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Observational, student, and teacher perspectives on interpersonal teacher behavior: Shared and unique associations with teacher and student emotions

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ABSTRACT

Teachers' interpersonal behavior in class is important for teacher and student emotions. Often the same rater (either teacher or students) is used to assess both perceptions of teacher behavior and emotions, which makes it vulnerable to common-method bias. Including other perspectives on teacher behavior has been proposed as a solution, but it is unclear to what extent different perspectives are correlated and how to separate their shared and unique variance in explaining emotions. Behavior of 80 teachers was rated from three perspectives (observers, students, and teachers) in terms of Agency (i.e., social influence) and Communion (i.e., friendliness). The three perspectives overlapped more strongly for teacher agency than for communion. Especially for students, teacher communion was a stronger predictor of emotions than agency. Our innovative statistical approach showed that the strong association between ratings of teacher behavior and emotions of the same rater are unlikely to result from common-method bias only.

1. Introduction

Teachers' and students' emotional experiences in class have profound consequences for their performance and well-being (e.g., Grayson & Alvarez, 2008; Mega, Ronconi, & De Beni, 2014; Pekrun, Goetz, Titz, & Perry, 2002). Therefore, it is important to investigate how to foster positive and to reduce negative emotions. It has been proposed that teachers' interpersonal behavior in the interaction with their students is an important antecedent of teacher emotions, but empirical evidence is scarce (Chang, 2013; Spilt, Koomen, & Thijs, 2011). Moreover, studies investigating the association between teacher behavior and student emotions have mostly relied on student ratings for both teacher behavior and emotional outcomes (e.g., Becker, Goetz, Morger, & Ranellucci, 2014; Burić, 2015; La Guardia, Ryan, Couchman, & Deci, 2000; Mainhard, Oudman, Hornstra, Bosker, & Goetz, 2018; Mazer, McKenna-Buchanan, Quinlan, & Titsworth, 2014). This could be problematic because of common-method or same-rater bias (i.e., variance that is attributable to the measurement method rather than to the constructs the measures represent; Hoyt, 2000; Podsakoff, MacKenzie, Lee, & Podsakoff, 2003; Spector, Rosen, Richardson, Williams, & Johnson, 2019). Thus, the association between teacher behavior and student emotions might have been overestimated because both were reported by students, using questionnaires. It has therefore been suggested that it is preferable to obtain measures of the two constructs (in our case, teacher behavior and emotions) from two different sources (Podsakoff et al., 2003).

While most studies on teacher behavior in class used student ratings (Brattesani, Weinstein, & Marshall, 1984; Wubbels & Brekelmans, 2005), there are also some studies using external observation (Praetorius, Lenske, & Helmke, 2012; Van der Lans, 2018) or teacher reports (Clunies-Ross, Little, & Kienhuis, 2008; Veldman, Admiraal, Mainhard, Wubbels, & Van Tartwijk, 2017). Using different perspectives may be a good solution for avoiding common-method bias. However, this could potentially introduce another problem, because, at least for teacher behavior, the overlap between different perspectives seems to be only weak to moderate (Clausen, 2002; Dobbelaer, 2019; Fauth, Decristan, Rieser, Klieme, & Büttner, 2014; Scherzinger & Wettstein, 2019). Also, including all three perspectives is often not practically feasible and it is unclear whether and how the choice for a specific perspective affects the magnitude and conclusions regarding the association with emotional outcomes.

Therefore, the present study investigated to what extent external

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observation, student ratings, and teacher self-report of interpersonal teacher behavior during a lesson overlap versus represent unique perspectives. We use this dataset to illustrate a novel statistical approach based on multiple regression, which allows to calculate the explained variance of different combinations of predictors, and the shared and unique variance of each (set of) predictors. Having a better grasp of how the three perspectives on teacher behavior overlap and add to each other in predicting teachers' and students' emotional outcomes can provide valuable information for future research; for example, by highlighting to what degree measures of teacher behavior are interchangeable in research on teacher and student outcomes. Moreover, our statistical approach might also be applicable to other areas of research, where different perspectives are involved, such as research in the work and organizational psychology domain in which ratings from employees and employers are used to assess the organizational climate or leadership aspects.

1.1. Teacher behavior as antecedent of teacher and student emotions

In the present study we focused on explaining differences in teacher and student emotions. The classroom is a setting in which both teachers and students experience a broad range of emotions (Frenzel et al., 2016; Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011), which affect other teacher and student outcomes. For students, higher levels of positive and lower levels of negative emotions have been associated with a deep approach to learning (Trigwell, Ellis, & Han, 2012), more use of metacognitive strategies (Pekrun et al., 2002), better self-regulation, and higher motivation (Mega et al., 2014), all of which are considered to have a positive effect on student achievement. Teacher emotions do not only affect student emotions and performance (Frenzel, Goetz, Stephens, & Jacob, 2009; Lazarides, Gaspard, & Dicke, 2018), but daily emotional experiences of teachers are also viewed as the building blocks of teachers' feelings of burnout and work-related well-being (Chang, 2013; Grayson & Alvarez, 2008; Houben, Van den Noortgate, & Kuppens, 2015).

To support positive emotional experiences of teachers and students, it is important to investigate not only the effects, but also the antecedents of emotions (Hagenauer, Hascher, & Volet, 2015; Mazer et al., 2014). Many previous studies highlighted the role of the social environment and individuals' appraisal of this environment for their emotional experiences (Fischer & Van Kleef, 2010; Goetz, Pekrun, Hall, & Haag, 2006). In the current study, we focused on teachers' interpersonal behavior in class as a critical component of the social environment (Chang, 2009; Spilt et al., 2011; Wubbels & Brekelmans, 2005).

Teachers' interpersonal behavior in class has been operationalized using interpersonal theory (Horowitz & Strack, 2011). Interpersonal theory postulates that to describe behavior of people in interaction with others two dimensions are at the same time needed and sufficient (Fabrigar, Visser, & Browne, 1997). These two aspects of interpersonal behavior are denoted by the meta-labels Agency and Communion. Agency refers to aspects of behavior concerning taking the lead, conveying social influence, or control. Communion refers to aspects of behavior indicating friendliness, affection, or warmth in the interaction with others. Wubbels, Créton, and Hooymayers (1985) adapted interpersonal theory to the classroom setting by introducing the Interpersonal Circle for Teachers (IPC-T; see Fig. 1). All interpersonal behavior of teachers (i.e., the prototypical words around the circle) can be characterized as a specific combination of agency and communion (Brekelmans, 1989; Mainhard, Brekelmans, Den Brok, & Wubbels, 2011; Wubbels, Brekelmans, Den Brok, & Van Tartwijk, 2006). For example, a teacher can be hesitant to act (i.e., uncertain; moderately low communion and low agency) or employ strict classroom management (i.e., imposing; moderately low communion and high agency).

Teacher behavior that is characterized by high levels of agency and communion (i.e., being both warm and demanding; Ross, Bondy, Bondy, & Hambacher, 2008) is preferred by both students and teachers (Sun, Mainhard, & Wubbels, 2018; Veldman, van Tartwijk, Brekelmans, & Wubbels, 2013; Wubbels & Brekelmans, 2005; Wubbels & Levy, 1991). Especially teacher communion has been associated with higher levels of positive student emotions, stronger feelings of support, and higher student well-being (Becker et al., 2014; La Guardia et al., 2000; Lei, Cui, & Chiu, 2018; Mainhard et al., 2018; Mazer et al., 2014). Teacher control (i.e., high levels of agency), on the other hand, seem especially relevant for teacher emotions (Hagenauer et al., 2015).

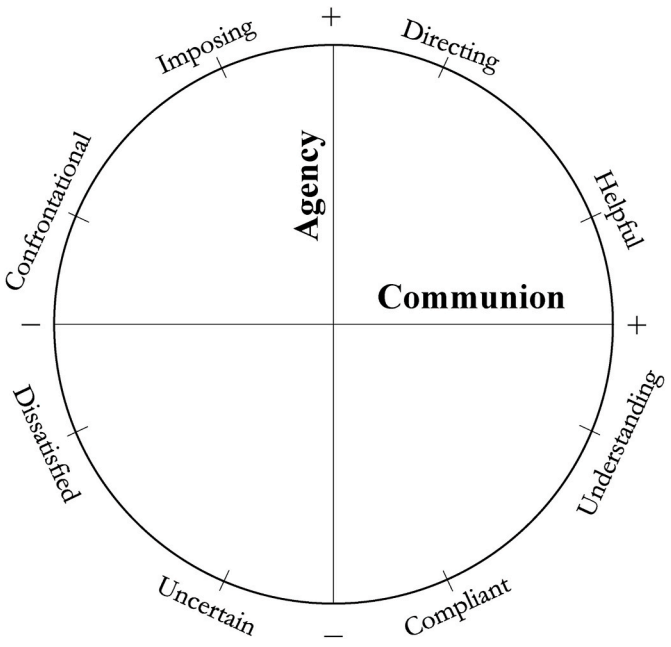

Fig. 1. The interpersonal circle for teachers (IPC-T; Wubbels et al., 2012, 2006).

Many studies in this area relied on student ratings of both teacher behavior and student emotions. While this is on the one hand valuable (and maybe even necessary) to get insight into internal processes and appraisals of students (Becker, Keller, Goetz, Frenzel, & Taxer, 2015; Frenzel, 2014; Pekrun, 2006), it might also lead to common-method or same-rater bias and thus, an overestimation of the true association between teacher behavior and emotional outcomes (Podsakoff et al., 2003). Moreover, although it has been repeatedly suggested that external observation of teacher behavior could be a valuable addition to research with questionnaires, studies including observations in the context of teacher and student emotions are scarce. Before discussing the differences and similarities between observer, student, and teacher perspectives, we first shortly discuss the advantages and disadvantages of each perspective.

1.2. Three perspectives on teacher behavior in class

1.2.1. External observation

The use of external observation to assess teacher behavior has a longstanding tradition (Durkin, 1979; McCutcheon, 1981) and is still often used to evaluate teacher effectiveness (Cohen & Goldhaber, 2016; Kane & Staiger, 2012; Martinez, Taut, & Schaaf, 2016). The main reason for including an external observer is their objectivity. An outsider perspective might better reflect what actually happened in class, because external observers do not participate in the classroom interaction (Praetorius et al., 2012; Scherzinger & Wettstein, 2019). Moreover, due to extensive training, observers often have expert knowledge about (preferred) teaching practices, and they might be better able to judge teacher behavior because they are likely to have observed multiple teachers and therefore have built elaborate (internal) standards for comparison (Kane & Staiger, 2012; Muijs, 2006).

On the other hand, the psychologically more disconnected nature of external observation that allows for more objectivity can also be a drawback in classroom research, specifically in the context of emotions. Typically, observers do not share a classroom history with the teacher and students and therefore have access to much less information regarding the processes observed, particularly when only short video excerpts are rated. Observation is time-consuming, thereby often resulting in studying only brief periods of teaching (e.g., the first 10 min of the lesson) which challenges the generalizability of findings to other situations and other teacher-student pairings (Praetorius et al., 2012; Scherzinger & Wettstein, 2019; Semmer, Grebner, & Elfering, 2004; Van der Lans, 2018), and potentially also the predictive value for emotional outcomes. The more general (relational) classroom context may be crucial as it potentially conveys important –sometimes idiosyncratic– subtleties that are relevant to teacher and student emotions (Pennings & Mainhard, 2016). For example, observers might misinterpret certain teacher behaviors, leading to substitution of the missing information with dominant, earlier observed behavior, or adherence to common stereotypes (e.g., halo-effect; Nisbett & DeCamp Wilson, 1977; Thorndike, 1920). Also, observers have their own personal history and despite training, their previous experiences in school and personal or professional opinions might affect their observations (Semmer et al., 2004). Indeed, it has been found that up to 40% of the variance in external observer ratings may be attributable to these types of observer biases (Hoyt & Kerns, 1999; Praetorius et al., 2012). Therefore, multiple observers are needed to achieve a reliable score (Kane & Staiger, 2012).

1.2.2. Student ratings

Several decades ago researchers started to use students as multiple observers of the teacher (Brattesani et al., 1984; Skinner & Belmont, 1993; Wubbels et al., 1985). Aggregated student perceptions often give a reliable estimate of teacher behavior, because idiosyncrasies of individual students are filtered out. Especially for constructs such as interpersonal teacher behavior, that are relatively straightforward to observe, reliable estimates of teacher behavior can already be achieved based on groups of as little as 10 students (Brekelmans, 1989) or (very) short observations (Ambady & Rosenthal, 1993; Mainhard, Wubbels, & Brekelmans, 2014). An advantage is that in a typical classroom 20 or more students are available, which boosts the reliability of aggregated measures (Kane & Staiger, 2012; Lüdtke, Robitzsch, Trautwein, & Kunter, 2009). Like external observers and in contrast to teachers' self-perceptions, students have a more observational role when reporting on teacher behavior and students often have experienced many different teachers and teaching styles, which increases the validity of student ratings (Clausen, 2002; Scherzinger & Wettstein, 2019). Using students compared to observers has the advantage that students have a shared history with their teacher and can place teacher behavior during the lesson in context.

At the same time, this shared history is a potential drawback, as it may color student perceptions, for example through selective attention (Clayson & Sheffet, 2006; Shevlin, Banyard, Davies, & Griffiths, 2000), or critical incidents in class that happened a few days or weeks before a rating is provided (Wagner et al., 2016). Besides that, students may be prone to give socially desirable answers. Also, students' evaluation of teachers' interpersonal behavior might be influenced by the teachers' general instructional style (Den Brok, Bergen, & Brekelmans, 2006), students' self-regulation, or teacher attention (Wagner et al., 2016).

1.2.3. Teacher report

Another way to get insight into (interpersonal) teacher behavior is to ask teachers themselves (Hargreaves, 2000; Morris-Rothschild & Brassard, 2006). The main advantage of using teacher self-report is that teachers have the best insight into their own intentions, thoughts, and appraisals that are guiding their behavior in class (Becker et al., 2015; Shavelson & Stern, 1981), as well as into the role of the classroom context and the curriculum (Goe, Bell, & Little, 2008). Especially in the context of teacher emotions, teachers can provide unique insights into their behavior that might be tightly connected to how they feel about a lesson.

However, self-report measures have also been critiqued frequently, mainly because they are prone to biases, such as the effect of teachers' mood on their answers (Goetz et al., 2015) and self-serving biases that may lead to overestimation of one's own abilities (Biemans, Jongmans, De Jong, & Bergen, 1999; Brekelmans, Mainhard, Den Brok, & Wubbels, 2011; Podsakoff et al., 2003). Moreover, it might be difficult for teachers to evaluate their own teaching, because they are actively participating in the situation itself (Scherzinger & Wettstein, 2019). Because many teachers work in isolation, it may also be hard for them to apply general standards to their own behavior (Biemans et al., 1999). Furthermore, and this may also be true for student perceptions and some observational approaches, retrospective methods such as questionnaires or interviews may be affected by recall inaccuracies (Becker et al., 2014; Carson, Weiss, & Templin, 2010), the personality of respondents (Barrett, 1998), or subjective beliefs (Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013). Although some teacher self-report methodologies like experience sampling, in which multiple short questionnaires are applied during the lesson, may solve part of these problems, they are also inconvenient for teachers and potentially reduce the ecological validity of research in classrooms (Becker et al., 2014).

1.3. Similarities and differences of observer, student, and teacher perspectives

Studies on the similarities and differences between two or three of the perspectives in the context of (interpersonal) teacher behavior showed varying results. It was found that observer and aggregated student perspectives show considerable overlap (Donker, Van Gog, & Mainhard, 2018; Maulana & Helms-Lorenz, 2016; Scherzinger & Wettstein, 2019). This may at least in part be due to the fact that both measures concern external observations of the teacher. Especially for aspects of teaching that are relatively straightforward to observe, such as interpersonal behavior, observer and student perceptions might be reliable measures (Kane & Staiger, 2012; Kunter & Baumert, 2006). Also, because multiple students or observers typically score the same teacher, their aggregated scores are less vulnerable to idiosyncrasies of individual raters (Lüdtke et al., 2009; Scherzinger & Wettstein, 2019). Teachers themselves have been found to overestimate the quality of their own behavior in class and thus tend to have a more positive perception of their behavior than observers and students, especially when the overall quality of the teacher-student relationship is lower (Brekelmans et al., 2011; Wubbels, Brekelmans, & Hooymayers, 1992). Nonetheless, Clunies-Ross et al. (2008) found considerable overlap between self-reported and observed teaching strategies. A possible explanation for this is that both observers and teachers are usually professionally trained in what good teacher behavior entails, which is not true for students. However, as interpersonal teacher behavior is relatively straightforward to judge, student ratings may be correlated with both observer and teacher ratings (Brekelmans et al., 2011; Kunter & Baumert, 2006). Finally, teachers' and students' perspectives have been found to overlap and it has been proposed that this is because they have a shared classroom history and because the general relationship quality is taken into account when evaluating momentary teacher behavior (Den Brok et al., 2006; Pianta, 2006). Moreover, item wording in student and teacher questionnaires is often parallel, as is the case for the measure used in the current study, which may increase their overlap (Brekelmans et al., 2011). Although it has been suggested that teachers and students interpret instructional constructs differently (Kunter & Baumert, 2006), we expect this effect to be limited for interpersonal behavior, as this construct regards more simple, basic social perceptions rather than specific didactic actions performed by the teacher (Brekelmans et al., 2011; Den Brok et al., 2006).

1.4. Predicting emotions from multiple perspectives on teacher behavior

When the goal is to explain maximum variance in teacher and student emotions, one might opt for including all three perspectives on teacher behavior (Funder & Dobroth, 1987; Kane & Staiger, 2012; Kenny & La Voie, 1984). However, this is often not feasible and may not even be necessary. Standard multiple regression analyses are however not straightforward for providing clear decisions on which perspectives to include. When including several predictors (e.g., the three perspectives), the explained variance of one of the predictors is often large, while the others do not seem to add much (Horst, 1941; Pandey & Elliott, 2010). What cannot be seen in the results of multiple regression analyses is to what extent this large explained variance of one predictor consists of overlap with another predictor (as shown by correlation analyses; shared part) or the unique assets of a perspective (i.e., unique part). A Venn diagram (see Fig. 2) visualizes the overlapping and unique parts in an intuitive and straightforward way. However, simple addition and subtraction of the effects by using separate and combined (multiple) regression analyses only leads to a correct calculation of the size of the shared and unique parts of predictors when there are no suppressor effects (Horst, 1941; Kennedy, 2002; O'Brien, 2018). For example, adding teacher reports to student ratings may not only increase the total explained variance in emotions, but may also enlarge the explained variance due to student ratings beyond the variance that this first predictor could explain when it was the only predictor in the analysis. Such suppressor effects may occur when the relationship between the first predictor and the dependent variable was blurred by their shared relationship with the second predictor (Ganster, Hennessey, & Luthans, 1983). In such cases the unique variance of student ratings might be underestimated and, inaccurately, attributed to teacher reports. Moreover, when only including the first predictor in the analyses, the association with the outcome variable might be misrepresented. When there is shared variance between the various predictors (e.g., because student and teacher perspectives are both influenced by the shared classroom history) regression analyses might thus not lead to the right conclusions about uniqueness and overlap. To the best of our knowledge there is no statistical solution available yet to separate the shared and unique explained variance of predictors. Therefore, we developed a novel statistical approach to split the total explained variance of emotions into shared and unique parts for the three perspectives. The empirical part of the current paper can be viewed as an illustration of the use of this approach with data on teacher interpersonal behavior and teacher and student emotions.

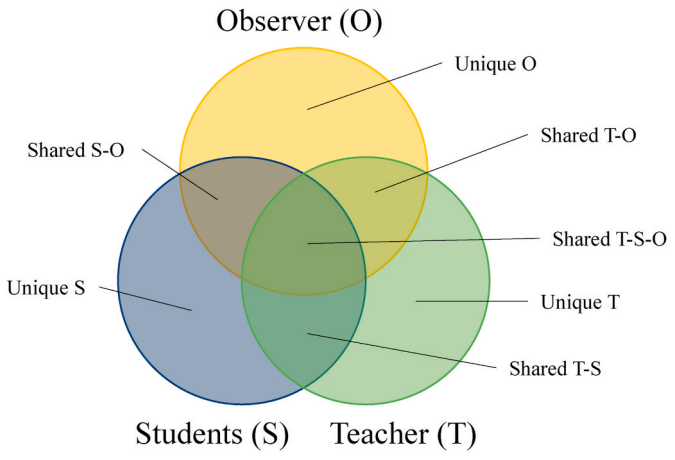

Fig. 2. Simple Venn diagram visualizing the unique and shared/overlapping parts between the three perspectives.

1.5. The present study

Because many studies used only one or two perspectives in their investigations, a comprehensive estimation of similarities and differences among the observer, student, and teacher perspective is needed. Moreover, the few studies that investigated the three perspectives simultaneously (see Dobbelaer, 2019; Fauth et al., 2014; Scherzinger & Wettstein, 2019) did not estimate their potential differential effects on teacher and student emotions. It is important to take this into account, because just knowing that perspectives are different does, for example, not help to decide which perspective(s) are most meaningful or valid to include in future studies. The present study adds to the literature by investigating the overlap between observer, student, and teacher perspectives on teacher behavior, and the shared and unique value of the three perspectives in explaining variability in teachers' and students' emotional outcomes. Moreover, the statistical correction method we introduce here has value beyond the specific topic of the current study and could be applied in other fields as well.

The first research question that guided the present study was:

1) To what extent do external observers, students, and teachers agree in their perception of interpersonal teacher behavior (i.e., levels of teacher agency and communion)?

It was expected that all three perspectives would be moderately correlated. We expected that the observer and student perspectives would overlap to a larger extent than either of them would overlap with the teacher perspective, because both observers and students can be seen as multiple observers of the teacher, which potentially increases the reliability of the aggregated perspective (Scherzinger & Wettstein, 2019; Wubbels et al., 1992). Moreover, we expected overlap between teachers and observers as they both have expert knowledge on teacher behavior (Clunies-Ross et al., 2008), and we expected overlap between teachers and students because of their shared classroom history (Den Brok et al., 2006; Pianta, 2006).

Our second research question was:

2) To what extent do the three perspectives explain shared and unique variance in teacher and student emotions?

We expected that the shared parts of the perspectives would be the strongest predictors of teacher and student emotions, because these shared parts represent most clearly what people agree on regarding a teacher's behavior. Moreover, because emotions represent a relatively subjective measure and personal appraisals play an important role in the formation of emotions (Becker et al., 2015; Frenzel, 2014; Pekrun, 2006), we expected that teachers' self-report and students' ratings of teacher behavior would be the strongest predictors of teacher and student emotions, respectively. Finally, we expected that teacher communion was a stronger predictor of student emotions than agency (Lei et al., 2018; Mainhard et al., 2018).

2. Methods

2.1. Participants

The data used is part of the Dynamics of Emotional Processes in Teachers (DEPTh) project (Donker, van Gog, Goetz, Roos, & Mainhard, 2020). Participants were Dutch secondary school teachers, teaching a variety of subjects. The sample consisted of 80 teachers (41 females) with a mean age of 43.7 years (SD = 11.5 years) and on average 13.4 years teaching experience (SD = 9.7 years). Participating teachers were asked to select a lesson with a challenging group of students to ensure a broad range of experienced emotions. Most teachers selected a group in third or fourth grade (80%; range 1st to 6th grade). In total, 1819 students with a mean age of 15.1 years (SD = 1.1 years) participated. 50.3%

of them were female. Average class size was 22 students ($SD = 5$). Most classes were taught by the participating teacher two or three times a week (73.8%; range 1–7 times) with a typical duration of 45–50 min per lesson (76.3%; range 45–90 min).

2.2. Procedure

The local ethics committee approved the study. Participants were contacted via school newsletters, social media, and educational consultants to ensure a broad range of teachers in the sample (i.e., confident and struggling teachers). Participation was voluntarily and all teachers and students included in the present study signed informed consent forms. A total of 57 out of 1819 students (3.1%) did not consent. These students did not fill out questionnaires and were seated in a part of the classroom that was not visible on camera.

For the observations, two video cameras were placed in the classroom: one in the back of the classroom and one in the front of the classroom. Teachers wore a small microphone during the lesson. We used the camera in the back for the coding of teacher behavior. In this way, observers coded teachers' behavior as if they were seated in the back of the classroom.

Teachers were instructed to proceed as normal and did not receive any training or intervention. Technical failure resulted in missing videos for four lessons. For the remaining classrooms, an average of 41 min 43 s ($SD = 13$ min 12 s) of data on interpersonal behavior was available. The last ten minutes of the lesson were reserved for filling out a questionnaire on paper, featuring teachers' and students' perception of teachers' interpersonal behavior in terms of agency and communion during the lesson and their positive and negative emotions. After participation teachers received a gift card and a personal report with aggregated class scores on the questionnaire items.

2.3. Instruments

2.3.1. Teacher interpersonal behavior

2.3.1.1. External observation. Continuous Assessment of Interpersonal Dynamics (CAID; Mainhard, Pennings, Wubbels, & Brekelmans, 2012; Pennings et al., 2014; Sadler, Ethier, Gunn, Duong, & Woody, 2009) was used to assess interpersonal teacher behavior from moment to moment. One real-life classroom lesson was recorded on video and teacher behavior was coded in terms of agency and communion afterwards with a joystick device. CAID uses the interpersonal circle as an underlying coding scheme with both axes ranging from −1000 to 1000 to enable fine-grained tracking of behavior. Each video was coded by three out of four trained coders (for more information about the coding procedure and training, see Lizdek, Sadler, Woody, Ethier, & Malet, 2012). Videos were coded in 15-min segments to prevent coder fatigue. Segments with low reliability were re-coded by the most deviating coder or (when none of the coders clearly deviated) by a fourth independent coder (8.41% of all segments). The codes of the three coders with the highest reliability were averaged for the analyses. The overall intra-class correlation (ICC; two-way random effects, consistency, three raters; Koo & Li, 2016) was 0.71 ($SD = 0.12$) for agency and 0.63 ($SD = 0.13$) for communion, which indicates strong to moderate agreement, respectively (LeBreton & Senter, 2008). CAID saves the coordinates of the joystick on the coding scheme every 0.5s, but we took the aggregate of all these moments ($M = 500$, $SD = 158$) as an indication of teachers' average agency and communion levels during the lesson. For the analyses we divided the score by 1000 to match the teacher and student reports (where scores ranged from −1 to 1).

2.3.1.2. Student ratings and teacher self-reports. We used the 24-item Questionnaire on Teacher Interaction (QTI; Wubbels et al., 1985) to assess both the students' perspective as well as the teachers' perspective on teachers' interpersonal behavior, with strictly parallel item wording. Items were answered on a five-point Likert scale ranging from 1 (*never*) to 5 (*always*). Students were asked how they perceived their teacher, and teachers were asked how they perceived themselves as teacher. Each item started with 'This teacher … '. Using third person singular also for self-report items is common practice in personality research and has been suggested to diminish self-serving biases (Hofstee, 1994). As a circumplex structure (see Fig. 1) is underlying the questionnaire, all items load both on the agency and communion dimensions. See Appendix A for the weights per octant/subscale of the questionnaire. For example, the item 'This teacher is a good leader' has a high loading for the agency dimension (i.e., 0.92) and a moderately high loading for communion (i.e., 0.38), while the item 'This teacher is patient' loads moderately low on agency and high on communion (for more information, see Brekelmans et al., 2011; Den Brok et al., 2006; Locke, 2011). Reliability was good for the teacher questionnaire ($\alpha_{agency} = 0.78$, $\alpha_{communion} = 0.82$) and for the individual student ratings ($\alpha_{agency} = 0.76$, $\alpha_{communion} = 0.89$), and excellent for the aggregated student ratings ($\alpha_{agency} = 0.90$, $\alpha_{communion} = 0.95$). Measurement invariance analyses suggest that teacher and student measures are similar when using the agency and communion dimension scores (Brekelmans et al., 2011), which is what we did in the current study.

2.3.2. Teacher and student emotions

Teachers' and students' emotions after the lesson were measured using adapted versions of the Achievement Emotions Questionnaire (Pekrun et al., 2011) and the Teacher Emotions Scales (Frenzel et al., 2016). Nine discrete academic emotions were assessed (i.e., anger, anxiety, boredom, disappointment, enjoyment, pride, relaxation, relief, and shame) with 31 items. For the analyses, we grouped the emotions in a positive (enjoyment, pride, relaxation) and negative (anger, anxiety, boredom, disappointment, relief, shame) factor. Reliability of the teacher questionnaire was good ($\alpha_{positive} = 0.82$, $\alpha_{negative} = 0.82$). Reliability of the student questionnaire was sufficient, both for the aggregated class level ($\alpha_{positive} = 0.69$, $\alpha_{negative} = 0.84$) and the individual student level ($\alpha_{positive} = 0.63$, $\alpha_{negative} = 0.78$).

2.4. Analyses

Assumptions for correlational and regression analyses were checked in SPSS version 24. One outlier was identified for students' rating of agency (z-score = −3.44), but as this value was in line with the observed and teacher-reported agency for this teacher, we kept it in the dataset. There were no multivariate outliers. All skewness and kurtosis values were between −1.96 and 1.96. Visual inspection of scatterplots confirmed the assumptions of normality, homoscedasticity, and linearity for all analyses. The residuals were independent and normally distributed.

Descriptive statistics were calculated with Mplus (version 8.2; Muthén & Muthén, 2017). Intraclass correlations (ICC) were used to check the proportion of total variance that could be attributed to between-class differences (i.e., ICC(1)) and the reliability of the student measures at the teacher/class level (i.e., ICC(2); Lüdtke et al., 2009; Snijders & Bosker, 2012). To answer the first research question, we examined the overlap between observer, student, and teacher perspectives and teacher and student emotions at the class/teacher level while accounting for the nested structure of the data (i.e., students nested in teachers) with correlational analyses in Mplus.

For the second research question, which was approached at the teacher/class level, we used (multiple) regression analyses in R (R Core Team, 2017) with teacher and student positive and negative emotions as dependent variables. We entered aggregated observer, aggregated student, and teacher-perceived teacher agency and communion as predictors, both as single as well as combined predictors (7 options in total, see Table 2). To be able to calculate the unique and shared contributions of each predictor to both teacher and student emotions, we used a novel

Table 1
Descriptive statistics and multitrait-multimethod matrix for perspectives on teacher behavior and teacher and student emotions.

		Descriptive statistics					Correlations									
		M	*SD*	*n*	ICC(1)	ICC(2)	1	2	3	4	5	6	7	8	9	10
Teacher behavior																
External observation																
1	Agency	.28	.13	75			-									
2	Communion	.33	.09	75			.03	-								
Student perception																
3	Agency	.19	.21	1788	.46	.95	**.49**	.02	-							
4	Communion	.31	.29	1788	.46	.95	.06	**.44**	-.05	-						
Teacher report																
5	Agency	.18	.17	79			**.40**	-.10	**.66**	.00	-					
6	Communion	.39	.18	79			.05	.10	-.10	**.52**	.15	-				
Emotions																
Student emotions																
7	Positive	3.56	0.68	1784	.15	.79	.11	**.35**	.06	**.78**	.06	**.44**	-			
8	Negative	2.03	0.56	1786	.17	.82	-.12	**-.46**	**-.20**	**-.81**	-.17	**-.38**	**-.94**	-		
Teacher emotions																
9	Positive	3.77	0.62	79			**.28**	**.25**	-.02	**.30**	.19	**.51**	**.31**	**-.32**	-	
10	Negative	1.79	0.58	79			**-.30**	**-.27**	-.12	**-.37**	**-.36**	**-.51**	**-.27**	**.32**	**-.77**	-

Note. Bold coefficients were significant at $p < .05$.

Table 2
Total and unique sum of squares of the three perspectives on teacher behavior in various combinations.

	Teacher Emotions						Student Emotions					
	Positive			Negative			Positive			Negative		
Total variance	25.89			23.98			6.59			4.99		
	SS_T	SS_C	SS_U	SS_T	SS_C	SS_U	SS_T	SS_C	SS_U	SS_T	SS_C	SS_U
Explained variance - Communion												
Observer	1.28	1.63	0.22	1.57	1.86	0.31	0.61	0.61	0.00	0.81	0.81	0.03
Student	2.52	3.22	0.00	2.83	3.39	0.00	3.31	3.31	1.90	2.80	2.80	1.58
Student + Observer	2.75	3.44	0.47	3.16	3.70	0.67	3.31	3.31	0.47	2.84	2.84	0.66
Teacher	7.85	7.90	5.15	5.85	5.92	3.20	0.95	0.95	0.01	0.57	0.57	0.00
Teacher + Observer	8.58	8.60	0.00	6.88	6.91	0.00	1.42	1.42	0.00	1.26	1.26	0.00
Teacher + Student	7.92	8.37	1.81	6.20	6.59	1.85	3.32	3.32	0.80	2.81	2.81	0.44
Teacher + Student + Observer	8.60	8.60	0.95	6.91	6.91	0.88	3.32	3.32	0.14	2.84	2.84	0.12
Explained variance – Agency												
Observer	2.20	3.00	0.22	2.30	3.05	0.15	0.05	0.06	0.02	0.04	0.04	0.00
Student	0.05	2.70	0.33	0.73	1.48	0.02	0.03	0.04	0.01	0.15	0.16	0.05
Student + Observer	2.53	3.98	0.00	2.32	3.06	0.36	0.06	0.06	0.02	0.16	0.16	0.00
Teacher	2.26	4.36	0.93	4.18	4.92	2.38	0.01	0.01	0.00	0.09	0.07	0.00
Teacher + Observer	3.12	4.57	1.06	4.69	5.43	1.44	0.05	0.06	0.00	0.08	0.08	0.02
Teacher + Student	3.24	4.69	0.64	4.56	5.30	0.00	0.04	0.04	0.00	0.15	0.16	0.05
Teacher + Student + Observer	4.90	4.90	1.73	5.45	5.45	1.10	0.06	0.06	0.01	0.16	0.16	0.04

Note. SS_T = total explained variance by each (combination of) perspective(s), SS_C = corrected total explained variance by each (combination of) perspective(s), SS_U = unique explained variance by each (combination of) perspective(s).

statistical technique that enabled us to separate the unique and shared associations, even in the case of suppressor effects or large overlap between variables. An explanation of this aproach and the R code can be found in Appendix B. In short, we corrected the explained variance in several steps by combining the information from the various multiple regression analyses. We used listwise deletion to be able to compare the Sum of Squares (SS) across the analyses, resulting in a final sample of 76 teachers for the second research question.

3. Results

3.1. Descriptive statistics

Descriptive statistics for teacher behavior from the observer, student, and teacher perspective are reported in Table 1. For student-perceived teacher agency and communion, the ICC(1) values show that about half of the variance was located at the classroom/teacher level (hereafter teacher level), thereby confirming that aggregated student perceptions of teachers' interpersonal behavior could be considered a reliable classroom climate construct (also see ICC(2) values). Teachers and students reported, on average, lower levels of teacher agency than observers. For teacher communion, students reported on average the lowest values, followed by observers and teachers. Further, both teachers and students reported a higher level of positive than negative emotions, but students reported slightly higher levels of negative emotions than their teachers. The classroom aggregate of student emotions was reliable (Lüdtke et al., 2009), but the ICC(1) values indicated that only a relatively small proportion of the variance in student emotions was shared between students.

3.2. Correlational analyses

There was a large and statistically significant overlap between external observation, student ratings, and teacher self-reported levels of

agency (see Table 1). For communion, there was a significant association between student ratings and observers and student ratings and the teacher. Interestingly, and against what a shared expert role of teacher and observer would imply, there was no significant association between the observed and teachers' self-reported levels of communion, suggesting that teachers perceived their communion differently from what was observed. In accordance with the theoretical independency of agency and communion (i.e., the level of someones agency does not allow to infer communion; Fabrigar et al., 1997; Horowitz & Strack, 2011), agency and communion measures were not statistically associated in our sample.

Bi-variate correlations indicated that higher communion levels during the lesson according to all three perspectives (observer, student, and teacher) were associated with significantly higher levels of positive teacher and student emotions and lower levels of negative emotions, although the effect was clearly stronger for students. For students, only higher levels of student-perceived teacher agency were associated with lower levels of negative student emotions. Teachers who reported higher levels of positive emotions and lower levels of negative emotions were more likely to report higher levels of teacher agency themselves. In line with this, higher levels of observed agency were associated with lower levels of negative teacher emotions.

3.3. Shared and unique associations with emotions

To answer the second research question, Table 2 first presents the results of standard multiple regression analyses (see SS_T-column), reflecting all possible constellations of one/two/three perspectives on teacher agency and communion as predictors of teacher and student emotions. Especially for students, teacher communion explained more variance in their emotions as compared to teacher agency. The total explained variance when including all three predictors simultaneously (i.e., bottom row) ranged from almost zero (0.06 of 6.59) for student positive emotions as predicted by teacher agency to 56.9% (2.84 of 4.99) for the prediction of student negative emotions from teacher communion.

The problem with findings from standard multiple regression analyses is that we do not know to what extent the overlap of one perspective with the other perspectives (see the results of correlational analyses in Table 1) could explain part of the associations between a perspective and an emotional outcome, and whether suppressor effects may be present in any of the analyses. To examine these shared and unique associations of perspectives with the outcome variables, we developed a method to split the variance in shared variance between predictors and unique variance for each of the perspectives by contrasting the findings from several multiple regression analyses (for more information, see Appendix B). The results are presented in Table 2 and Fig. 3. When comparing the SS_T- and SS_C- columns of the tables, it becomes clear that there were suppressor effects in the standard regression analyses. For example, the predictive value of the students' perspective on teacher agency had almost no predictive value for teacher positive emotions in the standard regression method (i.e., 0.05), but when using our correction method, a much larger predictive value (i.e., 2.70) was found for the student perspective, which was probably suppressed due to the large overlap with the observer and teacher perspective.

In general, teachers' and students' own perspective explained a relatively large percentage of variance in their own emotional outcomes, especially in the case of communion. Both the total corrected effect of their own perspective (i.e., SS_C) as well as only their unique perspectives on teacher agency and communion (i.e., SS_U; the part that is not overlapping with any of the other perspectives) were strong predictors of emotional outcomes. In addition, the overlap between teacher and student perspectives on teacher communion (i.e., the part student and teacher agree on) explained a smaller but still substantial part of the

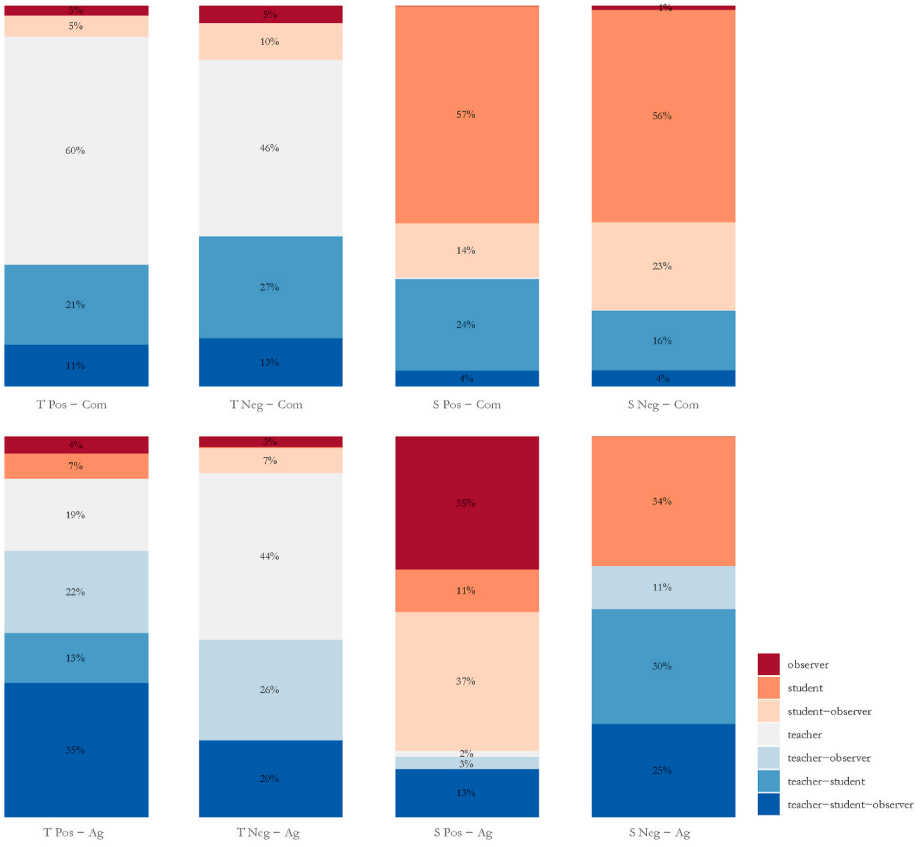

Fig. 3. Illustration of the percentage of unique explained variance by the various perspectives and their combination. *Note.* T = teacher, S = students, Pos = positive emotions, Neg = negative emotions, Com = Communion, Ag = agency.

variance in both teacher and student emotions. Specifically for students' emotional outcomes also the overlap in perceived communion between students and observers was a significant predictor.

For teacher agency, the effect of teachers' and students' own unique perspective was less pronounced as compared to communion. Instead, we found a larger percentage of explained variance in emotions for the overlap between teacher, student, and observer perspectives (i.e., the part that they all agreed on). Moreover, for teacher emotions, the overlap between teacher and observer, potentially reflecting the expert view on teacher behavior, also explained a relatively large part of the variance. Fig. 4 illustrates the findings for teacher positive emotions in a Venn diagram. It can be clearly seen that for teacher agency there is much more overlap between the perspectives when explaining emotional outcomes than for teacher communion. Combining the observer and student perspective on teacher agency would explain almost the same amount of variance in teachers' positive emotions compared to including only the teacher perspective.

4. Discussion

Teachers' behavior in interaction with students has been proposed as an important predictor of teacher and student emotions (Becker et al., 2015; Mainhard et al., 2018; Spilt et al., 2011). When investigating these associations, previous studies often relied on the same rater for both teacher behavior as well as emotional outcomes, which makes them vulnerable to common-method or same-rater bias (Podsakoff et al., 2003). It has been suggested that using another perspective on teacher behavior, such as external observation, would be beneficial. However, only few studies on teachers' interpersonal behavior did include all three perspectives simultaneously (Dobbelaer, 2019; Fauth et al., 2014; Scherzinger & Wettstein, 2019), and thus it was not clear how the three perspectives were associated. The present study therefore included the observer, student, and teacher perspective simultaneously to investigate their overlap. Moreover, we introduced a novel correction method to disentangle the shared and unique role of the three perspectives in explaining teachers' and students' emotional outcomes by contrasting the findings of several regression analyses with one, two, or three perspectives as predictors.

The main findings were that the observer, student, and teacher perspectives showed medium to high correlations for agency and communion, except for the observer and teacher perspective on communion, which did not overlap. Especially for student emotions, teacher communion was a better predictor than agency. Student ratings and teacher self-reports of teacher behavior were the best predictors of student and teacher emotions, respectively. This association could not have been fully driven by common-method bias, because we showed that the overlap between two or three of the perspectives also accounted for part of this variance. For teacher emotions, including the combination of observer and student perspectives on teacher agency explained almost the same amount of variance compared to only the teacher perspective, and these could thus be seen as alternatives for teacher report. For student emotions, students' own perspective was irreplaceable, and the observer and teacher perspective could only add little to this perspective. In sum, the results showed that different perspectives on teacher behavior are not interchangeable and each perspective has its own assets. Our newly developed methodological approach could help to disentangle shared and unique effects of various predictors on all kind of outcomes. The unique and shared explanatory value might depend on the specific outcome variables under investigation.

4.1. Overlap between observer, student, and teacher perspectives

In line with previous studies (Brekelmans et al., 2011; Scherzinger & Wettstein, 2019; Wubbels et al., 1992), we found large overlap between externally observed levels of teacher interpersonal agency, student ratings, and teachers' self-reported agency. For communion, we found that only the student perspective was associated with both the observer perspective and the teacher perspective. The observer and teacher perspective were not significantly associated. The overlap between observers and students may exist because both are rating teachers' interpersonal behavior from a more distant, outsider perspective with, in addition, the possibility to compare between several teachers (Clausen, 2002). Moreover, for both students and observers, we included several raters which increased their reliability and the robustness for idiosyncrasies of individual ratings (Lüdtke et al., 2009; Scherzinger & Wettstein, 2019; Wubbels et al., 2006). The overlap between the teacher and student perspective on communion may be due to the fact that both potentially take into account their shared classroom history and might rate the teachers' behavior in the observed lesson in light of previous behaviors (Becker et al., 2015; Frenzel, 2014). That observers and teachers did agree on the level of agency, but not on the level of communion, might indicate that teacher agency is easier to observe objectively, which is also reflected in the higher reliabilities of observational coding for agency in the current study as well as in previous research (Pennings et al., 2018; Sun, Pennings, Mainhard, & Wubbels, 2019).

4.2. Shared and unique explained variance in emotions

Overall, we found that higher levels of teacher agency and communion were associated with higher levels of positive and lower levels of negative teacher and student emotions, which is in line with earlier research (Becker et al., 2015; Lei et al., 2018; Mainhard et al., 2018). For students, especially their perception of teacher communion was associated with their emotions. This is in line with Mainhard et al. (2018), who found that especially communion predicted variability in student enjoyment. Students who feel that their teachers care for them or like them might feel more supported and therefore experience higher levels of positive emotions (Lei et al., 2018; Mainhard et al., 2018; Sun et al., 2018). For teachers, we also found a stronger association and more explained variance in emotions for teacher communion compared to teacher agency, but the differences were less pronounced. For teachers their level of agency in class (i.e., having a leading role) thus also seems

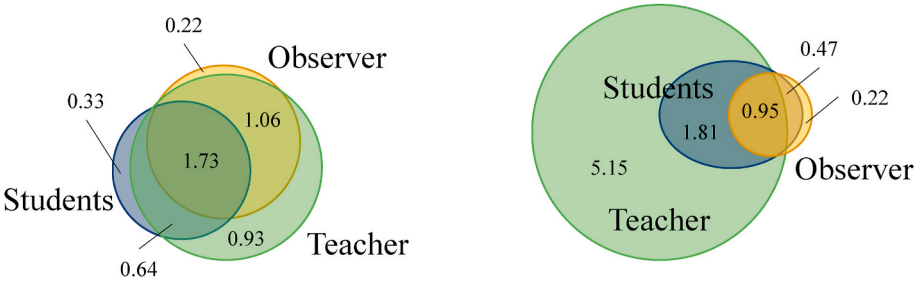

Fig. 4. Illustration of the explained variance for teachers' positive emotions from the three perspectives on teacher agency (left) and teacher communion (right). The numbers represent the unique and shared explained variance (SS_U).

to be an important predictor of experiencing positive emotions after the lesson. This is something that could be addressed in teacher education programs.

Our findings showed that students' and teachers' own perspectives on teacher behavior were the strongest predictors of students' and teachers' emotions, respectively. This corresponds to previous findings using the same rater for both predictor (i.e., teacher behavior) and outcome (i.e., emotions in our case; Becker et al., 2015; Maulana & Helms-Lorenz, 2016; Pekrun, 2006; Skinner, Kindermann, & Furrer, 2009). An individual's interpretation of behavior thus seems to have a strong association with their emotions. This is in line with appraisal theories of emotion (Frenzel, 2014; Frijda, Kuipers, & Ter Schure, 1989), which highlight idiosyncratic interpretations of the (social) environment. For teachers, it might thus be important to not only 'objectively' show high levels of agency and communion in their lessons, but also to experience this as such in order to affect their emotions (Veldman et al., 2013). For students, the actual teacher behavior in class is important (see also next paragraph), but their interpretation of teacher behavior seems even more important for their emotional outcomes. We should note, however, that this association may be partly due to same-rater bias.

This study confirmed that the association between teacher/student perceptions and teacher/student emotions cannot be completely attributed to common-method bias. We showed that the student perspective on communion was correlated with the teacher perspective, and that about 25% of the explained variance in positive emotions originally attributed to the students' perspective only could be attributed to the overlap between students and teachers (probably due to their shared classroom history; Scherzinger & Wettstein, 2019; Semmer et al., 2004). For the association between teacher agency and teachers' negative emotions we found a similar effect. Although the original regression analyses attributed the largest part of the explained variance to the teacher perspective, our correction method showed that about 30% of this effect could be attributed to the overlap between observers and teachers as well as about 20% to the overlap between all three perspectives.

For teacher emotions, the unique explained variance by the observer or student perspective was small as compared to the teachers' own perspective. Similar results were found for the role of the observer and teacher perspective for student emotions. Although these perspectives could not explain much variance in emotions on their own, including them next to teachers' or students' own perspective helped to account (at least in part) for common-method bias (Podsakoff et al., 2003; Wagner et al., 2016). Also, for teachers, combining the observer and student perspective on teacher agency led to almost the same explained variance in teacher emotions compared to asking only the teacher.

4.3. Limitations and future directions

We presented a new correction method for regression analyses to split the shared and unique variance of different perspectives on teacher interpersonal behavior (i.e., agency and communion) in explaining emotional outcomes of teachers and students. A very important next step is to disentangle to what extent the strong effect of teacher reports on teacher emotions and student ratings on student emotions (even after attributing part of this to the overlap with other perspectives) represents real common-method bias versus the effect of an individual's idiosyncratic appraisal on both reports of behavior and emotions (Göllner, Wagner, Eccles, & Trautwein, 2018). The problem with current statistical methods to filter out common-method bias (e.g., Podsakoff et al., 2003) is that they usually take out the entire overlap between two constructs, including the part that may be due to meaningful individual psychological processes. Especially in the context of emotions, these appraisals are not trivial and taking them out will most likely result in a misrepresentation of the association between behavior and emotions. Future studies could try to measure appraisal processes more directly, for example by asking teachers and students how they appraised an event (Csikszentmihalyi & Larson, 1987; De Ruiter, Poorthuis, & Koomen, 2019; Keller, Chang, Becker, Goetz, & Frenzel, 2014), or by including more implicit or physiological measures of appraisal (Donker et al., 2018, 2020; Hollenstein & Lanteigne, 2014; Scherer, 2009).

Another limitation of the present study regards the differences in measurement between the observational perspective and the student and teacher perspective on teacher behavior. The observer perspective consisted of the mean of about 500 micro-genetic ratings over the course of the lesson, while students and teachers scored teacher behavior at one moment in time, after the lesson had ended. While for the observer mean scores each moment during the lesson was thus given equal weight, the students and teachers might have weighted teacher behavior in some 'critical incidents' during the lesson as more important. Especially teachers' behavior during such critical incidents might also have affected teacher and student emotions (Admiraal, Korthagen, & Wubbels, 2000; De Ruiter et al., 2019). Future studies could include a questionnaire for the observer perspective as well. This would also allow to test for measurement invariance between the three perspectives. Nonetheless, the intra-individual nature and the intensity of the observational data has also many advantages that could be explored in future studies (see for example Mainhard et al., 2012; Pennings et al., 2018).

Further, it should be noted that to be able to calculate the association between teacher behavior and student emotions, we aggregated student perceptions and emotions to the teacher/class level. The findings thus do only hold for the part the students in a classroom agree on. Despite their reliability (i.e., ICC(2) was >0.79 for all variables), students in the same class still differed considerably in their perceptions of teacher behavior and emotional experiences (i.e., ICC(1) ranging from 0.15 to 0.46). Accordingly, the total explained variance in student emotions was lower than for teachers. Future studies might want to further investigate differences between students and associations in specific teacher-student dyads (Göllner et al., 2018).

In the present study, we assessed teacher behavior during one lesson with one group of students. Future research should examine whether the association between teacher behavior and teacher and student emotions is similar in other classrooms, for example by incorporating teachers and students in different constellations to enable cross-classified modeling (Kenny & La Voie, 1984; Mainhard et al., 2018) or generalizability theory (Hoyt, 2000; Praetorius et al., 2012; Van der Lans, 2018).

Finally, although we assumed based on theoretical models that teacher behavior predicted emotions, it has also been shown that teacher and student reports of interpersonal teacher behavior might in turn be influenced by their emotions (Goetz et al., 2015). Also, we found significant correlations between teacher and student emotions (Frenzel et al., 2018; Frenzel, Goetz, Lüdtke, Pekrun, & Sutton, 2009), so it could be that teacher emotions directly affect student emotions, next to the agency and communion they convey in class. These causality questions need attention in future research.

4.4. Conclusion

The present study introduced a novel statistical approach to separate the shared and unique effects of several predictors on an outcome variable. This approach could be applied also in other contexts, such as organizational psychology, where employee and employer perspectives could be compared. For the topic in the current paper, we showed that the observer, student, and teacher perspectives on teacher behavior differ, and that they have different explanatory value for teacher and student emotions. Including teachers' and students' own perspective on communion seems of utmost importance to accurately predict respectively teacher and student emotions but including other perspectives (such as external observation) next to their own perspective might help to control (at least in part) for common-method bias. The discrepancies between different perspectives might also give teachers insight in how their behavior is perceived by others and how they can foster positive

student emotions. For teacher agency, combining the observer and student perspective could be a substitute for the teacher perspective, but for other combinations of predictors and outcomes this was hardly the case. Triangulating different perspectives is thus a necessary step in disentangling the complex association between teacher interpersonal behavior and emotional outcomes of teachers and students.

CRediT authorship contribution statement

Monika H. Donker: Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization. **Lian van Vemde:** Methodology, Formal analysis, Writing - original draft. **David J. Hessen:** Methodology, Software. **Tamara van Gog:** Conceptualization, Writing - review & editing, Supervision. **Tim Mainhard:** Conceptualization, Methodology, Writing - review & editing, Supervision.

Declaration of competing interest

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Appendix A. Weights per octant QTI

Octant	Weights	
	Agency	Communion
Directing	0.923880	0.382683
Helpful	0.382683	0.923880
Understanding	−0.382683	0.923880
Compliant	−0.923880	0.382683
Uncertain	−0.923880	−0.382683
Dissatisfied	−0.382683	−0.923880
Confrontational	0.382683	−0.923880
Imposing	0.923880	−0.382683

Note. Octants refer to the octants in Fig. 1. Each octant consisted of three questionnaire items that were all weighted separately according to the weights displayed in the table. For more information, see Brekelmans et al., 2011; Den Brok et al., 2006; Locke, 2011.

Appendix B. Annotated R code

```
# INPUT.
# Open data file with listwise deletion of missing values

df < -read.table (" [name datafile]. dat",header = TRUE).
df < -na.omit (df).

# Execute the various regression analyses for the (combination of) predictors. The example code was used to calculate the association between teacher communion and positive teacher emotions.

s1 <-anova (lm (TPosEmo TCom, data = df))[1,2] # Teacher (T).
s2 <-anova (lm (TPosEmo SCom, data = df))[1,2] # Student (S).
s3 <-anova (lm (TPosEmo OCom, data = df))[1,2] # Observer (O).
s12 <-sum (anova (lm (TPosEmo TCom + SCom, data = df))[1:2,2]) #T + S
s13 <-sum (anova (lm (TPosEmo TCom + OCom, data = df))[1:2,2]) #T + O
s23 <-sum (anova (lm (TPosEmo SCom + OCom, data = df))[1:2,2]) #S + O
s123 <-sum (anova (lm (TPosEmo TCom + SCom + OCom, data = df))[1:3,2]) #T + S + O.

# ANALYSES.
# If the explained variance of the two separate perspectives (s1 and s2) is smaller than the variance explained by including both predictors (s12), the unique explained variance of the shared part is the variance explained by s12 minus s1 minus s2. In all other cases, the unique explained variance of the shared part is the sum of s1 and s2 minus s12.

if (s1+s2<s12){d12<-s12-s1-s2} else {d12<-s1+s2-s12}
if (s1+s3<s13){d13<-s13-s1-s3} else {d13<-s1+s3-s13}
if (s2+s3<s23){d23<-s23-s2-s3} else {d23<-s2+s3-s23}

# We know that the sum of the explained variance by both perspectives (s12) and the unique variance explained by both perspectives (d12) is equal to the sum of the unique parts of d1 and d2. This information is used to come to a first estimation of d1, d2 and d3.

A < - matrix (c (1,1,0,1,0,1,0,1,1),nrow = 3).
b < - c (s12+d12,s13+d13,s23+d23).
```

```
d < - solve (A,b).

# Now a first estimation is made of the unique explained variance by the overlap between the three perspectives (d123) by subtracting the variance explained by the unique parts from the total explained variance. The estimation of d123 has to be smaller than the explained variance of each of the overlap between only two of the perspectives, which is why we calculate m.

d123 <- s123-sum(d)+d12+d13+d23
m < - min (c (d12,d13,d23))

# If d123 is smaller than m, the previous calculation still holds. In the case that d123 is bigger than m, we need to correct the various unique parts for at least the difference between d123 and m.

if (d123>m){
d [1] <- d [1]+d123-m
d [2] <- d [2]+d123-m
d [3] <- d [3]+d123-m
d12 <- d12+d123-m
d13 <- d13+d123-m
d23 <- d23+d123-m}

# In the case that d123 is negative, we need to correct the other parts by subtracting d123 from the previous estimation of the unique part.

if (d123 < 0){
d123 <- -d123
d [1] <- d [1]+d123
d [2] <- d [2]+d123
d [3] <- d [3]+d123
d12 <- d12+d123
d13 <- d13+d123
d23 <- d23+d123}

# We know that the total explained variance of d1 needs to be at least as big as the sum of d12 and d13 minus d123. If this is not the case, then we correct d1 to be at least the sum of d12 and d13 minus d123.

if (d [1]-d12-d13+d123 < 0){d [1]<-d12+d13-d123}
if (d [2]-d12-d23+d123 < 0){d [2]<-d12+d23-d123}
if (d [3]-d13-d23+d123 < 0){d [3]<-d13+d23-d123}

# Final check whether the sum of the unique parts corresponds to the total sum of squares as defined at the start (s123).

a <- sum(d)-d12-d13-d23+d123
d [1] <- s123*d [1]/a
d [2] <- s123*d [2]/a
d [3] <- s123*d [3]/a
d12 <- s123*d12/a
d13 <- s123*d13/a
d23 <- s123*d23/a
d123 <- s123*d123/a
round (c (d,d12,d13,d23,d123),3).
sum(d)-d12-d13-d23+d123.
# OUTCOMES.
# CORRECTED TOTAL EXPLAINED VARIANCE (SSC).
#Corrected total explained variance by each (combination of) predictor(s).
round (d [1],3) # SSC teacher
round (d [2],3) # SSC student
round (d [3],3) # SSC observer
round (d12,3) # SSC teacher + student
round (d13,3) # SSC teacher + observer
round (d23,3) # SSC student + observer
round (d123,3) # SSC teacher + student + observer.

#UNIQUE EXPLAINED VARIANCE (SSU).
# Calculation of the unique explained variance by subtracting the shared parts from the total variance that could be explained by each predictor separately and by the combination of two or three predictors.

round (d [1]-d12-d13+d123,3) # SSU teacher
```

round (d [2]-d12-d23+d123,3) # SS_U student
round (d [3]-d13-d23+d123,3) # SS_U observer
round (d12-d123,3) # SS_U teacher + student
round (d13-d123,3) # SS_U teacher + observer
round (d23-d123,3) # SS_U student + observer
round (d123,3) # SS_U teacher + student + observer.

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