacher communion ("admonishing"). Gender-specific analyses revealed that for girls, both teacher agency and communion were indirectly associated with math anxiety through girls' perceived teacher expectation and self-concept. For boys, only the relation between teacher agency and math anxiety was indirectly associated through perceived teacher expectation and self-concept, with no indirect associations occurring between teacher communion and boys' math anxiety.

In What Way is Teacher Interpersonal Behavior Related to Students' Behaviors and Scholastic Competencies in Dyadic Interactions?

Across all studies, indicators of students' competencies (grades, learning-related key competencies, and standardized test scores; see main results of Study 1 and Tables 3.2 and S4.1) substantially related to teachers' interpersonal behavior and showed a negative association with teacher agency. Further, we found that not only did teachers communion relate to students' communal behaviors but also to their grades (Studies 1 and 2) and observed learning-related key competencies (Study 1), with higher-achieving students being faced with higher levels of teacher communion. These findings contribute to the existing body of research that suggests teacher agency and student agency, traditionally operationalized by the degree of student initiative, are negatively associated (Mainhard et al., 2012; Pennings et al., 2014, 2018; Roorda et al., 2013; Roorda, Spilt, et al., 2017; Thijs et al., 2011). As we

investigated not only the students' degree of initiative but also their competence levels in terms of complementary relationships with the teacher's behavior, we considered specific properties of the complementarity principle (Carson, 1969; Sadler et al., 2009) within educational contexts in which the students' competence level and development should form key drivers of interpersonal interactions. These competence levels likely reflect the degree of initiative students are able to display in classroom interactions, suggesting that more competent students may elicit or require less directive behavior from teachers. Importantly, this process is reciprocal, meaning that low competence levels and low initiative of a student provoke high agency in the teacher. This perspective reinforces the idea that interpersonal mechanisms, such as reciprocal patterns of agency, align with theoretical models of adaptive teaching. In particular, the expertise reversal effect (Kalyuga, 2007; Tetzlaff et al., 2025) suggests that the level of instructional support provided by the teacher should align with students' competence levels, positioning adaptivity as a key precondition for effective learning. However, this raises a critical question: Is such adaptivity in an interpersonal interaction beneficial for students' learning progress? More specifically, should teachers adjust their level of agency to align with each student's learning prerequisites in order to create the most effective classroom environment?

The expertise reversal effect (Kalyuga, 2007; Tetzlaff et al., 2025) posits that instructional assistance tailored to individual learning dispositions enhances student learning. Reconsidered within an interpersonal framework, this implies that teacher agency should be negatively related to students' competence levels, which may naturally occur through automatic psychological processes described by the complementarity principle (Carson, 1969; Sadler et al., 2009). However, empirical evidence supporting this interpretation remains mixed. A recent study by Koeppen et al. (2025) examined the relationship between teacher agency adapted to students' competence levels and students' psychological need fulfillment and motivation. Using dyadic data from 1,796 elementary school students and 77 teachers

who reported on their interpersonal behavior, the study found that it was not the adaptation of agency to individual competence levels that supported need fulfillment and motivation. Rather, across all competence levels, low teacher agency combined with high levels of communion were most strongly associated with positive motivational outcomes. This study also demonstrated that teacher agency levels that exceeded what students' competence levels appeared to require were detrimental to student motivation (Koeppen et al., 2025). This finding aligns with Study 3 of this dissertation, where we similarly observed that, after controlling for students' competence levels, high levels of teacher agency were associated with decreased self-concepts, lower perceptions of teacher expectations, and increased student math anxiety. These elevated levels of agency may have exceeded the instructional support actually needed by the student based on their competence levels. Overall, students appeared to benefit emotionally and motivationally when teachers employed relatively low levels of agency combined with high levels of communion. This is consistent with findings from studies grounded in Self-Determination Theory (Aelterman et al., 2019; Deci & Ryan, 2000), showing that students benefit most from an autonomy-supportive teaching style (which translates to low agency and high communion) rather than a structured teaching style (which translates to high agency and high communion) in their levels of autonomous motivation (Domen et al., 2020) and individual levels of engagement (Jang et al., 2010).

In contrast, a recent meta-analysis by Tetzlaff et al. (2025) provides support for the expertise reversal effect (Kalyuga, 2007). According to their findings, students with low prior knowledge benefited most from high instructional assistance, with an effect size of $d = 0.505$, while students with high prior knowledge benefited most from low assistance, with an effect size of $d = -0.428$. A key distinction between this meta-analysis and the aforementioned empirical studies lies in their object focus. The studies included in the meta-analysis employed experimental designs and examined how learning tasks are structured and presented with an emphasis on instructional design, often conveyed through the learning materials

(Tetzlaff et al., 2022, 2025). In contrast, the studies by Domen et al. (2020), Jang et al. (2010), and Koeppen et al. (2025) center on the teacher's interpersonal behavior in classroom interactions. This distinction is highly relevant, as classroom instruction encompasses both the precise design of lesson materials and the interpersonal dynamics of teaching, which operate in parallel. Both considerations align with the adaptive teaching framework proposed by Corno (2008), who distinguishes between macro-adaptations, defined as planned and long-term changes in instructional design that are also embedded in learning materials, and micro-adaptations, which refer to immediate, context-specific responses during teacher-student interactions, such as interpersonal behavior. This dissertation focused exclusively on the latter. Future research should explore how these two forms of adaptation, namely interpersonal behavior and instructional task structure, interact and how each individually and collectively relate to students' motivation, emotions, and performance. Notably, in the context of interpersonal interactions, it appears especially important to balance high levels of support with the preservation of students' autonomy and the maintenance of high expectations.

In What Way is Dyadic Teacher Interpersonal Behavior Related to Teachers' and Students' Emotions, particularly in the Context of Math Anxiety?

Study 2 indicated that math teaching anxiety of primary school teachers substantially relates to their interpersonal behavior in dyadic interactions, characterized as a combination of agency and communion in the Interpersonal Circumplex (Kiesler, 1996; Leary, 1957). Further, Study 3 revealed that the teacher's dyadic interpersonal behavior is significantly associated with individual students' experiences of math anxiety and its antecedents (e.g., students' perceived teacher expectations and math self-concept). Considering dyadic interactions is essential, as it acknowledges that students' experiences are individualized and shaped by how the teacher interacts with them personally, for example, allowing for the examination of gender-specific associations. Synthesizing both studies, findings suggest that the teacher's behavior in dyadic interactions may serve as an important link through which the

teacher's own math anxiety relates to students' emotional experiences (and vice versa). This is particularly relevant given that emotions like math anxiety are often not directly observable due to display rules that govern emotional expressions in classroom settings (Rafaeli & Sutton, 1989; Stark & Bettini, 2021; Sutton, 2004). According to the Emotions as Social Information model (Fischer & Van Kleef, 2010; Van Kleef, 2009, 2016), individuals convey emotions through expressive behavior, which in turn triggers inferential processes and affective reactions in the others. Applied to the context of this dissertation, a teacher's math teaching anxiety may not be openly expressed (Sutton, 2004) but rather regulated through behavior along the dimensions of agency and communion during dyadic interactions. Students observe and interpret these emotional cues, forming inferences that shape their own affective reactions and behavior. This conceptualization is also supported by Frenzel et al.'s model of teacher emotions (Frenzel et al., 2021), which suggests that teachers' emotional experiences influence student outcomes indirectly through their classroom behavior. This raises an important question: Can math anxiety be socially transmitted from teachers to students through dyadic interpersonal teacher behavior? Research has already demonstrated that math anxiety can be transmitted from parents to children (Gunderson et al., 2012; Maloney et al., 2015; Z. Wang et al., 2021). The possibility of transmission from teachers to students was considered as early as the 1980s by Bush (1989), yet empirical evidence remains limited and inconsistent. While some studies have shown that teacher math anxiety negatively affects student achievement (Beilock et al., 2010; Hadley & Dorward, 2011; Ramirez, Hooper, et al., 2018; Schaeffer et al., 2021), the mechanisms behind this relationship are not yet fully understood. Studies have proposed specific transmission mechanisms. Beilock et al. (2010) suggested that the effect of female teachers' math anxiety on the achievement of their female students was mediated by the students' endorsement of gender stereotypes, although this finding could not be consistently replicated (Schaeffer et al., 2021). Ramirez, Hooper, et al. (2018) found that teacher math anxiety affected student achievement through perceived

endorsement of fixed mindsets. McLean et al. (2023) found that primary school teachers' math and science anxiety were linked to students' math and science anxiety, but only among students from low socioeconomic backgrounds. Moreover, factors such as teachers' confidence in teaching math and their perceived competencies have also been identified as predictors of student math anxiety (Lau et al., 2022).

The findings from Studies 2 and 3 contribute to this literature by providing detailed evidence on how teacher math anxiety is associated with specific configurations of interpersonal behavior along the agency and communion dimensions and how these behavioral patterns are related to student math anxiety[16]. Interestingly, the results suggest that the behaviors associated with math-anxious teachers, most notably "ignoring-resigning" teacher behavior, do not directly overlap with the behaviors most strongly associated with student math anxiety, which was most highly associated with "demanding-strict" teacher behavior. This mismatch implies that while math teaching anxiety in teachers may exhibit

[16] In fact, I was able to test this association in the sample of Study 3 (n = 42 teachers, n = 731 students). In this study, teachers also reported their math teaching anxiety with exactly the same items as assessed in Study 2 (Ganley et al., 2019). Using a multilevel path model in *Mplus*, I have investigated whether teachers' math teaching anxiety was associated with students' math anxiety through the axis scores of agency and communion. Results indicated that there was no direct association between teachers' math teaching anxiety and student math anxiety (β = -.19, 95%-CI [-.59; .20]), and also no indirect association through teacher agency (β = -.02, 95%-CI [-.13; .09]) or communion (β = .05, 95%-CI [-.07; .18]). Further, I have investigated whether there was a transmission from female teachers (n = 32) to girls (n = 271). However, there was also no transmission from female teachers' math teaching anxiety onto girls' math anxiety directly (β = -.07, 95%-CI [-.60; .46]), and through teacher agency (β = .04, 95%-CI [-.19; .27]) or communion (β = .02, 95%-CI [-.09; .13]).

behaviors that reflect emotional withdrawal, these may not be the primary behaviors that provoke anxiety in students. A possible exception to this pattern may exist in gender-matched dyads. Specifically, the octant "admonishing" was associated with math anxiety in both female teachers and female students, suggesting a potential transmission pathway from women to girls. However, this association did not reach statistical significance in our sample (see Footnote 16), possibly due to limited sample size (n = 32 female teachers and n = 271 girls), and should therefore be interpreted with caution. Despite this, the gender-specific findings make a meaningful contribution to the literature on emotional transmission processes, as they suggest a mechanism that has not yet been thoroughly explored. One theoretical explanation is that girls may identify more strongly with same-gender teachers due to shared gender identity, making them more sensitive to and more likely to imitate those teachers' emotional expressions, potentially leading to the inference that math, as a domain, elicits negative emotions in same-gender role models (Perry & Bussey, 1979). This hypothesis was empirically tested by Beilock et al. (2010), though it could not be reliably replicated (Schaeffer et al., 2021). In contrast, our findings emphasize a different mechanism, demonstrating that math-anxious female teachers display precisely the interpersonal behavior configuration ("admonishing" interpersonal behavior) that is most strongly associated with math anxiety in girls. Hence, it may not be math anxiety in general that is transmitted, but rather specific behavioral expressions of anxiety that resonate more strongly within gender-matched interactions. However, this interpretation should be treated with caution, as we were not able to empirically support the presence of such a transmission process.

Nonetheless, both studies revealed substantial gender-specific patterns in the associations examined, which merits further attention in future research. Our focus on math, a subject strongly associated with gender stereotypes (Nosek et al., 2002; Steffens & Jelenec, 2011), provides an important context for interpreting these patterns. Exploratory analyses of the relationship between teacher and student math anxiety revealed gendered trends that may,

in part, reflect the domain-specific nature of the emotion. While these findings require replication, it is conceivable that they may be influenced by internalized beliefs about gender and mathematical ability held by both teachers (Makarova & Herzog, 2015; Tiedemann, 2002) and students (Henschel, Jansen, et al., 2023). However, this interpretation remains speculative, as we did not directly assess the presence or endorsement of such stereotypes. It is also possible that the observed effects are influenced by other gender-related factors beyond math-specific stereotypes, such as gendered emotional display rules (Rafaeli & Sutton, 1989; Stark & Bettini, 2021) or girls' generally greater reliance on the teacher-student relationship for emotional support (McCormick & O'Connor, 2015; Valiente et al., 2019). These factors may operate independently of domain-specific beliefs. Regardless, the findings clearly suggest that the association between teacher interpersonal behavior and emotional experiences in both teachers and students is gendered in nature and should be investigated further with this complexity in mind.

Implications for Theory

The Role of Interpersonal Teacher Behavior in Adaptive Teaching Research

The findings of this dissertation provide novel insights into the mechanisms by which teachers adapt to students' characteristics. While existing research on adaptive teaching has predominantly emphasized adjustments in instructional strategies, materials, and content delivery, the present study extends this focus by conceptualizing adaptivity through the theoretical framework of Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957). This perspective reveals that (mal)adaptations also manifest at the interpersonal level within teacher-student interactions. For that, several interpersonal factors that influence adaptivity warrant careful consideration.

The findings from this dissertation can inform research on adaptive teaching by its emphasis on teacher behavior as a combination of agency and communion (Horowitz & Strack, 2011). Moving beyond a high/low dichotomy of assistance supplied by the teacher,

the effectiveness and interpretation of teacher assistance may not only depend on the degree of assistance, but also on how it is delivered interpersonally (see also Decristan et al., 2022). Identical levels of support can be perceived very differently by students depending on whether they are accompanied by warmth and emotional attunement (i.e., high communion) or delivered in a cold, controlling manner (i.e., low communion). Generally, research indicated that all students profit from high communal teacher behavior (Emslander et al., 2025); hence teacher behavior should always be characterized by high levels of communion. To that end, it is important to recognize that teachers exhibit specific interpersonal tendencies related to communion, which must be taken into account. First, consistent with the complementarity principle (Carson, 1969; Sadler et al., 2009), teachers displayed less communion toward students who themselves showed low levels of communal behavior (Study 1). Second, teachers also tended to show less communion toward students with lower grades (Studies 1 and 2) and lower learning-related key competencies (Study 1). These patterns underscore the need to consider interpersonal dynamics when investigating and promoting adaptive teaching practices that are equitable and responsive to all learners.

A core principle of adaptive teaching is that the level of teacher assistance should gradually decrease as students develop the competencies to work independently. This process, commonly referred to as *scaffolding* (Van De Pol et al., 2010), aims to foster students' self-regulation and autonomous learning. However, due to the cross-sectional nature of the data used in this dissertation, it is not possible to determine whether teachers actually implement this gradual release of responsibility over time. Research on teacher-student interactions provides relevant insights by considering the complementarity principle (Carson, 1969; Sadler et al., 2009). Studies analyzing moment-to-moment interactions (Pennings et al., 2018) have demonstrated that teacher behavior in one time frame elicits complementary responses from students in the next and vice versa. With regard to agency, this implies that high teacher agency (e.g., directive or controlling behavior) may elicit low student agency (e.g., passivity),

which in turn can provoke continued high agency from the teacher, reinforcing a cyclical pattern. This might be particularly important when faced with a highly passive student, such as a math-anxious student, who in turn will always provoke high levels of agency in the teacher. From an interpersonal perspective, this dynamic may conflict with the goals of scaffolding (Van De Pol et al., 2010). While scaffolding requires teachers to gradually withdraw control to promote student independence, the interpersonal logic of complementarity may lead teachers to maintain or even increase their control in response to students' passive behaviors and low competencies. Research on interpersonal complementarity thus suggests a potential tension: when teachers adopt highly agentic behaviors, students may become less active and less independent, undermining the intended developmental trajectory toward autonomy.

The findings highlight how teachers' emotional states can constrain their ability to adapt interpersonally to student needs. Study 2 of this dissertation showed that teachers' math teaching anxiety was associated with lower levels of communion and, among male teachers, lower levels of agency. Importantly, these anxiety-related behavioral patterns occurred consistently across different students, suggesting that teacher anxiety operates as a stable constraint on interpersonal flexibility rather than a response to particular student characteristics. Such person-level factors may constrain teachers' behavioral flexibility, limiting their ability to respond effectively and qualitatively to individual student needs. Conversely, other research has shown that positive person-level variables, such as teacher enthusiasm and self-efficacy, are positively associated with the capacity to adapt instruction to student needs (Kalinowski et al., 2024). Taken together, this body of evidence suggests that promoting teachers' professional development and emotional well-being are essential for fostering the interpersonal adaptability that underpins effective adaptive teaching.

The Role of Interpersonal Behavior in Emotion Research

The interpersonal lens of this dissertation also has implications for research on teachers' and students' emotions. First, this dissertation demonstrated that teacher interpersonal behavior may serve as a crucial link between teacher emotions and student emotions. The findings show that teachers' own math teaching anxiety systematically relates to how they behave interpersonally with students and that dyadic interpersonal behaviors also relate to students' math anxiety levels. While this relationship has been recognized in established theories on teacher (Frenzel et al., 2021) and student emotions (Pekrun, 2006; Pekrun et al., 2023), previous research has typically examined this relationship by relying on broad and theoretically scattered operationalizations of teacher behavior, often focusing on how teachers generally behave towards their entire class. By utilizing the Interpersonal Circumplex (Kiesler, 1996; Leary, 1957) and defining dyadic interpersonal behavior along the dimensions of agency and communion, this approach opens new avenues for investigating how other teacher and student emotions relate to specific configurations of interpersonal behavior and whether this behavior serves as a mediating variable in emotional transmission processes. While no clear transmission process was observable in this dissertation due to a mismatch between the behavior profiles associated with teacher math teaching anxiety and those related to student math anxiety (as outlined above), this pattern might not hold for other emotions. As the underlying theoretical frameworks pertain to emotions in general (Frenzel et al., 2021; Pekrun et al., 2023; Van Kleef, 2009), it is plausible that a range of emotional experiences are related to interpersonal behavior, not limited to math anxiety. Empirical support exists for the transmission of positive emotions such as joy from teachers to students (e.g., Frenzel et al., 2009, 2018) through mechanisms such as facial expressions (Frenzel et al., 2024; Marx et al., 2025). It is conceivable that teachers' interpersonal behavior displayed in dyadic interactions might also function as a mediating factor for the transmission of positive emotions. However, the context specificity of these processes should not be

overlooked. This dissertation focuses on math anxiety, reflecting the importance of adopting a subject-specific perspective on emotions in education (Frenzel et al., 2015; Goetz et al., 2007, 2010; Kunter et al., 2011). Relatedly, Donker et al. (2020) found that teachers' subject-unspecific, lesson-focused relaxation, enjoyment, boredom, anger, anxiety, relief, pride, disappointment, and shame were substantially related to their agency and communion in moment-to-moment interactions. Interestingly, in line with the male sample of Study 2 of this dissertation, they showed that teachers' anxiety, as indicated by items such as "During this lesson, I was nervous", was related to low levels of agency and negatively, though not significantly, related to communion (Donker et al., 2020). In contrast, Kreutzmann et al. (2024) found that teachers' dyadic anxiety that was directed towards a specific student, as indicated with items such as "When I teach this child, I feel tense and nervous", was related to higher levels of teacher agency combined with low communion. Hence, the association between teachers' interpersonal behavior and their emotions appears to be context-specific, depending on whether the anxiety is experienced in relation to a particular lesson, the subject matter, or an individual student within the classroom, which is potentially related to their appraisals within the specific contexts (Frenzel, 2014). Further, as outlined above, particular attention should be given to gendered pathways of this association.

Another significant advantage of the interpersonal approach is that it inherently accounts for the mutual influence between teachers and students, consistent with the complementarity principle (Carson, 1969; Sadler et al., 2009). This aligns with the proposed "recursive" effects of student outcomes and teacher emotions articulated by Frenzel et al. (2021), which recognizes that not only do teacher emotions impact student outcomes, but student behaviors and outcomes also influence teacher emotions and behaviors. More specifically, students may also evoke interactions with the teacher (Nurmi & Kiuru, 2015), and teachers' appraisals of these student behaviors play a crucial role in shaping their own emotional responses and subsequent behaviors. For instance, research has consistently found

that student misbehavior relates to lower positive and higher negative emotions in teachers (Aldrup et al., 2018; Hagenauer et al., 2015). This pattern can also be understood through the complementarity principle as demonstrated in Study 1 of this dissertation: when students behave in hostile or oppositional ways, this may trigger complementary responses in teachers, leading them to become less warm and caring in return. Furthermore, as shown in Study 1, teachers might also react with overly high control (agency) over the student, which can be detrimental to student motivation. This creates a negative transactional cycle where student hostility leads to teacher coldness and excessive control, which may further escalate student negative behavior and emotions. Understanding these interpersonal dynamics provides new insights into how negative classroom climates develop and, crucially, how these destructive cycles might be recognized and interrupted through targeted interventions.

Finally, the results of this dissertation indicate that teachers' math teaching anxiety relates to low-qualitative interpersonal behavior. Future research should consider the teachers' more general emotional well-being and its impact on their interpersonal behavior. The teaching profession is associated with higher psychological strain as compared to other professions (Johnson et al., 2005), and research has demonstrated that low emotional well-being in teachers is associated with lower teaching effectiveness (Arens & Morin, 2016; Klusmann et al., 2008, 2016, 2022) and also less qualitative instructional behavior (Klusmann et al., 2022). It is therefore plausible that higher levels of teacher burnout and emotional exhaustion may be associated with lower-quality interpersonal interactions or even rigid, inflexible patterns of interpersonal behavior, similar to those observed in individuals with psychopathological disorders (Girard et al., 2017).

Practical Implications

This dissertation has several important practical implications for teachers, teacher education, and teacher professional development. Importantly, (1) teachers should recognize that their interpersonal behavior plays a crucial role in shaping classroom dynamics and

student outcomes, (2) teachers and teacher educators should understand that interpersonal behavior is best conceptualized through the dimensions of agency and communion, and (3) teachers and teacher educators should be aware that interpersonal behavior often unfolds at the dyadic level, highlighting the importance of individualized interactions with students.

Teachers should be sensitized to the interpersonal nature of their behavior, both in terms of complementary reactions with students and in relation to broader person-level tendencies, such as their own subject-related anxieties (e.g., math anxiety). Importantly, their behavior should always be conveyed with high levels of communion, as all students profit the most from a warm teacher-student relationship (Emslander et al., 2025). Furthermore, effective adaptive teaching requires maintaining a delicate balance between providing necessary support and preserving student autonomy. Even when guiding more intensively, teachers should aim to empower the student rather than foster dependency (Aelterman & Vansteenkiste, 2023; Pianta et al., 2003). While this principle may sound straightforward, it poses a significant challenge for teachers. Teachers have to closely monitor their own behaviors and oftentimes have to respond in a non-complementary way to break negative interaction cycles, for instance, when confronted with student hostility, disengagement, passivity, anxiety, or low competencies.

For that, it is essential to recognize this substantial strain that is put on teachers. Within teacher professional development, teachers and teacher educators need to understand that teacher behavior always reflects a combination of agency and communion. Hence, teacher education programs should be specifically designed to address these needs by introducing teachers to the Interpersonal Circumplex (Kiesler, 1996; Leary, 1957). Teachers can learn to observe the behaviors of themselves and others', for instance, using the observation tool presented in Study 1, and engage in structured reflection. Further, they need to understand complementary interaction patterns, and develop the flexibility to respond constructively to diverse student behaviors (for reference to such training in the field of

clinical psychology, see Kiesler Circle Training; Guhn et al., 2019; Ollrogge et al., 2025). In addition, teachers must be aware of how their personal experiences and characteristics, such as subject-related anxieties, can interfere with their ability to act in students' best interests. Supporting teachers in managing these internal challenges is therefore essential. All of this underscores the significant demand placed on teachers' emotion regulation strategies. To respond optimally in difficult classroom situations, teachers need to develop adaptive emotion regulation strategies. Rather than relying on suppression or emotional avoidance, teachers should learn to use reappraisal techniques, for example, viewing student hostility as a sign of unmet needs rather than personal disrespect. Such strategies allow teachers to stay emotionally engaged without becoming overwhelmed. To help teachers improve their emotion regulation strategies, there are successful training programs available for both pre-service (Kumschick et al., 2018) and in-service teachers (Carstensen et al., 2019).

In addition to the interpersonal dimensions of teacher-student interaction, this dissertation highlights the crucial role teachers play in the development and prevention of math anxiety among students. Although a variety of student-centered interventions already exist, such as competence-building programs, reappraisal of physiological responses, and mindset interventions (for an overview, see Ramirez, Shaw, et al., 2018), this work underscores the impact of teacher behavior on the emergence of math anxiety. The findings suggest that teachers should adopt a highly communal and moderately low-agentic interpersonal behavior towards students' who are particularly at risk of experiencing math anxiety, such as girls. This combination communicates high expectations while fostering a supportive and emotionally safe learning environment, which helps students develop a positive academic self-concept in math. At the same time, efforts to prevent math anxiety in teachers themselves are equally important. Research indicates that both math anxiety and math teaching anxiety are already present in primary school teachers during their university training, particularly among those without a math specialization (Artemenko et al., 2021;

Patkin & Greenstein, 2020). Moreover, this anxiety tends to persist regardless of teaching experience (Gresham, 2018; Patkin & Greenstein, 2020). Therefore, teacher education programs should prioritize building both mathematical competencies and self-efficacy, not only in understanding math but also in teaching it effectively.

Strengths & Limitations and Directions for Future Research

Strengths

This dissertation demonstrates several notable theoretical and methodological strengths. Most importantly, this dissertation relies on Interpersonal Theory (Horowitz & Strack, 2011; Kiesler, 1996; Leary, 1957) as a comprehensive theoretical framework, offering three major advances. First, the emphasis on dyadic interpersonal teacher behavior represents a fundamental advantage over traditional class-level analyses, capturing the differences between individual teachers and students. Second, it conceptualizes teacher behavior as a combination of agency and communion dimensions (Horowitz & Strack, 2011), recognizing that effective teaching encompasses both managerial-guiding and social-emotional aspects. Third, the circumplex structure allows for rigorous mathematical modeling and empirical validation of particular theoretical propositions (Gurtman, 1991, 1992; Gurtman & Balakrishnan, 1998). This approach not only supports the evaluation of teacher behavior per se but also enables investigation of how distinct configurations of agency and communion relate to associated variables, including student behaviors, academic competencies, and math anxiety in both teachers and students.

Additionally, this dissertation utilized evidence from multiple data sources, integrating teacher self-reports, student self-reports, direct observations, and standardized test scores to provide comprehensive corroboration across methodological approaches and reduce common method biases (Podsakoff et al., 2003). Finally, the commitment to open science practices, including data sharing when feasible and systematic publication of analysis scripts and materials in the online repository of the Open Science Framework, enhances transparency and

replicability despite the absence of preregistration, thereby strengthening the potential scholarly impact of the findings (Center for Open Science, 2025).

Limitations and Future Directions

Despite the strengths of this dissertation, several limitations warrant acknowledgment beyond those already discussed in relation to individual studies within each chapter. First, the results of this dissertation purely rely on cross-sectional data due to the time-consuming design of assessing dyadic data. This limits the ability to draw causal conclusions. While Study 2 suggests that math teaching anxiety may influence teachers' interpersonal behavior, and Study 3 suggests that teachers' interpersonal behavior may impact students' experience of math anxiety, the observed associations could equally reflect student characteristics shaping teacher behaviors, environmental factors affecting both parties, or other unmeasured variables. Future research could address this limitation through controlled experimental designs. For instance, with adherence to ethical guidelines, math teaching anxiety could be experimentally induced by exposing teachers to unfamiliar or challenging lesson content, allowing researchers to observe how this manipulation directly affects teachers' interpersonal behaviors and emotional expressions toward students. Similarly, experimental paradigms using videos or structured role-plays could systematically manipulate specific teacher behaviors (for instance, see Traulsen & Zander, 2024) to examine their causal impact on students' anxiety levels and behavioral responses. These experimental approaches would help establish the directionality of influence, whether teacher behaviors drive student anxiety, student behaviors evoke specific teacher responses, or both processes occur simultaneously.

The reliance on cross-sectional data further presents a significant challenge for understanding complementarity in teacher-student interactions. Complementarity involves responsive behaviors that unfold over time, where one person's actions influence another's responses. The current findings show that certain teacher and student behaviors tend to occur together, but we cannot determine whether these represent true complementary responses or

simply reflect other unmeasured factors. To address this limitation, future research should employ experimental approaches that manipulate specific teacher behaviors through training or structured scenarios to test whether changes in teacher actions causally influence student responses. Additionally, longitudinal designs using experience sampling or moment-to-moment coding across multiple sessions could reveal whether complementary patterns truly emerge over time or whether the current findings reflect more stable relationship characteristics. This approach could clarify whether complementarity in teacher and student behaviors emerges consistently over time, meaning that teachers and students always exhibit complementing degrees of agency, or whether teachers gradually reduce their support as students become more independent (Van De Pol et al., 2010).

Another important limitation is that we were unable to account for the frequency, duration, or initiator of teacher–student interactions. Prior research has shown that teacher expectations significantly shape how teachers interact with students. For example, teachers tend to provide more complex instructional input, more opportunities to participate, more constructive feedback, and a warmer, more respectful emotional climate to students they expect to perform well (Gentrup et al., 2020; Harris & Rosenthal, 1985; Jussim et al., 2009). This perspective is supported by the positive association we found between teacher communion and student competencies. Moreover, we are not able to account for whether the student or the teacher most commonly initiated the interaction (Nurmi & Kiuru, 2015). Research in preschool settings suggests that children described as more aggressive are more likely to initiate interactions with teachers, whereas children characterized as shy or anxious more often prompt teachers to initiate the interaction (Coplan & Prakash, 2003).

Additionally, the generalizability of the findings on math anxiety from Studies 2 and 3 across different school levels remains uncertain, as both studies focused exclusively on primary school samples. This limitation is particularly relevant given that previous research has shown math anxiety to be most prevalent among primary school teachers (Artemenko et

al., 2021; Hembree, 1990). Moreover, in relation to Study 3, math anxiety in students is generally lower at the primary level compared to secondary school (Barroso et al., 2021). At the same time, younger students tend to depend more heavily on their teachers for emotional and instructional support (Jerome et al., 2009; E. O'Connor, 2010). These developmental and contextual differences suggest that the observed associations may differ across educational stages. Therefore, future research should replicate and extend these findings in secondary school settings to examine whether similar patterns hold and how they may be moderated by developmental or contextual factors.

Conclusion

This dissertation highlights that interpersonal dynamics in dyadic interactions are fundamental to understand effective education. The research reveals that teacher behavior characterized along the dimensions of agency and communion significantly relates to student academic outcomes and emotional experiences, particularly in math education. The findings broaden traditional views of adaptive teaching by demonstrating that effective instruction entails mutual interpersonal adaptations and requires high-quality interpersonal relationships with individual students. The research also advances the understanding of emotional interplay in educational contexts, showing that both teachers' and students' math anxiety relate significantly to specific interpersonal behavior patterns, with notable gender effects. Ultimately, this dissertation emphasizes the need to recognize classrooms as fundamentally relational in order to identify how beneficial relationships between teachers and students are shaped and maintained.

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APPENDIX

Full Item set to the 18-item version of the Questionnaire on Dyadic Interpersonal Teacher Behavior

Reference: Kreutzmann M., Frühauf M., Hannover B., & Koeppen, K. (2024). Communal and agentic teacher behavior in teacher-child dyads. A new self-report scale based on a circumplex approach. *Frontiers in Education, 9*:1397936. https:/doi.org/10.3389/feduc.2024.1397936

Each description was preceded by the prompt: "Now it's about [unique identifier]. For the following questions, think about what it is like for you as a teacher with this child in particular in the classroom and how you behave towards him/her." To ensure confidentiality, teachers were asked to allocate each student to a pre-existing unique identifier (i.e., names of trees and plants) and use that code when describing their interpersonal behavior towards each child. Students entered the teacher identification code as well as their individual identifier at the beginning of the student survey which allowed us to match teacher and student data.

Helping-Guiding

1. Wenn [Deckname] eine Aufgabe noch nicht richtig lösen kann, helfe ich ihm/ihr dabei, etwaige Fehlkonzepte zu erkennen und so auf die Lösung zu kommen.
   If [unique identifier] cannot yet solve a task correctly, I help them to identify any misconceptions and thus to find the solution.
2. Wenn [Deckname] beim Lösen einer Aufgabe Schwierigkeiten hat, dann zeige ich ihm/ihr gern Schritt für Schritt, wie das Problem gelöst werden kann.
   If [unique identifier] has difficulties solving a task, I am happy to show them step by step how to solve the problem.

Directing

1. Wenn ich Aufgaben stelle, überprüfe ich stets, ob [Deckname] verstanden hat, was er/sie tun muss.

When I give assignments, I always check that [unique identifier] understands what they need to do.

2. Ich gebe [Deckname] immer klare und schrittweise Anweisungen, wann er/sie welche Aufgaben im Unterricht bearbeiten soll.

   I always give [unique identifier] clear and step-by-step instructions on when they should work on which tasks in class.

Demanding-strict

1. Ich verlange von [Deckname], gestellte Aufgaben exakt wie vorgegeben zu erledigen.

   I require [unique identifier] to complete assigned tasks exactly as given.

2. Besonders bei [Deckname] fordere ich oft ein, im Unterricht mitzuarbeiten.

   Especially [unique identifier] I often ask to work in class.

Admonishing

1. Ich gebe [Deckname] keinen allzu großen Handlungsspielraum, damit er/sie nicht meinen Unterrichtsplan kaputt macht.

   I do not give [unique identifier] too much leeway so that they do not ruin my lesson plan.

2. [Deckname] maßregele ich mit Blicken, bei der Sache zu bleiben.

   I discipline [unique identifier] with glances to stay concentrated.

3. Von [Deckname]wende ich mich während des Unterrichts oft gezielt ab, um sein/ ihr Arbeitsverhalten zu optimieren.

   I often turn away from [unique identifier] during the lesson in order to optimize their working behavior.

Ignoring-resigning

1. Ich unterrichte die Lerninhalte nach Plan, ohne mich von [Deckname] davon abbringen zu lassen.

I teach the learning content according to plan, without letting [unique identifier] get in the way.

2. Um den Unterrichtsfluss aufrechtzuhalten, gehe ich von einer Lernaktivität zu einer neuen Lernaktivität über, ohne im Besonderen zu berücksichtigen, wie [Deckname] damit klarkommt.

   To keep the flow of the lesson going, I move from one learning activity to a new learning activity without paying particular attention to how [unique identifier] is coping.

3. Ich habe gelernt, nicht zu viel meiner Aufmerksamkeit auf [Deckname] zu verwenden.

   I've learned not to focus too much of my attention on [unique identifier].

Indeterminate-waiting

1. Ich lasse [Deckname] im Unterricht einfach mitlaufen.

   I just let [unique identifier] run along in class.

2. Wenn [Deckname] Aufgaben bearbeitet, mische ich mich nur selten ein, er/sie wird schon klarkommen.

   When [unique identifier] is working on tasks, I rarely interfere, they will be fine.

Participating-tolerating

1. Beim Lernen gebe ich besonders [Deckname] viele Freiräume.

   I give [unique identifier] in particular a lot of freedom when learning.

2. Ich beobachte [Deckname] Arbeitsverhalten im Unterricht und lasse ihn/sie gern gewähren.

   I observe [unique identifiers] work behavior in class and am happy to let them have their way.

Understanding- interested

1. Ich höre speziell [Deckname] immer geduldig und interessiert zu, wenn er/sie etwas im Unterricht beiträgt.

I particularly listen to [student unique identifier] patiently and interested when they contribute something in class.

2. Ich bemühe mich stets, auf die von [Deckname] geäußerten Interessen zu reagieren und diese in das Unterrichtsgeschehen mitaufzunehmen.
   I always try to respond to the interests expressed by [unique identifier] and incorporate them into the teaching process.

Eidesstattliche Erklärung zur Dissertationsschrift

Hiermit versichere ich,

- dass ich die von mir vorgelegte Arbeit selbständig abgefasst habe,
- dass ich keine weiteren Hilfsmittel als die von mir angegebenen verwendet habe,
- dass ich die vorliegende Arbeit noch nicht für andere Prüfungen eingereicht habe,
- dass ich kenntlich gemacht habe, welche generativen Modelle zu welchem Zweck und in welchem Umfang eingesetzt wurden (beispielsweise bei der Aufbereitung des Forschungsstandes, bei der Entwicklung einer wissenschaftlichen Methode, bei der Auswertung von Daten oder bei der Hypothesengenerierung). Eingesetzte KI, die sich nicht auf den wissenschaftlichen Inhalt der Dissertationsschrift auswirkt (bspw. Grammatik-, Stil-, Rechtschreibprüfung, Übersetzungsprogramme), muss nicht angegeben werden.
- dass ich sichergestellt habe, dass durch die Verwendung generativer Modelle kein fremdes geistiges Eigentum verletzt wird und kein wissenschaftliches Fehlverhalten etwa in Form von Plagiaten entsteht (vgl. geltende Stellungnahme der Deutschen Forschungsgemeinschaft und deren Kodex)

Mir ist bewusst,

- dass ich im Falle eines Täuschungsversuchs die Dissertation nicht bestanden habe,
- dass ich, sofern ich zur Erstellung dieser Arbeit generative Modelle verwendet habe, die Verantwortung für eventuell durch die KI generierte fehlerhafte oder verzerrte (bias) Inhalte, fehlerhafte Referenzen, Verstöße gegen das Datenschutz- und Urheberrecht oder Plagiate trage.

Berlin,
Madita Frühauf

Unterschrift