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Joy is reciprocally transmitted between teachers and students: Evidence on facial mimicry in the classroom

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STRUCTURED ABSTRACT

Background: The critical importance of positive emotions for classroom functioning is well established and teachers' and learners' trait-based joy during class has been shown to covary. This has been interpreted as evidence of emotional contagion across teachers and learners. However, no research to date seems to have explored in-situ processes of emotional contagion, thus the social dynamic of positive emotion transmission during instruction is poorly understood.
Aims: In this study, we aim to explore one fundamental mechanism proposed to underlie emotional contagion, namely facial mimicry. We seek to provide evidence of facial joy mimicry between teachers and students during real-life instruction, and explore its relations with teachers' and learners' subjective session joy experiences.
Sample: Participants were 13 university instructors and 69 of their students.
Methods: Participants' joy expressions were captured through a multi-camera setup and submitted to AI-based automated facial emotion coding. Facial mimicry within each teacher–student dyad was determined through cross-recurrence quantification analysis.
Results: Instructors' and students' facial expressions of joy co-occurred substantially above chance level -2s and +3s seconds relative to the instructors' expressions. Post-session self-reported joy was significantly positively correlated with the instructor–student dyad mimicry quantity for instructors, but not for students.
Conclusions: Our findings suggest that joy transmission between teachers and students is a reciprocal process, and that teachers seem to emotionally benefit from joint episodes of positive expression in class.

Teaching and learning are inherently social and interactive, and they can involve strong emotional experiences among teachers and students alike (Harvey et al., 2012; Pekrun et al., 2017; Pekrun & Linnenbrink-Garcia, 2014). Research over the past twenty years has accumulated convincing evidence that teachers' and students' emotions are critical for their performance and well-being. Recently, scientific interest in positive emotions in particular has surged, and it has been shown that they are highly relevant for well-functioning learning environments (e.g., Dewaele et al., 2019; Frenzel et al., 2021; Graesser, 2020; Loderer et al., 2020). Specifically, joy and enthusiasm have been shown to be salient and frequent for both teachers (Hascher & Waber, 2021; Keller et al., 2014, 2016) and students (Goetz et al., 2006; Pekrun et al., 2002). One finding within this strand of research addressing positive emotions in the classroom is that joy can transmit from students to teachers, and vice versa (e.g., Frenzel et al., 2009; Frenzel et al., 2018). This finding has been obtained through self-report assessments of teachers' and students' habitual emotional experiences in class, as reported at multiple time points across a schoolyear. As such, those findings on joy transmission rest on the observation that teachers' and students' reports of their tendencies to enjoy class (i.e., their trait joy) develop more favorably across a schoolyear in classes with high average joy levels, and vice versa for students.

Such covariation between self-reported emotional experiences during social interactions is typically interpreted in terms of emotion transmission. This phenomenon has also been reported in contexts other than teaching, such as couples, mother–infant dyads, professional

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leader–staff and employee–customer dyads (see Marx, 2020, for an overview). However, the actual processes underlying emotion transmission are poorly understood and rarely explored in applied settings. A key proposition of the present contribution is that macro-level covariation between teachers' and students' self-reported habitual joy experiences is fueled, in a bottom-up fashion, by micro-level covariation: That is, by repeated instances of joint joy experiences among teachers and students during instruction. We suggest that the face is a particularly important channel through which teachers' and students' emotional experiences are communicated to one another. Thus, mimicry of facial joy expressions should be one important mechanism that drives such emotional convergence among teachers and students (see also Talebzadeh et al., 2020). Based on this assumption, the key goal of the present study was to explore whether there is empirical evidence of systematic cross-recurrence of teachers' and students' facial expressions of joy, during their real-time class learning interaction. Doing so, we strive to add to a better understanding of interpersonal emotion transmission in general, and to derive practical implications for the classroom, specifically with respect to recommendations on teachers' up-regulation of their positive facial expressiveness during teaching. Many authors recommend that teachers should work on their positive expressiveness and enthusiasm during teaching. There is consistent, cross-culturally universal evidence that displayed enthusiasm attracts student attention, boosts motivation, joy and engagement, and thus increases performance (Dewaele & Li, 2021; Frenzel et al., 2019; Keller et al., 2016; Moè et al., 2021; Xie et al., 2022), and corresponding trainings have been developed (e.g., Patrick et al., 2000). However, there are also voices that warn against potential negative effects of such emotional labor in the classroom if the emotion expression is not authentic and executed only on a surface level (Brotheridge & Lee, 2002; Hülsheger & Schewe, 2011; Taxer & Frenzel, 2018). If the present research showed that teacher joy expressions were systematically reciprocated by students in classrooms and that teachers emotionally benefitted from such joy mimicry by their students, then recommendations for teachers to up-regulate their positive expressivity would receive new compelling support.

1. Conceptualization of emotion transmission and emotional mimicry

Many terms are used in the literature to denote the phenomenon of people converging in their emotions when interacting socially. Among those are emotion transmission, emotional contagion, emotional crossover, and emotional mimicry.[1] They all describe the phenomenon of two people experiencing and/or expressing similar emotions during an interaction, presupposing some sort of temporal dynamic in that one interaction partner experiences the emotion first, and then the other one follows. Importantly, the term emotional mimicry is set apart from the other terms as it specifically considers and emphasizes the role of facial expression in this process. Facial mimicry involves one person facially expressing their emotional state, which is mirrored, or imitated, by their interaction partner within seconds (Hess, 2021; Hess & Fischer, 2014). Whether this happens consciously or automatically, or whether it is mediated by cognitive processes, remains a topic of scientific debate (Murata et al., 2016).

It has long been proposed that facial mimicry is a fundamental process underlying emotional contagion (Bischof-Köhler, 1988; Hatfield et al., 1992; Olszanowski et al., 2020; Schoenewolf, 1990). These authors argue that expressions reflect (or, through facial feedback, trigger) the subjective experience of an emotion – for example, feeling happy while one smiles (for recent multi-lab evidence on the facial feedback hypothesis, see Coles et al., 2022). Accordingly, micro-level mimicry processes are understood as one underlying process for two people converging in their subjective emotional experiences during an interaction. In line with such reasoning, we propose that once two interaction partners engage in a joint activity, and thereby mimic each other's facial expressions during substantial proportions of their interaction, they will also converge emotionally in terms of their subjective experiences of the joint activity. If such processes during repeated personal encounters persist over time, their habitual emotional experiences in the joint context should also converge. Based on this reasoning, we seek to explore teacher–student emotional mimicry as we propose it to be one possible driving process of teacher–student self-reported habitual emotion covariance as reported earlier.

2. Prior evidence on teacher–student joy transmission

There are a handful of studies providing evidence of systematic covariation between teachers' and students' experiences of joy in class. For example, Moskowitz and Dewaele (2019) reported that students' perceptions of their teachers' general happiness covaried with their own affective judgments of the teacher and class in an adult learning context (English as a Second Language). Becker et al. (2014) used a series of post-session diaries to show that secondary school students' perceptions of their teachers' joy during instruction were related to the students' own reported levels of joy in class, above and beyond the effects of student-perceived instructional practices. Talebzadeh et al. (2020) used video-based recall to obtain a teacher's and his five learners' moment-to-moment self-ratings of joy experiences of an English as a Second Language (ESL) lesson. They also obtained interview and observational data and report that there were instances of shared self-reported joy across the teacher and those five learners, as well as bodily and gestural mimicking (nodding, laughter). Further, there are two studies linking teacher-reported and student-reported joy in longitudinal repeated-measures designs in a secondary school context (Frenzel et al., 2009, 2018). Frenzel et al. (2009) showed that students' math class joy developed more positively across years 7 and 8 of secondary school if their 8th-grade mathematics teacher reported higher levels of teaching joy. Frenzel et al. (2018) extended the design to a fully cross-lagged model and provided evidence that teachers' joy developed more positively across the schoolyear when the average class joy was higher at the beginning of the schoolyear. This implies that emotion transmission between teachers and students seems to be a two-way street: Joy can transmit from teachers to students, and vice versa.

These findings stem from studies that predominantly used teachers' and students' self-reported joy in class. Clearly, self-report has limitations. It is restricted to consciously accessible and verbally describable processes, and it can be subject to various biases. Most importantly, self-report cannot capture, in sufficient temporal resolution, real-time dynamics (Lajoie et al., 2021; Pekrun, 2020). The present study therefore sought to go beyond self-report to substantiate the existing findings on reciprocal teacher–student emotion transmission. To this end, we videotaped teachers and students during real-time instruction and submitted the video recordings to automated, frame-by frame, coding of facially expressed joy. Automated facial expression coding is an emerging approach in educational research specifically in the context of digital learning environments (e.g., Bosch et al., 2016; Harley et al., 2015; Lajoie et al., 2021). However, barely would this technology have been applied to field data yet (for an exception, see Tonguç & Ozaydın, 2020). We hypothesized that if emotion transmission exists between teachers and students, they should mimic each others' joy expression during instruction, or in other words, there should be above-chance cross-recurrence of their joy expressions during classroom interaction.

[1] Some authors also speak of emotional synchrony. However, the term synchrony implies some sort of periodic oscillatory pattern of the behavior of interest (Pikovsky & Rosenblum, 2007) which we do not expect to exist for emotion expressions during human interaction. Instead, we propose emotion expression to occur event based, thus not necessarily following any periodic pattern, and therefore refrain from using the term emotional synchrony.

3. Functions and temporal dynamic of emotional mimicry

Emotional mimicry works as a social regulator during interactions and fosters affiliation between individuals (Hess, 2021; Hess & Fischer, 2013). As such, mimicry serves a "social glue" function in human interaction. The degree to which emotional mimicry occurs between interaction partners is not universal, though, instead, it depends on individual, contextual, and relational factors. For example, previous affiliations such as friendship, group membership, and positive or negative attitudes towards each other can also influence the extent of emotional mimicry (Hess et al., 1995; Jakobs et al., 1999; van der Schalk et al., 2011) and it occurs less in competitive or hostile settings (Weyers et al., 2009). Correspondingly, given the interindividual and intergroup differences between teachers, students, and classes, we expect that there will be variance across classrooms with respect to the joy mimicry levels between teachers and their students.

Further, it has been shown that a high frequency of emotional mimicry among two people interacting is experienced as pleasant (Kühn et al., 2011). Consequently, one may speculate that when there are high levels of teacher–student joy mimicry during the course of a given session, both the teacher and their students should experience that session as more pleasant.

As stated above, emotional mimicry necessarily involves a certain temporal dynamic as the phenomenon implies that one interaction partner needs to display the emotional expression first before the other can mimic it. While this can be a fully symmetric phenomenon with each interaction partner mimicking the other one equally frequently, emotional mimicry research has also shown that sometimes one person mimics the other more frequently than vice versa. Then this person is referred to as taking the role of a 'leader', the other one the role of a 'follower.' Studying such leader-follower dynamics in emotional mimicry can provide valuable additional insights regarding the nature of interactions. For example, in a collaborative exam task, Dindar et al. (2020) found that leading emotional mimicry in a group is also indicative of leading the task at the cognitive and behavioral level.

It could be assumed that teachers mainly take the leading role in the teacher-student emotion expression sequence. This has also been reported by Talebzadeh et al. (2020) who inferred from their observations of five ESL learners and their teacher that "it was mainly the teacher who initiated the contagion and they were mainly reciprocated by the learners" (p. 14). Nevertheless, teachers also actively seek affiliation with their students so they may also be highly responsive to student positive emotion expressions. In other words, it could be that either teachers or students predominantly lead potential emotional mimicry processes during their interaction, or this could be a symmetric phenomenon. We treated this as an exploratory research question in our study.

4. The present study

The key goal of the present contribution was to get insight into the micro-level, in-situ phenomenon of facial joy expression mimicry between teachers and students. Advanced video technology and automated facial coding methodology offer new avenues for studying such processes not only in laboratory settings, but also in the field. Specifically, the present study is contextualized in the field of higher education, sampling university instructors and their students. The study contributes to the existing research on emotions in the classroom in several ways. First, it goes beyond self-report by considering teachers' and students' facial expressions of their emotional experiences. Second, the present study explores the affective dynamics in real-time rather than on a personal habitual level. Third, it explores the teacher–student interactive dynamic from a leader-follower perspective, thus determining the extent to which students respond to teachers' expressions and vice versa. Fourth, it links the phenomenon of teacher–student joy mimicry back to self-reported session joy to find out whether higher levels of joy mimicry between teachers and students were associated with subjectively experienced pleasantness of the session. In sum, we had two directed hypotheses and one research question of a more exploratory nature.

Hypothesis 1. There is above-chance joy expression mimicry between teachers and their students.

Exploratory Research Question 1: Is there a leader-follower-pattern involved in those mimicry processes, implying that students' facial expressions follow teachers' facial expressions more often, or vice versa?

Hypothesis 2. The degree of joy mimicry between teachers and students is related to teachers' and students' self-reported joy during the session as judged after class.

5. Method

5.1. Participants and procedure

5.1.1. Sample

The highly intimate type of data collected in this study, namely rather close-up video recordings of the participants' faces and upper torsos, implied a convenience sampling approach. Participant recruitment happened through snowball techniques, disseminating email invitations to university instructors at the beginning of the summer semester at a large university in southern Germany. A total of $N = 13$ instructors (of which 62% identified as female, 38% as male) agreed to participate. They taught in Psychology Bachelor and Master programs, as well as in general teaching degree and school psychology degree programs. The contents of the classes included educational psychology, empirical research methods, teaching English, and educational science in elementary and secondary education. The instructors were on average 40 years old ($SD = 11.3$ years, Min = 27, Max = 55). There were no a-priori constraints for the lecturers concerning the content or structure of their sessions, but the final sample realized in this study turned out to consist of small-sized lectures or seminars which all followed a typical teacher-centered approach to instruction.

The participating instructors, in turn, invited the students of one of their current classes to join the study. For students, participation was also voluntary. Just like the instructors, they were assured that their data would be kept confidential and would only be used for the specific purposes of this study. A total of $N = 69$ students agreed to participate (of which 90% identified as female, 10% as male). They were on average 24 years old ($SD = 4.5$ years, Min = 20, Max = 50). The classes were generally small in size ($M = 16.0$, Min = 6, Max = 37) and the average number of participating students was 5.3 (Min = 2, Max = 7). This corresponded with an average of 40.1% of the students per class being videotaped. Table 1 provides more details on the recorded classes, including instructor gender, seating arrangement, number of students in class, and recorded students. Further information about the recorded classes cannot be detailed on the class level for data protection reasons.

The study was approved by the Ethics Review Board of the principal investigator's institution. Participation in the study was voluntary, written informed consent was obtained from all participants, and no identifiers that could link individual participants to their results were obtained.

5.1.2. Recording procedure and camera setup

All recorded sessions followed the same procedure: Cameras were set up before the start of class. From the typically 90-min-long sessions in the German higher education system, the first 45 min were recorded. Right after, participants completed a short self-report questionnaire assessing their retrospective ratings concerning their emotional experiences during the past 45 min. The present analyses focus on participants' reports of session joy (for details on measurement, see below).

Both instructors and students were videotaped individually using

Table 1
Contextual and instructor details for the videotaped sessions.

#	Instructor gender	# Recorded students	# Students in class	% recorded	Seating arrangement	Study program	Instructor's facially expressed joy (% frames)	Mimicry index (class-average)[a]	Proportion of dyads led by instructor[b]
1	female	2	9	22	Parallel rows (instructor in the front)	M.Sc. Psychology Program	25.29	0.36	0.0
2	female	6	8	75	Parallel rows (instructor in the front)	Teacher Training Program	2.12	0.64	66.7
3	female	5	19	26	Parallel rows plus one row on the side (instructor in the front)	Teacher Training Program	33.66	1.26	80.0
4	female	6	37	17	Parallel rows (instructor in the front)	School Psychology Program	7.65	0.18	83.3
5	female	7	15	47	U-shaped (instructor at open end)	M.Sc. Psychology Program	23.74	1.01	57.1
6	male	7	20	35	U-shaped with additional parallel rows in the back (instructor at open end)	Teacher Training Program	7.94	0.35	85.7
7	female	4	10	40	Parallel rows (instructor in the front)	M.Sc. Psychology Program	6.96	0.41	100.0
8	male	4	11	36	Parallel rows (instructor in the front)	Teacher Training Program	5.72	0.71	75.0
9	male	5	6	83	Parallel rows (instructor in the front)	School Psychology Program	4.23	0.05	40.0
10	female	5	20	25	U-shaped (instructor at open end)	B.Sc. Psychology Program	6.85	0.57	60.0
11	male	7	25	28	U-shaped with additional parallel rows in the back (instructor at open end)	Teacher Training Program	6.66	0.58	28.6
12	male	4	18	28	Parallel Rows (instructor in the front)	Teacher Training Program	9.17	0.30	25.0
13	female	7	10	70	Parallel Rows (instructor in the front)	School Psychology Program	23.42	1.40	28.6

Note.
[a] A dyadic mimicry index for each instructor-student dyad was obtained by summing up all recurrences of joy expressions in the critical time window of −54 lags to +85 lags relative to the instructor's expression. Shown here are average mimicry indices per class.
[b] Dyads were characterized as student- or instructor-led based on an either negative or positive lag predominance in the initial time window of −150 to +150 lags. Shown here is the proportion of instructor-led dyads per class.

multiple action cameras which were jointly operated using a remote control. The student cameras were attached to the students' desks in front of them and the instructor camera was mounted on a height-adjustable camera tripod. The videotaped students were sitting in seats well-distributed across the classroom. Instructors were told they could move freely during the session, and that they would be videotaped once they were within the camera's field of view. The height of the instructors' camera tripod was adjusted depending on their choice to either sit or stand most of the time during their session. Accordingly, the camera's field of view was set up to capture the participants' faces and upper torsos. The videos were recorded at a frame rate of 30 frames per second [fps] (see Marx, 2020, for more details on the video procedure). We analyzed one videotaped session per instructor.

5.1.3. *Video coding*

To process the video data, we used the iMotions software platform version 7.1 (iMotions, 2019) in combination with the automated facial expression coding module Emotient FACET which is a commercialized version of the CERT software (Littlewort et al., 2011). FACET is based on the Facial Action Coding System (FACS) by Paul Ekman and colleagues (Ekman et al., 2002) and uses machine learning algorithms which have been trained using large face databases with expert human FACS codes as criteria. It has been shown to be among the best-performing commercial automatic classifiers for facially expressed emotions (Dupré et al., 2020).

The software provides so-called evidence scores for a range of discrete emotions for each detected frame of a video, including the emotion of joy, which we used for the present study. In detecting joy, the software returns positive evidence if, in terms of Ekman et al.'s (2002) facial action codes, the action unit 6 (cheek raiser, *orbicularis oculi*) and the action unit 12 (lip corner puller, *zygomaticus major*) are activated. Evidence scores indicate whether an expert human coder would code a given video frame as representing a particular discrete emotion or not, in form of a logarithmic odds ratio (iMotions, 2021). Thus, higher evidence scores indicate higher odds that a certain facial expression is present in a particular frame; yet they cannot be validly translated into a measure of the intensity of that facial expression. However, beyond a given threshold value of the evidence, FACET provides valid and meaningful data as to whether a given emotion is facially expressed (see also Stöckli et al., 2018). We chose the threshold for the joy evidence such that it translated to a probability of 0.80 that an expert human coder would classify the video frame as showing joy.

In order to check whether these AI-generated evidence scores could be considered valid also for our video data collected "in the wild" (Cross et al., 2023), we ran sensitivity and specificity analyses comparing them against human judgements. To this end, we systematically selected 12 frames from each instructor and 13 students (one from each class), specifically: (1) three frames where a human coder watching the video identified a joy expression; (2) three frames where the human coder did not see a joyful expression; (3) three frames where the algorithm had marked an above-threshold joy evidence score; and (4) three frames where the algorithm had marked a below-threshold joy evidence score. Next, we cross-coded each of these instances to check convergence. For the instructor recordings, 93% of the joy expressions identified by the algorithm were also classified as joy expressions by the human coder, thus demonstrating sensitivity of the system (assuming validity of the human coding). In 97% of the cases that the algorithm coded a facial expression as non-joy, the human also did so, thus demonstrating specificity of the algorithm's coding. Conversely, 97% of the joy expressions identified by the human were congruently classified by the algorithm, and in 94% of the cases that the human coder coded as non-joy, the algorithm did so, too. For the student videos, numbers were slightly lower, with an algorithm sensitivity/specificity of 0.89/.88 (assuming validity of the human coding). Conversely, 84%/92% of the human-coded joy/non-joy frames were congruently coded by the algorithm. Overall, we interpreted these findings as solid evidence of the validity of the AI-detected facial joy expressions used in our main analyses.

5.2. Measures

5.2.1. Facially expressed joy

The automated coding software processed $M = 79{,}832$ video frames (or 44.4 min) per instructor and $M = 79{,}306$ video frames (or 44.1 min) per student, respectively. On average, $M = 77.96\%$ of these video frames could be detected and analyzed by the coding software for the instructors and $M = 67.78\%$ for the students, respectively. Reasons for detection failure were temporarily strongly tilted or turned heads, poor lighting conditions, coverage of the face by hands, etc. As described above, we used iMotions FACET to classify the participants' facial expressions as joy vs. no-joy, in mutually exclusive categories for each video frame. Non-detected frames were classified as no-joy.

5.2.2. Self-reported session joy

We assessed self-reported experiences of session joy using the single item "In the past 45 min, I enjoyed class" for students and "In the past 45 min, I enjoyed teaching" for instructors. Items were answered on a scale from 1, *strongly disagree*, to 5, *strongly agree*. This rating was obtained immediately after the videotaping ended. Such a single-item approach to retrospectively assessing discrete emotions during class has been used successfully in prior research with students and teachers (Frenzel et al., 2015; Keller et al., 2018).

5.3. Statistical analyses

The data reported herein were analyzed using SPSS version 29.0.0.0, R, version 4.0.1 (R Core Team, 2021), and Mplus version 8.8 (Muthén & Muthén, 1998-2017). No data were excluded. All quantitative data and the analysis codes for all analyses are available at https://osf.io/me8qw/. The original video data are not made accessible due to personal data protection.

We conducted two sets of preliminary statistical analyses. Firstly, we explored the descriptive statistics regarding frequency and distribution of instructors' ($N = 13$) and students' ($N = 69$) self-reported and facially expressed joy. Secondly, we inspected the correlation between facially expressed joy (percent time of total session duration) and post-session self-reported joy for both instructors and students. We obtained those correlations in Mplus, including self-reported session joy as categorical (ordered) variable. For the student-level analyses, we considered the nested structure of the data by using the TYPE = COMPLEX command, using instructor ID as cluster variable.

Our main statistical analyses pertained to the exploration of the co-dynamic of the instructors' and students' expressions, on the most granular level of video frames (1/30th of a second). These analyses involved the $N = 69$ instructor-student dyads. To address Hypothesis 1 (existence of above-chance teacher-student mimicry), for each instructor and each student, time series of occurrences of facial expressions of joy during the session were obtained (basically strings of 0s [no joy expressed] and 1s [joy expressed]). Those time series were up to 81.000 units in length (45 min * 60 s * 30 frames per second). Then, for each dyad, a cross-recurrence quantification analysis (CRQA) was run. The analysis was conducted with the crqa R package version 2.0.2 (Coco & Dale, 2014). In CRQA, two time series are linked (here: instructor and student), to quantify both perfect co-occurrence (i.e., both instructor and student expressing joy at the exact same time) as well as lagged cross-recurrence (i.e., the student expressing joy a little later than the instructor or vice versa; see Fig. 1 for a visualization). In other words, this approach quantifies, for every single frame in the two synchronized time series (here, instructor and student), whether or not the critical behavior occurred (here: joy expression). In addition to perfect co-occurrence, it also records whether there is lagged cross-recurrence (e.g., instructor expressed joy at frame 1, and student expressed joy at frame 1 + n). It depends on the observed behavior of interest how much later a certain cross-recurrence is considered relevant (e.g., a student expressing joy at one moment, and the instructor expressing joy 10 min later would not be considered relevant facial mimicry). An initial critical time window defining relevant lags can be determined as a parameter in the CRQA analysis script. Considering previous literature on temporally coordinated behaviors in dyadic interaction (e.g. Schoenherr et al., 2019), we considered lags of±150 frames (30 fps * 5s) as initial time window of interest. As such, we used CRQA to identify instances of joy mimicry considering the frame-by-frame temporal dynamic of these interaction partners' facial expressions across the 45 min of recorded course instruction. In so doing, we defined mimicry as perfect co-occurrence or lagged cross-recurrence of joy expressions in the instructors' and students' faces.

In addition to quantifying frequencies of cross-recurrence of behaviors in the instructor-student dyads, we also used CRQA to explore leader-follower patterns (Research Question 1). To this end, we quantified, within our initial time window of −150 to +150 lags, how often student expressions of joy preceded instructor expressions of joy (sum of recurrences at lags −150 to −1), and how often instructor expressions of joy preceded student expressions of joy (sum of recurrences at lags +1 to 150). If the sum of recurrences at lags −150 to −1 was larger than the sum of recurrences at lags +1 to +150, this implies that the student tended to lead the mimicry in that dyad. If the positive lags predominated, then the instructor would tend to lead the mimicry processes in that dyad.

However, simply quantifying the amount of thus-defined mimicry is not sufficient to judge whether the frequency of cross-recurrence is above chance. When crossing two time series of around 81.000 1s [joy] and 0s [non-joy], instances of co-occurrence or lagged cross-recurrence of 1s is to be expected, yet it is unclear if they are disproportionately frequent. To test this, we used a surrogate approach. In surrogate analysis, it is crucial that the actual data and the surrogate data have the same characteristics such as sampling frequency and data length (Lancaster et al., 2018). Therefore, we created surrogate data by randomizing the order of 1s [joy] and 0s [no-joy] in both the instructors' and students' time series, while retaining the same instructor-student dyads, in order to preserve joy occurrence frequency distributions across the real and surrogate dyads (Louwerse et al., 2012). We then tested, for each lag of ±150 frames, whether the observed cross-recurrence between the real and surrogate dyads was statistically different. We used Mann-Whitney U tests for those comparisons. This served two purposes: Purpose (1) was to determine, for each time lag, whether or not lagged cross-recurrence of joy expression between instructors and students was

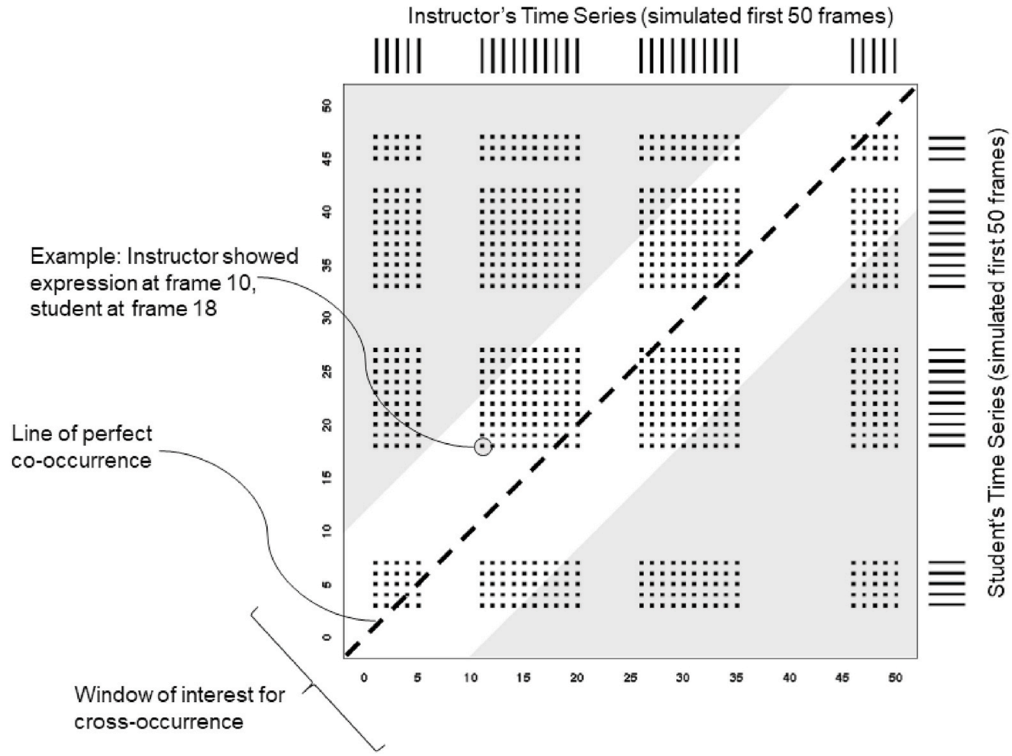

Fig. 1. Visualization of Quantifying Interpersonal Mimicry Through Cross-Recurrence Analysis
Note: CRQA plots (see also Coco & Dale, 2014) can be used to show the co- and cross-recurrences of a behavior of interest (here: facial expression of joy) for two interaction partners (here: instructor and student). In this Figure, the time series of occurrence of joy expressions are additionally shown opposite the x-axis (for instructors) and opposite the y-axis (for students). Within the matrix, points reflect relative moments in time where instructor and student joy expression either perfectly co-occur, or cross-recur, whereas non-events do not produce points on the plot. Instances where the student's expression followed the instructor's expression are located above the diagonal, and instances where the instructor's expression followed the student's expression are located below the diagonal. Only cross-recurrences within a predefined window of interest are considered relevant, marked by the white corridor.

above chance at all, to address Hypothesis 1. Purpose (2) was to identify the time window for which lagged cross-recurrence in the real dyads as opposed to the surrogate dyads was most pronounced. We used this time window for creating an overall sum score for cross-recurrence for each dyad, which we propose to use as a quantification of mimicry in each dyad. As such, these analyses allowed us to take a data-driven approach to determining the empirically best-supported time window for quantifying instructor–student joy expression mimicry, instead of an arbitrary a priori-assumption of reasonable reaction time lags for mimicking an interaction partner's facial expression. Additionally, this analysis provided further insight into our exploratory research question: If this time window was symmetrically distributed around the lag zero across all dyads, then there would be no tendency for either instructors or students to lead the mimicry. If there was a systematic shift of this critical time window toward the negative or positive lags, then this would be an indicatin of a general leader-follower predominance of either the students or the instructors.

Finally, in a last analysis step after having quantified the amount of joy mimicry for each instructor–student dyad, we explored whether these mimicry scores were linked with post-session retrospective self-reported joy (Hypothesis 2). To this end, we obtained correlations (a) between each student's self-reported joy and the degree of joy mimicry with their instructor in the past 45 min, and (b) between the instructors' self-reported joy and the average joy mimicry across all participating students in that class.

6. Results

6.1. Preliminary analyses

Table 2 displays the frequencies and distributions of self-reported and facially expressed joy for both instructors and students. Instructors on average displayed joy in about 12% of the time in the 45 videotaped minutes (see Table 1 for details on each instructor's joy expression frequencies). Students displayed considerably less joy, only 4% of the time. We propose that these findings are plausible, given that the courses in our sample were all characterized by teacher-led, direct instructional contexts. In such contexts, the role of the teacher is more active than that of the students. In certain ways, teachers are 'on stage'

Table 2
Descriptive statistics for facially expressed and retrospectively self-reported session joy for students and instructors (95% Confidence Intervals in Brackets).

		Facially expressed joy (% frames of session)	Self-reported joy (post-session)
Students (*N* = 69)	*M*	3.77 [2.88; 4.61]	3.68 [3.46; 3.88]
	SD	3.67 [2.71; 4.44]	0.90 [0.72; 1.04]
	Min/Max	0.004/15.63	1/5
	Skewness	1.48 [0.91; 2.06]	−0.57 [-1.06; −0.08]
	Kurtosis	1.88 [-0.14; 4.67]	0.23 [-0.77; 1.71]
Instructors (*N* = 13)	*M*	12.57 [7.77; 18.19]	4.31 [4.00; 4.62]
	SD	10.13 [5.29; 12.51]	0.63 [0.44; 0.80]
	Min/Max	2.12/33.66	3/5
	Skewness	1.07 [-0.24; 2.75]	−0.31 [-0.24; 2.75]
	Kurtosis	−0.30 [-2.11; 9.17]	−0.32 [-2.11; 9.15]

or 'on display' in front of the students who all direct their gazes toward the teacher and thus form an 'audience.' In contrast, individual students in a class will likely feel comparably less focused on, reducing the frequency of their outward facial expressions of joy. In terms of retrospectively self-reported session joy, instructor ratings also were higher than students', with means well above 3 on the 5-point Likert scale for both. The distributions of facially expressed and self-reported joy of both instructors and students were non-normal, while facially expressed joy tended to be positively skewed and self-reported session joy negatively skewed, for both instructors and students. Further, both the facially expressed and self-reported indicators demonstrated positive kurtosis for students, and negative kurtosis for instructors. It is important to note that these parameters should be interpreted with caution given our small sample sizes.

Table 3 displays correlations between students'/instructors' session joy as reported at the end of class and their facially expressed joy during class. These correlations were positive and medium-sized for both groups ($r = 0.33/.46$ for students/instructors), indicating that the more instructors and students facially expressed joy during class, the more they also reported to have enjoyed the class. However, it is worth noting that the correlation did not reach statistical significance for instructors due to the small sample size.

6.2. Leader-follower-pattern and significance of instructor–student joy mimicry

For each dyad, we compared the sum of all recurrences from lag −150 to −1 with the sum of all recurrences from lag +1 to +150. Based on this comparison, we characterized dyads as "student-led" when there were more recurrences in the negative lags, and as "instructor-led" when there were more recurrences in the positive lags. To illustrate this, Fig. 2 shows two exemplary plots of the proportions of lagged joy expression recurrence in the critical time window of −150 to +150 lags for one instructor-student dyad that was characterized by the instructor leading the mimicry (upper panel), and one dyad that was characterized by the student leading the mimicry (lower panel). There were 29 student-led and 40 teacher-led dyads, so on average, 58% of the dyads were characterized as instructor-led, implying a trend for instructors to lead the joy mimicry. We observed this trend in most of the classrooms, with 8 of the 13 instructors leading the mimicry for the majority of the observed dyads in their classes. However, for the remaining five instructors, the majority of the observed dyads were led by the students. The exact proportions of dyads led by instructors per class are detailed in Table 1.

Next, we tested Hypothesis 1 which stated that the observed amounts of instructor-student cross-recurrence of joy expression should be above chance. To this end, we performed Mann-Whitney U tests for the

Table 3
Validation of the automated facial joy coding and cross-recurrence quantification: Correlations with session joy as reported retrospectively after the session by students and instructors (95% Confidence Intervals in Brackets).

		Self-reported Joy (post-session)		
		r	[CI]	*p*
Students (*N* = 69)	Facially expressed joy	0.334	[0.096; 0.572]	0.006
	Mimicry Index	−0.033	[-0.368; 0.301]	0.845
Instructors (*N* = 13)	Facially expressed joy	0.461	[-0.054; ,975]	0.079
	Mimicry Index (class-average)	0.858	[0.494; 1.222]	<0.001

Note. The single-item self-report of session joy was treated as ordinal variable. The fact that students were nested within instructors was accounted for by using the TYPE = COMPLEX command in Mplus. The mimicry index corresponds with the average instructor–student dyad cross-recurrence in the time window of −54 lags to +85 lags relative to the instructor's expression.

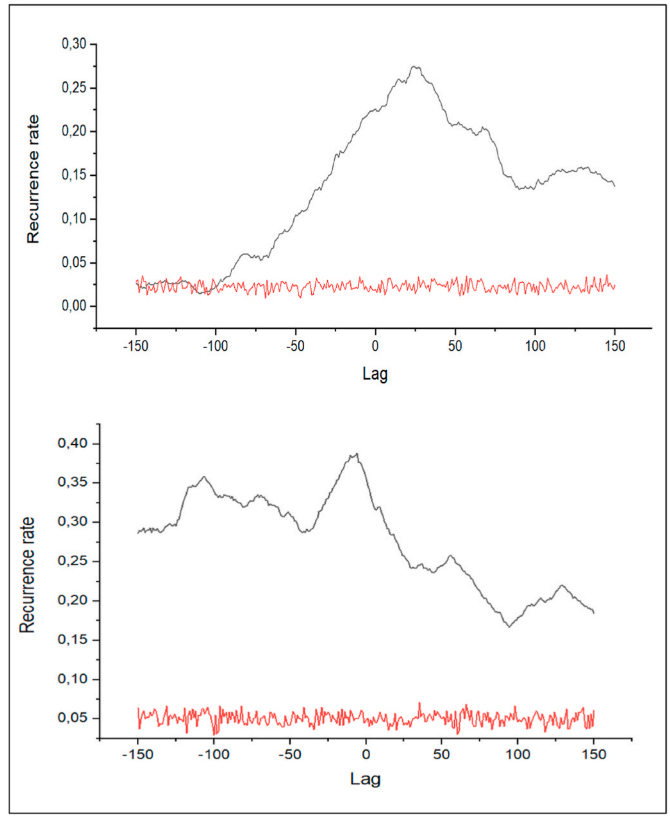

Fig. 2. Exemplary Plots for Frequencies of Joy Expression Recurrence in Two Instructor-Student Dyads Within the Initial Window of Interest From −150 to +150 Frames (−5 s to + 5 s).
Note: Lags were constructed as student frame showing joy expression minus instructor frame showing joy expression (i.e., positive values indicate that instructors were first to express joy), negative values indicate students were first. Black lines depict real dyads, red lines depict surrogate dyads. Top panel: Example for instructor-led mimicry (predominance of positive lags). Bottom panel: Example for student-led mimicry (predominance of negative lags). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

pairwise lag comparison between each dyad's original and its surrogate. Again taking Fig. 2 as illustration, this corresponds with comparing the recurrence proportions as depicted in black (real dyads) with the recurrence proportions depicted in red (surrogate dyads), for each lag of our initial window of interest (−150 to + 150 lags).

Fig. 3 shows the *p*-values for these pairwise comparisons between each dyad's original and its surrogate, for each lag. Confirming our first hypothesis, these results imply that the cross-recurrence of facially expressed joy was clearly above chance within this time window, while the distribution of the *p*-values followed a systematic U-shape, with real/surrogate differences becoming less consistent with larger lags. We visually inspected this *p*-value distribution and applied a reasoning analogous to the idea of a scree-plot (as typically used in the context of Eigenvalue trends in principle components analysis originally proposed by Cattell, 1966) to decide at which point there were "gaps" or "elbows" in this graph. We identified such gaps, or elbows, between lags −55 and −54 on the negative end, and between lag 85 and 86 on the positive end of the graph (see Fig. 2). We concluded that the range between −54 and + 85 lags – i.e., between about −2 s and +3 s relative to the instructor's joy expression – can be considered a critical lag window (see area marked in grey in Fig. 3) for joy expression cross-recurrence between the instructors and their students. Within this range, the *p*-values for the real/surrogate comparison also proved to be consistently below 0.003. As such, this was a statistically quite strictly defined critical range,

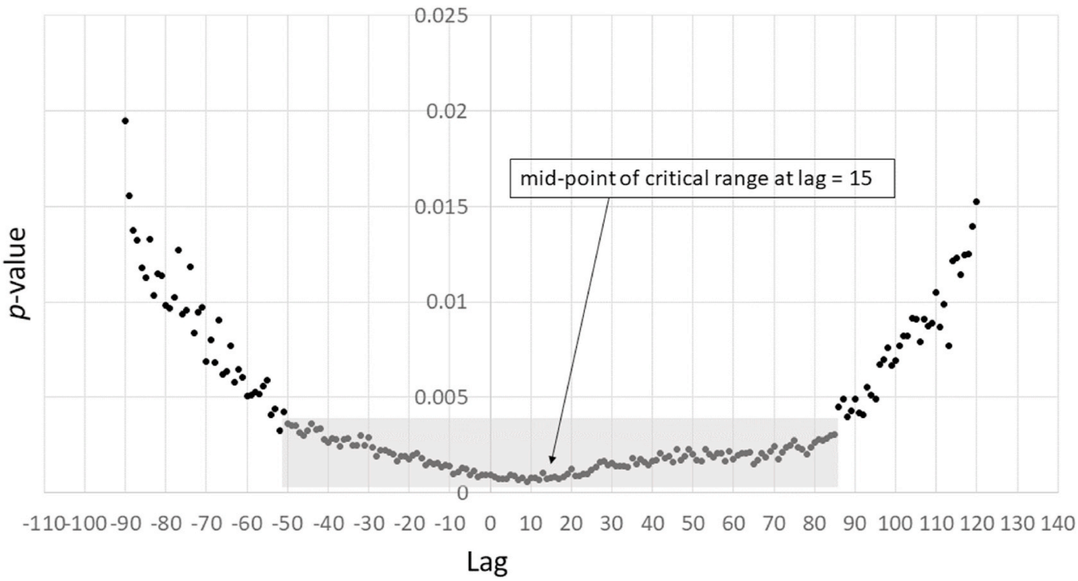

Fig. 3. P-values for the Comparison Between each Dyad's Original and its Surrogate by Lag. Greyed Area Indicates Lag Scope Considered Critical Based on Reasoning in Analogy to a Scree Plot.
Note: Lags were constructed as student frame showing joy expression minus instructor frame showing joy expression (i.e., positive values indicate that instructors were first to express joy), negative values indicate students were first. The critical range was identified to lie between −54 and + 85 lags based on the gaps observed in this graph below and above those lags.

which at the same time corresponds with a substantively reasonable lag for facial mimicry to occur, as judging from earlier research (Dimberg et al., 2002; Hess, 2021). A further important detail of this finding in terms of our exploratory research question was that this lag window was not symmetrically allocated around zero. Instead, the midpoint of this critical lag window was at lag +0.15 – i.e., around +500 msec – between the instructors' and a subsequent student expression of joy. This again reflects that there was a tendency for a predominance of instructor-over student-led instances of facial mimicry.

Fig. 4 shows four exemplary CRQA plots. Equivalent to the conceptual plot as depicted in Fig. 1, these plots show the time series and joy expression recurrences for the corresponding instructor and their students between frames 45001 to 54000, (i.e., minutes 25 to 30 of the recorded session; plotting area was limited by computational and visualization constraints). These plots illustrate the variability across the trajectories, patterns of joy expressions, and mimicry instances. They also demonstrate that those were highly idiosyncratic for each dyad.

6.3. *Links between Instructor–Student joy mimicry and self-reported session joy*

Finally, we sought to test whether the degree of joy mimicry between instructors and students was related to both sides' self-reported experiences of session joy as reported after class. To this end, as described above, we created an index of instructor–student joy mimicry for each instructor–student dyad by averaging across all cross-recurrences of joy expression between lag −54 and lag +85 (with values of zero indicating no cross-recurrence and values of 1 indicating perfect co-occurrence or lagged cross-recurrence). On average, within this time window, 0.64% of the frames were cross-recurrences, and more importantly, this index also varied considerably across dyads (i.e., $M = 0.64$; $SD = 0.75$; Min = 0.001 and Max = 4.88). It also deviated from a normal distribution (Skewness = 2.83, Kurtosis = 10.57). Given that these indexes were nested within instructors, we inspected the intraclass-correlation of the index to see to what degree it varied across all dyads, and within instructors. The resulting ICC was 0.164, indicating that while some variance (16.4%) was attributable to the instructors, the larger proportion of the variance (83.6%) was within instructors, implying that the cross-recurrence of joy between instructors and their students was a predominantly idiosyncratic and dyad-specific index.

To examine whether, in line with Hypothesis 2, joy mimicry between instructors and students was related to session joy as reported after class, we ran correlations, treating self-reported session joy as ordinal variables (see Table 3). For students, we used the dyad-specific mimicry index and their individual self-reported session joy. We considered the nestedness of students within instructors using the command TYPE = COMPLEX in Mplus. For instructors, we correlated instructor-reported session joy with the average mimicry index across all instructor–-student dyad indexes in each class (see Table 1 for descriptives). As can be seen in Table 3, for students, the correlation was not significant. In contrast, for instructors, the correlation was clearly positive ($r = 0.82$, $p < 0.001$), indicating that instructors subjectively experienced teaching as more enjoyable when their own joy expression co-occurred more frequently with their students' joy expression. It is worth noting that the mimicry index was also positively correlated with the degree to which teachers' expressed joy ($r = 0.65$, $p = 0.017$), which is no surprise as only expressions that are shown can be mimicked. However, the correlation between teacher session joy and the class-average mimicry index held when controlling for the instructors' levels of joy expression (partial correlation = 0.70, $p = 0.011$).

7. Discussion

The present study was designed to empirically test the assumption that teachers and students systematically and mutually mimic each other's facial expressions of joy during instruction. This assumption was rooted in observations of covariation of teachers' and students' habitual joy experiences in class reported earlier (Becker et al., 2014; Frenzel et al., 2009, 2018; Moskowitz and Dewaele, 2019). We used a multi-camera setup to capture university instructors' and their students' facial expressions during class, submitted those video recordings to automated facial expression coding, and applied cross-recurrence quantification analysis to quantify the amount of emotional mimicry within each instructor–student dyad. We found support for the validity of the facial expression coding in that post-session self-reported joy was positively correlated with the amount of time where instructors and

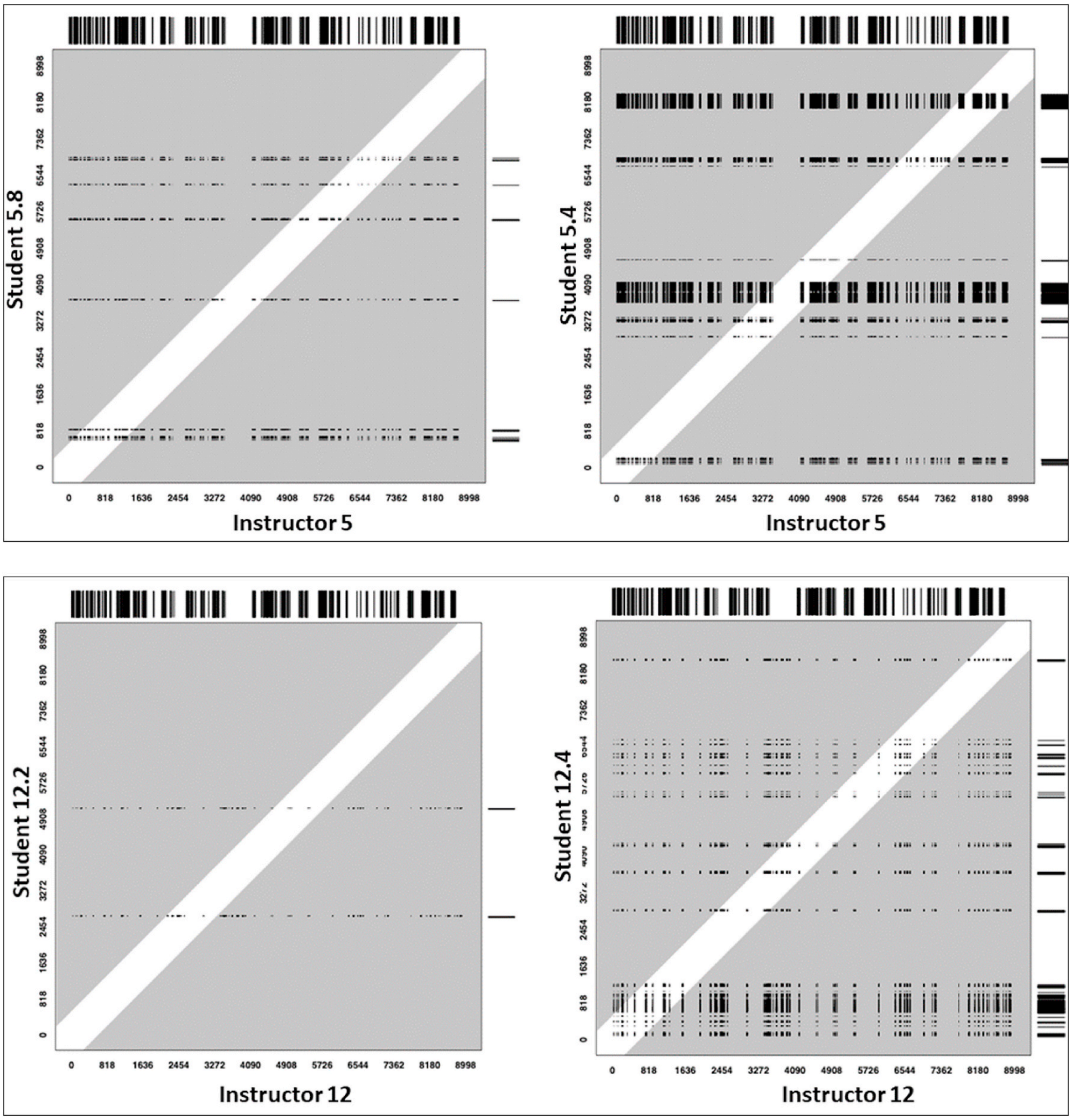

Fig. 4. Exemplary Cross-Recurrence Plots for Two Instructors With Two of their Students.
Note. The plots depict minutes 25 to 30 from the 45-min session (frames 45001 to 54000; plotting area was limited by computational and visualization constraints). Four exemplary dyads are shown, with two exemplary students nested in two exemplary instructors (top panel: Instructor 5 with their students 4 and 8; bottom panel: Instructor 12 with their students 2 and 4). Within each panel, the left plot exemplifies relatively low cross-recurrence, and the right plot exemplifies relatively high mimicry. Equivalent to Fig. 1, the plots show the timelines of the instructor's joy expressions opposite the x-axis, and the timeline of the student's joy expressions opposite the y-axis. Due to the large amount of data, adjacent frames are depicted without space in between, thus, repeated instances of joy expressions across multiple frames appear as solid black boxes. Relevant mimicry in terms of cross-recurrence within our determined critical time window of −54 lags to +85 lags relative to the instructor's expression is marked with the white corridor.

students facially expressed joy as classified by an automated coding software (Emotient FACET; iMotions, 2019). Such moderately sized correlations fully correspond with magnitudes of this coherence reported for the emotion of joy on an interindividual level earlier (Reisenzein et al., 2013).

Our first key substantial finding was that students' facial expressions of joy cross-recurred substantially above chance level ($p < 0.003$) during a time window of about -2s and +3s seconds relative to the instructors' expressions. This implies that within this critical lag window, there was substantially above-chance mimicry of instructor and student joy expression, with either students being first in expressing joy and followed by their instructors' joy expression, or vice versa. We propose that this finding can be interpreted in a way that teacher–student facial expression mimicry is a two-way street. The present study was embedded in a higher education setting, sampling university instructors and their students, but we propose that the observed mechanisms of teacher-student joy mimicry are generalizable to other learning settings, too. Yet it is important to note that the absolute frequency of such joint moments of expressed joy among university instructors and their learners were quite low. One reason for this might be that in university learning contexts, there are limited opportunities for interpersonal interactions between faculty and students (Robinson et al., 2019). It might be an interesting route for future research to explore if teacher-student mimicry frequency was higher in learning settings which involve more intense social and emotional exchange between teachers and learners, for example in primary and secondary school levels.

Our second key finding was that there was a predominance of instructor- over student-led facial mimicry. Almost 60% of the observed dyads showed higher frequencies of instances where the instructors expressed joy first, and then the student followed. However, it is worth noting that this predominance of instructor-over student-led mimicry was not equally evident in all instructors. For five of the 13 instructors in the sample, there was a predominance of student-led mimicry. Further support for instructor-led mimicry came from our finding that the time window for substantial above-chance mimicry frequencies was not symmetrically distributed around zero. Instead, its center was around lag +15 (+500msec), implying that the most pronounced instance of instructor–student joy mimicry was for instructors to express joy, and then students to express joy about 500 msec later. This is a typical time window for facial mimicry to occur (e.g., Dimberg et al., 2002; Hess, 2021). Our finding on a predominance of instructor-over student-led facial mimicry is in line with Talebzadeh et al.'s (Talebzadeh et al., 2020) observations of one ESL lesson. In their study, for four of the five observed students, it was predominantly the teacher who initiated the joy expressions, and there was only one student who seemed to lead the expressions and was mimicked by the teacher.

The present study is thus the first to provide evidence on the convergence between earlier-reported macro-level links between instructors' and students' self-reports of joy with micro-level joy expression mimicry between instructors and students during classroom interaction. This seems conceptually meaningful in terms of repeated micro-level covariation fueling, in a bottom-up fashion, covariation between teachers' and students' self-reported habitual joy experiences in the long run. Yet given the considerable difference between self-report data and facial expression data for capturing emotions, finding such converging evidence of emotion transmission between teachers and students is by no means trivial.

The third key finding of the present study pertained to the function and meaning of mimicry in the classroom, as operationalized through our newly introduced mimicry parameter based on cross-recurrence analysis. We had hypothesized that the link between this parameter and the session joy as reported after class should be positive due to the "social glue" function of emotional mimicry. High frequency of emotional mimicry among interaction partners being experienced as pleasant has been reported earlier (e.g., Kühn et al., 2011). The hypothesis was partially supported: For students, mimicry was not correlated with self-reported class enjoyment, However, for instructors, the correlation was significant and substantial. This implies that teaching enjoyment was higher when instructor joy expression co-occurs with their students' joy expression. In other words, the more students within a class on average mimicked, and were mimicked by, the instructor, the more the instructor enjoyed the session.

As such, our data provides support for the assumption of a "social glue function" of joy mimicry only for instructors, with respect to accumulated joy mimicry across the instructor-student dyads in a class. These findings suggest that frequent joint episodes of joy during class that are shared between teachers and their students can be a source of wellbeing for teachers, while we cannot make solid inferences regarding the effects of teacher-student dyadic mimicry on student class enjoyment or student wellbeing more generally. One reason for the lack of a correlation with students' self-reported enjoyment may be that students' enjoyment can be due to a variety of reasons not related to the teacher, such as rewarding interactions with classmates (e.g., during groupwork) or experiences of success in mastering contents. Such experiences are not associated with the instructor in terms of joint positive facial expressions. However, it is worth noting that earlier research has already suggested that the social glue function of joy mimicry may be more important for teachers than for students. For example, Gehlbach et al. (2016) reported that teachers seek to foster positive relationships with students more so than vice versa. An asymmetrical pattern was also found in the trait-based study by Frenzel et al. (2018) who reported positive effects from student-reported math class enjoyment to their math teachers' class enjoyment across the schoolyear, but a null effect from teacher-reported enjoyment on students' enjoyment. Future research will need to substantiate these initial findings on the greater relevance of positive emotional transmission for teachers than for students, and to explore whether the instructional format (teacher-led lecture, groupwork, individual work scaffolded by the teacher) influences this effect.

Finally, it is important to note that the data reported herein is correlational and causal inferences must be made with caution. As such, the positive correlations between teacher-student mimicry and post-session joy may be interpreted in terms of emotional benefits for the teachers as a result of the mimicry, but it might also be the case that teachers who enjoy their classes more are more responsive to their students, which increases the frequency of mimicry.

7.1. Limitations and implications

This study is the first to show, by means of automated facial expression coding, that teachers' and students' expressions of joy covary systematically during real-time classroom interaction. In light of its innovative research approach, the present study still has a range of limitations, while it also bears important insights for future research and tentative implications for practice.

First, even though the present data base was very large with more than 50 h of recorded video containing around 80,000 frames per video, the size of the teacher sample was limited. Also, the student sample overrepresented females and the teacher sample potentially overrepresented beginning teachers (with three out of the 13 being younger than 30 years of age). Clearly, the present sample of 13 teachers is not sufficient to provide trustworthy parameter estimates for general joy expression frequencies for a larger population. Future studies need to replicate the present analysis, with larger samples, to test the generalizability of the findings across different teacher and student populations as well as contextual conditions, and to learn more about when and why joy mimicry occurs in the classroom. Such future research could explore potential effects of teacher and student variables, for example, gender, age, or teaching experiences, in light of prior research that indicates gender and age effects on emotional expression (Chaplin, 2015; Else--Quest et al., 2012), emotion recognition (Abbruzzese et al., 2019; Hayes et al., 2020), and age effects on emotion regulation (Livingstone & Isaacowitz, 2021). Future research could also target contextual effects, involving fine-grained interaction analyses, to test for effects of both static (e.g., class size) and dynamic contextual factors (e.g., teacher use of humor).

Also, the sample of 69 dyads we used for our analyses is limited, and they cannot, strictly speaking, be considered independent observations because they were nested within the 13 teachers. Nevertheless, it is worth considering that our results showed that the predominant proportion of variance in teacher–student joy cross-recurrence was on the dyad level rather than on the teacher level, which implies that each teacher–student interaction represents a quite idiosyncratic unit rather than teachers being the dominating figure for all possible dyads in a room full of students.

Furthermore, the facial expression coding technology is still in its infancy and the validity of the automated recognition of joy is not without criticism (Cross et al., 2023). Our own validity checks did support good sensitivity and specificity of the AI-generated codes for our data, but we cannot rule out that the coding algorithm sometimes failed both by reporting false alarms (e.g., erroneous detection of joy due to persons touching their faces, or shadows in the faces) and by missing signals (e.g., lack of detection of joy in the face due to too strongly tilted heads, or participants resting their faces on their arms). It is worth noting that given that we coded non-detectable frames as "no joy", our parameter estimates of joy mimicry between teachers and students tend to be conservative.

Clearly, the installation of the video cameras in front of the students and instructors brought about a disruption to the standard classroom procedures, and in some classes, the sample of videotaped students relative to the class size was low. Despite the small action cameras being mounted low at the students' desks and being rather unobtrusive, it is conceivable that instructors might have paid more attention to the students who were videotaped, which would have led to an overestimation of the relevance of dyadic mimicry frequencies related to these students. Given that an average of 40% of students per class agreed to be videotaped, and the participating students were seated at well-distributed locations across the room, we assume that the joy mimicry index obtained in this study was a sufficiently valid indicator of the quantity of joy mimicry across instructors and learners in those classrooms. Nevertheless, it is important to note that the lowest proportions of videotaped students per class were only 17% and 22%, and it remains open to question whether these students were representative of all students in those classes. For example, it might be the case that more active and responsive students were overrepresented in our student sample, which may have upwardly biased our frequency estimation of mimicry in the classroom. Research replicating our analysis with a larger teacher sample and sufficient representation of the students in a class is needed to validate the present findings.

Further, given that our data were collected in the context of authentic classroom situations in the field instead of a fully standardized lab environment, or a rather controlled computer-based digital learning setting, we cannot rule out that some of the mimicry episodes we quantified in the present study were due to parallel emotion elicitation rather than emotional mimicry (Hess & Fischer, 2014). In other words, instances where both the instructor and the student showed a positive facial expression may have occurred because both were amused about an external event rather than initiated by the other person's emotional expression. However, even such moments of parallel joy elicitation are indicators of shared situation appraisals and corresponding joint emotional experiences shared by instructors and students. For example, imagine a situation where the students in a class laugh about something that just happened outside the class window, and the teacher joins this laughter. Then this might not strictly be considered emotional mimicry, but it is still an episode of joint positive emotion expression in class. Accordingly, the observed positive correlation between the mimicry index and teachers' post-lesson reported joy may also reflect a positive covariation between shared moments of expressed joy, on the one hand, and teachers' experience of joy, on the other. Overall, we are confident that the mimicry index we obtained for the present study – the sum of lagged cross-recurrences of joy expressions by the students within a time window of around -2 and $+3$ s relative to the teachers' expression – is a valid measure of shared joy among teachers and students. We propose that in the long run, repeated instances of such events lead to a convergence of teachers' and students' habitual class enjoyment.

Finally, in terms of tentative practical implications, our findings support recommendations based on earlier research stating that, as a teacher, being (authentically) positively expressive during instruction is desirable not only for cognitive and motivational outcomes on the students' end (Frenzel et al., 2019; Keller et al., 2016; Moè et al., 2021), but also for the teachers themselves (Taxer & Frenzel, 2018). In this study, for the first time, we showed directly that displaying facial expressions of joy is rewarded in that students reciprocate the positive facial expression to the teacher, which in turn is positively linked with teaching enjoyment. As such, trainings for increasing positive affective expression and enthusiasm during teaching (e.g. Patrick et al., 2000) as well as fostering teachers' emotion regulation strategies seem recommendable, not only for the sake of students, but also for the teachers' own sake.

CRediT authorship contribution statement

Anne C. Frenzel: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Muhterem Dindar:** Formal analysis, Software, Validation, Visualization, Writing – review & editing. **Reinhard Pekrun:** Writing – review & editing. **Corinna Reck:** Writing – review & editing, Funding acquisition. **Anton K.G. Marx:** Project administration, Validation, Visualization, Writing – review & editing.

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