Measuring changes in face-to-face interaction between teachers and students using a sociometric sensor device after teacher training

（ソシオメトリック機器を用いたティーチャートレーニング後における教師と児童の対面相互作用の変化の測定）

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Measuring changes in face-to-face interaction between teachers and students using a sociometric sensor device after teacher training

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Introduction: Teacher training (TT) was developed to improve teachers' skills in interacting with students with neurodevelopmental disorders. Teachers can also apply these skills to students without neurodevelopmental disorders in their classrooms. Therefore the interaction between teachers and students would change before and after the TT. However, prior studies have not utilized objective tools to assess the changes in interactions caused by TT interventions. In this study, a wearable sociometric sensor device was used to assess the changes in face-to-face interactions during a group classroom activity to provide objective measures of interactions.

Methods: We evaluated face-to-face interactions using sociometric devices in six classes, a total of six teachers and 158 elementary school students, during a group activity task. An evaluation of teacher-student interactions by video recording was also used to examine the directions of changes in interaction time between the sociometric device and video recording.

Results: The changes in face-to-face interaction time between teachers and students were in the same direction in five of six teachers. The TT intervention did not significantly affect the interaction time in the current study.

Discussion: Based on the results, a wearable sociometric sensor device can serve as an objective measure for detecting changes in classroom interactions.

Keywords: teacher training, sociometric sensor device, behavioral therapy, neurodevelopment disorders, elementary school

1 Introduction

Teacher–student relationship has been a primary focus of educational research due to its impact on students engagement and outcomes. Previous studies have indicated that it is crucial for student school engagement, academic performance, school adjustment, and lower mental health problems (Baker et al., 2008; Roorda et al., 2011; Rucinski et al., 2018). Such an impact on teachers is particularly important for students who experience low peer status due to their deviant or aggressive behaviors in classrooms (Hendrickx et al., 2017), who receive lower support from their peers. Such student's behaviors often become maladaptive in the classrooms, hindering the development of positive relationships. While managing maladaptive behaviors in classrooms is crucial for teachers to build positive relationships with students, teachers often encounter difficulties dealing with students' maladaptive behaviors (Hodgens et al., 2000; Kasari et al., 2011; Majoko, 2016; Rotheram-Fuller et al., 2010). The difficulties are related to poor teacher well-being (Aldrup et al., 2018; Aloe et al., 2014; Corbin et al., 2019; Hoglund et al., 2015). In particular, neurodevelopmental disorders, including attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder (ASD), may also affect teachers' difficulties in building good relationships with their students (Ewe, 2019; Zendarski et al., 2020). They are associated with increased maladaptive behaviors in school children and central concerns in school staff. For instance, studies suggested that externalizing behaviors of children with ADHD or ASD can be primary concerns for difficulties and sources of stress (Greene et al., 2002; Zendarski et al., 2020), which negatively affects the quality of teacher-student interactions. Neurodevelopmental disorders are highly prevalent in schools, with rates ranging from 2 to 9% for ADHD (Sayal et al., 2018) and from 0.4 to 1.3% for ASD (Fombonne et al., 2021). In addition, a substantial number of students remain undiagnosed in mainstream classes (Bosch et al., 2022; Kim et al., 2011), which indicates the number could be even higher. A national survey in Japan revealed that 7.7% of elementary school students without intellectual disabilities experienced significant learning or behavioral difficulties (Ministry of Education, Culture, Sports, Science, and Technology., 2012). Therefore, understanding and managing behavior problems of students with difficulties or special needs has been required to enhance good teacher-student relationships in classrooms.

Teacher training (TT) is a program specifically designed for teachers who support students with developmental disabilities, aiming to enhance their skills in effectively engaging with these students and increasing their self-efficacy (Froelich et al., 2012; Ishii and Okuno, 2020; Ishii et al., 2020; Iwasaka et al., 2005; Onishi et al., 2015). This program draws upon a behavioral therapy program Parent training (PT) developed for parents of children with ADHD (Barkley, 2013; Whitham, 1991) and modified for Japanese parents of children with ADHD (Iwasaka et al., 2002) and ASD (Okuno et

al., 2011). While parents observe their children's behavior and change interaction, teachers choose one or two students in their classes and record their behaviors to understand and help them. The teachers increase positive interactions and develop skills to deal with students' maladaptive behaviors (Onishi et al., 2015). Several studies have indicated that the teachers applied positive attitude to the other students in the classes and lead their appropriate behaviors (e.g., helping friends who are in trouble, telling teachers about friends' good behaviors or efforts) regardless of their developmental disability (Froelich et al., 2012; Imanishi et al., 2014; Iwasaka et al., 2005; Onishi et al., 2015). Thus, TT may increase interactions between teachers and students by focusing on appropriate behavior, increasing positive feedback, and creating a supportive classroom environment; however, previous studies have exclusively utilized subjective teacher interviews (Onishi et al., 2015). Therefore, more objective measures to evaluate teacher–student interactions are required to investigate the usefulness of various educational interventions in school settings.

Conventionally, questionnaires (e.g., peer nomination) and observation have been common in evaluating interactions between teachers and students in classrooms (Pianta and Hamre, 2009; Wubbels and Brekelmans, 2005), although the methods reflect the respondents' perceptions. Another approach is coding interactive behaviors using the time sampling method by direct observations. While it is a well-known approach for assessing interactive behaviors in psychological studies, it is time-consuming and requires training. Therefore, there are challenges in using behavior observation in regular educational settings.

Recently, several studies have attempted to assess social interactions using wearable devices. Heravi et al. (2018) used bespoke wearable sensors on caps and shoes with a global navigation satellite system and inertial measurement unit to detect children interacting on a school playground. The system detected interactions based on the location of children and their linked movements and was particularly suitable for situations such as free play outside. Other studies used speech or vocal information to detect interactions between teachers and children with devices (Fasano et al., 2023; Irvin et al., 2017). Douglas et al. (2022) measured social proximity among children with ASD and their peers using sensor badges. The badges detected face-to-face interaction time and physical distance between two individuals with directional ultrasound transceivers when facing each other. Although various sensing devices have been developed, there are major challenges in detecting child behaviors and teacher-student interactions in educational settings (Elbaum et al., 2024). Wearable sociometric devices are capable of capturing and collecting data on face-to-face events between two or more individuals using infrared sensors, Bluetooth, accelerometers, and/or microphones. They enable continuous monitoring of the face-to-face interaction time of each individual and the group, whereas conventional behavioral observation measures, including direct and video observations, are

time-consuming and can be affected by the quality of the recorded information, such as eye gaze, facial expressions, and gestures (Douglas et al., 2022; Yamamoto and Hanai, 2015). The device has been used in recent studies of medical communication or interactions between health professionals that provide quantified face-to-face contact among individuals (Stefanini et al., 2021; Ito-Masui et al., 2020; Kawamoto et al., 2020a; Kawamoto et al., 2020b). While wearable devices, including sociometric devices, are of interest in improving teaching and learning performance in educational settings (Khosravi et al., 2022), the available evidence of sociometric sensors in schools or children is scarce. For example, Nakajima et al. (2019, 2020) conducted wearable sociometric device measurements in physical education and reported that class communication data provide potentially useful information for teachers, which illustrated the characteristics of communicative behaviors in the activities. Yamamoto et al. (2021) evaluated changes in the interactions of children with ASD after a group social skills intervention and showed that the devices could be useful for validating the intervention. These studies suggested some utilities of sociometric devices in evaluating children's interactions; however, further evaluations are needed to evaluate the performance of the device in detecting changes by the interventions in school settings.

This study aimed to capture changes in face-to-face interaction time during a group activity among teachers and their students, including students with special educational needs, using sociometric sensor badges before and after TT. The present study is explorative and not planned for hypothesis testing; hence, it aims to examine the nature of the sociometric device measurement by describing the measured indices, rather than a procedure to reject or support by hypothesis testing.

2 Materials and methods

2.1 Procedures

The research plan was presented to the principal, and teachers were recruited through brochures and information sessions. All participating teachers provided written informed consent. Students and their parents in mainstream classrooms of the teachers were distributed information about wearable sociometric sensor device measurement associated with intervention for the teachers through a written document. Their consent was obtained by opting out, granting them the option to refuse participation. Each participating teacher chose one or two students with special needs.

The group allocation of the study was not randomized, but was determined by the participants' intentions. Among the participating teachers, four received a TT group intervention program, and three did not receive any interventions.

We planned a group activity task to measure face-to-face time between the teachers and students. Group activities are among the most difficult situations for teachers to manage for students with behavioral problems (Faiz et al., 2019; Hirose et al., 2001). Before the measurement students were informed about the details of the activities and measurements. We evaluated face-to-face interactions between the teacher and students during a group activity using sociometric sensor devices, as well as the teacher's confidence, mental health, stress, work engagement, and efficacy. Additionally, we examined the behavioral problems of the target students of participating teachers during the TT. Interventions and measurements were conducted between September and December, 2019. This procedure was approved by the Institutional Review Board of the Graduate School of Human Sciences at Osaka University (protocol code 18056).

2.2 Participants

The participant teachers in this study were in charge of students with special needs in mainstream classrooms. The participants in this study comprised 7 elementary school teachers (M = 36.9, 2 men and 5 women) and 195 classroom students (101 boys and 94 girls, ranging from 6 to 12 years old) recruited from a public elementary school. The school is in a rural area of Hyogo prefecture, Japan and the school-size is medium with about 300 students. The eligible teachers for the program were (1) elementary school teachers who worked for more than 3 h a day in charge of students with special needs (e.g., difficulties in social interaction and communication, inattention, or hyperactivity), and (2) those who needed to improve their skills in dealing with students' behavior in the classroom. After teachers were recruited, students in their classrooms were recruited accordingly. The group allocation of the study was not randomized, but was determined by the participants' intentions. Among the participating teachers, four received a TT group intervention program, and three did not receive any interventions. Initially, four teachers participated in the study, but one teacher and his 37 students were excluded because the teacher's measurement was not correctly recorded during the measurement activity. Finally, 6 teachers (3 of whom received the TT intervention) and 158 elementary school students were included in the study. The characteristics of the participating teachers and students are presented in Table 1. Table 1 also shows information for 30 students with special educational needs. The special needs of students identified by the teachers included difficulties in social interaction or communication (n = 13, 43%), hyperactivity or inattention (n = 7, 23%), learning disabilities (n = 4, 13%), intellectual disability (n = 1, 3%), low vision (n = 1, 3%), and neurological disorder (n = 1, 3%). Information on other students were not available.

TABLE 1

Table 1. Participants' characteristics

Written requests for cooperation in the study were submitted to the elementary school principal, and consent was obtained from all participants. All teachers provided written informed consent. Students and their parents were informed about the study through a written document and were provided opt-out consent, granting them the option to refuse participation. We also provided the students with an oral explanation before conducting the measurements. This procedure was approved by the Institutional Review Board of the Graduate School of Human Sciences at Osaka University (protocol code 18056).

2.3 TT program

The TT program comprised five group sessions, consistent with previous TT studies (Iwasaka et al., 2005; Onishi et al., 2015)—Session 1: observing and understanding the target students' behaviors; Session 2: giving positive attention to the students' behaviors; Session 3: providing clear instructions; Session 4: waiting to praise; and Session 5: setting limitations and reflections. The entire program was conducted once every 2 weeks, over 3 months. Each session was originally 90 min long, but was shortened to 60 min starting from 4 pm during the teachers' working hours. During each session, the teacher reported the good behaviors of the target students and engaged in the following activities: sharing previous practices from homework, discussing the program content, and role-playing. Additionally, the teacher was encouraged to practice the skills learned in the TT in daily teaching and to record them. The program was facilitated by a trained teacher (the first author). To ensure program fidelity, all TT sessions were video-recorded and reviewed by a supervisor (the last author) using a checklist (Iwasaka et al., 2012). Ten items were rated on a 10-point scale and then summed to calculate the index scores of fidelity achievement. The scores indicate an adequate fidelity to the program (82%).

2.4 Measures

2.4.1 Measurement of face-to-face interactions

The Business Microscope® (Hitachi, Ltd., Tokyo, Japan; BMS) is a wearable sociometric sensor badge that provides a quantitative index of communication in a group setting (Gouda, 2015). The BMS was equipped with an infrared sensor and accelerometer. The infrared sensor detects face-to-face events within a distance of two meters and 120-degree angle. Each device had a unique ID that provided data on the person facing the device and its duration. The accelerometer recorded the

physical movements of the wearer. The badge measured 60.7 mm in length, 80.6 mm in width, and 11.5 mm in thickness, and weighed approximately 33 g. Further details of the device can be found in a technical report by Gouda (2015). We used data measured with an infrared sensor, recorded every 625 ms, during an activity task. The teachers and students wore each badge in transparent pockets in front of their bibs, as in previous studies (Nakajima et al., 2019, 2020; Yamamoto and Hanai, 2015). The total face-to-face time during the group activity task was calculated. The face-to-face interaction time was converted into time per 120 s to align the difference in measured time among the groups. We used teacher–student face-to-face time as an index of face-to-face interaction. The measurement process was video-recorded for confirmation and documentation.

In addition, we rated the teacher's behavior during the task based on video recordings as a conventional measure of teacher–student interaction time. The teacher's interactive behavior was assessed per 5-s frame during the task. Interactive behaviors such as nodding, talking, laughter, and pointing while facing or approaching the students were counted as interactions. The interaction time was converted into time per 120 s as with the BMS device measurement.

We used a group activity task to measure face-to-face time. Group activities are among the most difficult situations for teachers to manage for students with developmental disabilities (Faiz et al., 2019; Hirose et al., 2001). The students were divided into groups of five or six with the same sex ratio. Each group engaged in the block assembly task, which was planned to be completed within 15 min. The teacher was required to look after, support, and talk to students as usual.

For each group, we prepared 60 palm-sized building blocks (Kids' Adventure Jumbo Blocks, United States). The blocks were of four colors: red, blue, yellow, and green. To prevent observational learning and practice effects, the assembly tasks differed between the groups and the two time points, whereas the number of blocks required was the same. The difficulty levels of the tasks were adjusted to be similar. The rule "place the blocks next to each other so that they have different colors" was introduced to promote communication in each group. Tasks and rules were outlined at the beginning of each activity. Visual materials were also distributed so that the students in each group could review the tasks and rules. Each group was instructed to work mostly on a 2.2-m square rug. The day of the week, time schedule, and group composition were standardized, and the students did not collaborate with the same group members between the pre and post measurement dates to avoid practice effect.

2.5 Questionnaire

2.5.1 Questionnaire on the outcomes of teacher

Confidence Degree Questionnaire (CDQ) for teachers is a teacher-report scale to score teachers' confidence in supporting students at school (Ishii et al., 2020; Iwasaka et al., 2012). The original CDQ for families was modified for teachers. The CDQ for teachers comprises 18 items and is measured with five-point scale. Participating teachers evaluated themselves with the CDQ. Higher scores indicate higher confidence.

2.5.2 Evaluations of the students selected for teacher training sessions

Teacher's Report Form of the Child Behavior Checklist (TRF) is a teacher-report scale to score students aged between 5 and 18 years (Achenbach and Rescorla, 2001). The TRF assesses the behavioral, emotional, and social problems observed in students and comprises 113 items. It is measured on a three-point scale and has eight subscales: Anxious/Depressed, Withdrawn/Depressed, Somatic complaints, Social problems, Thought problems, Attention problems, Rule-breaking behavior, and Aggressive behavior. The Anxious/Depressed, Withdrawn/Depressed, and Somatic Complaints scales loaded together on the higher order scale Internalizing, whereas the scales for Rule-Breaking Behavior and Aggressive Behavior loaded together on the higher order scale called Externalizing. The original TRF in English has been translated into Japanese and standardized in Japan (Funabiki and Murai, 2017). Participating teachers evaluated the students they chose with the TRF. Higher scores indicate the more severe problems at school.

Social Responsiveness Scale-2 (SRS-2) School-Age Form is a teacher- or parent-report scale to score children or students aged between 4 and 18 years (Constantino and Gruber, 2012). The SRS-2 identifies the presence and severity of social impairment associated with autism spectrum disorders and comprises 65 items. It is measured on a four-point scale and has five treatment subscales: Social awareness, Social cognition, Social communication, Social motivation, and Restricted interest and Repetitive behavior. Social awareness, Social cognition, Social communication, and Social motivation loaded together on Social communication and interaction on DSM-5 scales. The original SRS-2 in English has been translated into Japanese and standardized in Japan (Torii et al., 2017). Participating teachers evaluated the students they chose with the SRS-2. Higher scores indicate the more severe ASD symptoms.

2.6 Analysis

We examined whether there was a consistency in the direction of changes in teacher–student face-to-face time as measured by the device and the conventional measure (i.e., teacher behavior assessed

through video rating). Because our study included only six teachers in the analysis, we did not use statistical comparisons and hypothesis testing in this analysis. We utilized network diagrams to evaluate face-to-face interactions both before and after the TT intervention. Data were transmitted to the developer's data center and analyzed using server algorithms (Hitachi Ltd., Tokyo, Japan). Data and network diagrams were created using a visualization engine (Hitachi Ltd., Tokyo, Japan) and Cytoscape 3.8.21 as described in a previous report (Yamamoto et al., 2021). In the face-to-face interaction network diagram, the nodes represent each individual, and the thicknesses of the lines correspond to the total interaction time between individuals.

To explore potential intervention effects on teacher–student face-to-face time, we used a two-level mixed analysis of variance (ANOVA) to examine group differences (teacher training and control) in face-to-face time between teachers and students. In this study, pre and post measurements (Level 1) were nested within teacher–student pairs (Level 2). The teacher–student pairs were nested within the classes (Level 3). As our study had only two measurements (i.e., pre and post) for each teacher–student pair, we tried to estimate the variance of random intercepts for Levels 2 and 3. The fixed effects included time (pre and post measurement), group (teacher training and control), and their interaction term (time × group). The treatment effects were estimated based on the coefficients of the interaction terms of the model.

The SPSS Statistics 27 (IBM Corp., Armonk, NY, USA) and R ver. 4.3.1 were used for statistical analysis. The significance threshold was set at $p < 0.05$. As our study lacking a sufficient number of classroom teachers for group comparisons, we estimated 95% confidence intervals (CI) to assess the potential effects of the interventions.

We also described the results of the questionnaires. Since the data are not adequate in sample size for hypothesis testing, we only reported individual scores for descriptive purpose.

3 Results

3.1 Face-to-face interaction time

3.1.1 Total Face-to-face interaction time between teacher and students

Individual face-to-face interaction time between teacher and students in a class measured by the sociometric device is shown in Figure 1. Video-based behavioral ratings indicated that both groups increased teacher–student interactive behaviors in one class and decreased teacher–student interactive behaviors in two classes (Table 2). In Table 2, numbers in each cell show individual teacher's interaction time with students based on video recording ratings. The directions of

quantitative changes were consistent for five of the six teachers for the sociometric device and video rating (Table 3).

FIGURE 1

Figure 1. Individual pre-post changes in each student in each class. The letters indicate the classes: teachers in panels (a–c) received the TT intervention; teachers in panels (d–f) did not receive the intervention.

TABLE 2

Table 2. Interaction time of teachers based on video recording.

TABLE 3

Table 3. Pre and post comparisons of interaction time of teachers using the sociometric device and video recording.

To examine potential intervention effects on teacher–student face-to-face time, we used a two-level mixed ANOVA to explore group differences (teacher training and control) in face-to-face time between teachers and students. An explorative analysis revealed that the Level 2 random intercept did not improve the model fit (Akaike Information Criterion = 2880 for the Level 2 random intercept model and 2875 for the Level 3 random intercept model). Consequently, only the Level 3 random intercept was estimated in the following analysis. The statistical analyses did not show a significant difference in face-to-face interaction time between the TT and control groups ($b = 3.94$, $SE = 7.09$, 95% CI = [−9.95, 17.82]). Figure 2 illustrates the pre-post changes in interaction time between the teacher and students, revealing no clear trends toward an increase or decrease between the TT and control groups. The face-to-face interaction network diagrams depict the total face-to-face time for every student pre- and post-TT (Supplementary Figures 1, 2).

FIGURE 2

Figure 2. Pre-post changes between groups in teacher–student interaction time.

3.2 Questionnaires

The results for individual teachers are shown in Supplementary Tables 1, 2. There were no clear improvements in teachers' mental health, confidence, work engagement, and self-efficacy. Supplementary Table 3 presents the TRF and SRS scores of the students selected by the teachers.

4 Discussion

In this study, we used wearable sociometric sensor devices to capture changes in teacher–student face-to-face interactions following TT. The device detected variability of pre-post changes between the teacher and students during a group activity task. These changes in the measurements were consistent in five of the six teachers, aligning with those obtained via conventional measurement—video-based behavioral ratings of interactive behaviors—thus supporting the validity of these devices in measuring teacher–student face-to-face interactions. In one class (class e), there was a discrepancy in the direction of change in interaction with the teacher before and after TT in the video recordings and sociometric devices (Table 3). This class showed an increase in interaction patterns that were biased toward one group at the post-measurement, which was different from the other classes (Supplementary Figures 1, 2). The consequence of the pattern was an increase in teacher interaction behavior, but a decrease in interaction with the children in the class as a whole. In addition, there were disparities in the ranges of interaction time measured by the sociometric device and teacher behavior ratings (Figure 1 and Table 2). While the sociometric device captured the face-to-face time with individual students, the behavior ratings index only reflected the teacher's behavior itself. The wearable sociometric device measures a different component of the teacher–student interaction. This variance in index characteristics results in a discrepancy in the range of measured interaction times. Wearable sociometric devices offer objective measures to capture interaction changes through classroom interventions, which have not been evaluated by teacher behavior ratings. Another possible explanation may be the questionable reliability of the device in measuring face-to-face interactions. As suggested by Hodge et al. (2020) the use of sociometric devices has not been well-validated in children. They also suggested that cautious evaluations are required for use of sociometric devices in measuring communication data. This study added partial evidence for measurement validity of the sociometric device in an elementary school setting, although further refinement would be necessary.

Measuring face-to-face time with more than one child requires multiple observers and video recordings, and the time required depends on the number of groups and group size (Yamamoto and Hanai, 2015). In this study, only teacher interactions could be counted in the videotaped data, and it was not possible to identify all child interactions. While video recording requires that the activity take place within the screen's confines, sociometric devices do not limit the location of activities.

Thus, the sociometric devices provide better utility in measuring activities between multiple teachers and children in schools, as suggested in this study. The sociometric devices make it possible to measure face-to-face information easily and over time. In addition, the time required to analyze face-to-face measures can be greatly reduced by reducing the need for manual coding (Yamamoto and Hanai, 2015). Even when observer masking is required for interventional studies, such tools facilitate objective evaluations. With these advantages, the tool may be helpful in measuring the educational benefits of school or classroom interventions by incorporating frequent, repeated measurements in everyday life in studies. However, we cannot identify what kind of interaction occurred in a face-to-face encounter with the tool alone, i.e., positive or negative interactions (Yamamoto et al., 2021). Therefore, multimodal measurements, such as location, movement synchronization, and speech synchronization (e.g., Lederman et al., 2018), may be considered in conjunction when specifying such detailed meanings is critical.

We did not identify any significant changes due to the TT intervention, although the variance in the outcome was partially explained by differences among individual teachers (Level 3). The results should be interpreted with caution because our sample comprised only six teachers. Because of the small number of teachers, individual differences among teachers, such as years of teaching experience and knowledge about child behavior problems, may affect the current results. In addition to the teacher's characteristics, the classroom composition would also be a critical factor that affects the potential impact of the intervention (Aguiar and Aguiar, 2020). In future interventional studies, such information is also required to understand the potential and interfering effects of educational interventions. Additionally, an increase or decrease in face-to-face interaction time during an activity may not correspond to positive behaviors or changes in teachers. Changes in indices themselves do not define the meaning of their behavior in a particular context. A TT intervention may either increase or decrease teachers' interactions depending on their functions (i.e., positive or negative). Therefore, changes in interaction time must be accompanied by meaningful indices or assessments of the functions of teachers' behaviors to interpret their functions. It should be noted that overly focusing on changes in such indices may instead hinder teachers from improving their behavior (Ito et al., 2020). Moreover, the measurements were conducted shortly after the program, and the time span may not have been adequate to observe behavioral changes in both teachers and students.

4.1 Strengths and limitations

The strength of this study was that it examined face-to-face interactions with a larger sample size of elementary school students. This study suggested that changes in face-to-face interactions can be measured using the Business microscope in classroom activities and the merits of further validation

of the sociometric devices in school settings. Such new devices and technologies would provide us with a better balance between effort and accuracy of the data measurement. Further validations of such techniques facilitate the progress of research in educational practices.

This study had several limitations. It should be noted that the present study was explorative to describe the characteristics of the sociometric device. Therefore, our study did not use hypothesis testing to validate the measurement due to the method used and sample size issues, except for the TT group comparisons. These limitations may limit the credibility of the findings of this study. In future studies, measurement characteristics should be established by studies with more rigorous methods with pre-registration and hypothesis testing or multimodal and extensive measurements in classrooms. Second, the results are based on a limited sample size. Results obtained from a larger number of teachers would facilitate a meaningful interpretation of interactions at each level (students and teachers). While this is an exploratory study, the participants were recruited from only a single school setting. These study characteristics may limit the findings' generalizability to diverse educational contexts (e.g., geographical settings, educational systems, and countries). The characteristics of the children or teachers may affect the reliability of the measurements. Third, face-to-face measurements between the teacher and students were conducted in experimental situations using group activities. The nature of the activities may affect teachers' behaviors, thereby influencing communication among teachers and students. The teacher-student interaction in this study was measured in a group activity that required student-student interaction using blocks to maintain an even distance between the groups. This setting had the property of equalizing the initial distance between the teacher and each student and enhancing the opportunity for interaction with each individual. However, this was a different form of interactive situation from the in-class activities in the classroom setting. It should be noted that the nature of the interaction may be different from the nature of interaction in a classroom setting. In future studies, it may also be useful to examine differences in measurement in natural settings and structured activities. Fourth, the interpretation of the index is affected by the context. The current study collected solely face-to-face interaction time without qualitative information on the nature of these interactions (e.g., positive or negative, instructional, or corrective). Future studies should include measurements that contain cues determining the nature of these interactions, allowing for more meaningful interpretations. Furthermore, developing sociometric devices that enable the combining of multimodal information and processing of the nature of the interactions between individuals may be beneficial for future studies. While the privacy of the teachers and students should be strictly protected (Kumar et al., 2019; Ogan, 2019), such an approach would provide implications for future educational practice.

5 Conclusion

Our study suggests that wearable sociometric sensor devices can capture changes in teacher–student face-to-face interactions in the classroom. Therefore, assessing group interactions using wearable sociometric devices is a promising method for evaluating changes in interactions through school interventions.

Data availability statement

The datasets presented in this article are not readily available because the data for the current study was not available due to ethical restrictions. Requests to access the datasets should be directed to HF, fjinoh@kokoro.med.osaka-u.ac.

Ethics statement

The studies involving humans were approved by Institutional Review Board of the Graduate School of Human Sciences, Osaka University. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because Students and their parents were informed about the study through a written document and were provided opt-out consent, granting them the option to refuse participation. We also provided the students with an oral explanation before conducting the measurements.

Author contributions

TN: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review and editing. HF: Conceptualization, Formal Analysis, Project administration, Supervision, Visualization, Writing – original draft, Writing – review and editing. TY: Investigation, Writing – review and editing. AI: Data curation, Writing – review and editing. MT: Conceptualization, Funding acquisition, Supervision, Writing – review and editing. HO: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at:
https://www.frontiersin.org/articles/10.3389/feduc.2025.1545758/full#supplementary-material

Footnotes

https://cytoscape.org/

References

Achenbach, T., and Rescorla, L. (2001). *Manual for the ASEBA School-Age Forms and Profiles.* Burlington, VT: University of Vermont.
Google Scholar

Aguiar, A. L., and Aguiar, C. (2020). Classroom composition and quality in early childhood education: A systematic review. *Child. Youth Serv. Rev.* 115:105086. doi: 10.1016/j.childyouth.2020.105086
Crossref Full Text | Google Scholar

Aldrup, K., Klusmann, U., Lüdtke, O., Göllner, R., and Trautwein, U. (2018). Student misbehavior and teacher well-being: Testing the mediating role of the teacher-student relationship. *Learn. Instr.* 58, 126–136. doi: 10.1016/J.LEARNINSTRUC.2018.05.006
Crossref Full Text | Google Scholar

Aloe, A. M., Shisler, S. M., Norris, B. D., Nickerson, A. B., and Rinker, T. W. (2014). A multivariate meta-analysis of student misbehavior and teacher burnout. *Educ. Res. Rev.* 12, 30–44. doi: 10.1016/J.EDUREV.2014.05.003
Crossref Full Text | Google Scholar

Baker, J. A., Grant, S., and Morlock, L. (2008). The teacher-student relationship as a developmental context for children with internalizing or externalizing behavior problems. *Sch. Psychol. Q.* 23, 3–15. doi: 10.1037/1045-3830.23.1.3
Crossref Full Text | Google Scholar

Barkley, R. A. (2013). *Defiant Children: A Clinician's Manual for Parent Training*, 3rd Edn. New York: The Guilford Press.
Google Scholar

Bosch, R., Pagerols, M., Rivas, C., Sixto, L., Bricollé, L., Espanõl-Martín, G., et al. (2022). Neurodevelopmental disorders among Spanish school-age children: Prevalence and sociodemographic correlates. *Psychol. Med.* 52, 3062–3072. doi: 10.1017/S0033291720005115
PubMed Abstract | Crossref Full Text | Google Scholar

Constantino, J., and Gruber, C. (2012). *The Social Responsiveness Scale*, 2nd Edn. Los Angels, CA: Western Psychological Services.
Google Scholar

Corbin, C. M., Alamos, P., Lowenstein, A. E., Downer, J. T., and Brown, J. L. (2019). The role of teacher-student relationships in predicting teachers' personal accomplishment and emotional exhaustion. *J. Sch. Psychol.* 77, 1–12. doi: 10.1016/J.JSP.2019.10.001
PubMed Abstract | Crossref Full Text | Google Scholar

Douglas, S. N., Shi, Y., Das, S., and Biswas, S. (2022). Validation of wearable sensor technology to

measure social proximity of young children with autism spectrum disorders. *Focus Autism Other Dev. Disabil.* 37, 24–33. doi: 10.1177/10883576211028223
Crossref Full Text | Google Scholar

Elbaum, B., Perry, L. K., and Messinger, D. S. (2024). Investigating children's interactions in preschool classrooms: An overview of research using automated sensing technologies. *Early Child. Res. Q.* 66, 147–156. doi: 10.1016/j.ecresq.2023.10.005
PubMed Abstract | Crossref Full Text | Google Scholar

Ewe, L. P. (2019). ADHD symptoms and the teacher-student relationship: A systematic literature review. *Emot. Behav. Difficulties* 24, 136–155. doi: 10.1080/13632752.2019.1597562
Crossref Full Text | Google Scholar

Faiz, Z., Arif, A., and Zia, S. (2019). Challenges faced by teachers during teaching students with developmental disability at primary school level in Lahore. *J. Inclus. Educ.* 3, 19–32.
Google Scholar

Fasano, R. M., Mitsven, S. G., Custode, S. A., Sarker, D., Bulotsky-Shearer, R. J., Messinger, D. S., et al. (2023). Automated measures of vocal interactions and engagement in inclusive preschool classrooms. *Autism Res.* 16, 1586–1599. doi: 10.1002/aur.2980
PubMed Abstract | Crossref Full Text | Google Scholar

Fombonne, E., MacFarlane, H., and Salem, A. C. (2021). Epidemiological surveys of ASD: Advances and remaining challenges. *J. Autism Dev. Disord.* 51, 4271–4290. doi: 10.1007/s10803-021-05005-9
PubMed Abstract | Crossref Full Text | Google Scholar

Froelich, J., Breuer, D., Doepfner, M., and Amonn, F. (2012). Effects of a teacher training programme on symptoms of attention deficit hyperactivity disorder. *Int. J. Spec. Educ.* 27, 76–87.
Google Scholar

Funabiki, Y., and Murai, T. (2017). ASEBA Koudou chekku risuto (TRF: kyoushi you) Hyoujunchi sakusei no kokoromi [Standardization of the Japanese version of the teacher's report form]. [Jidou Seinen igaku to sono kinsetsu Ryouiki]. *Jpn. J. Child Adolesc. Psychiatry* 58, 185–196. doi: 10.20615/JSCAP.58.1_185
Crossref Full Text | Google Scholar

Gouda, N. (2015). Ningen koudou biggudeeta wo shakai jissou kanounisuru bijinesukenbikyou [Business microscope that enable to implement human bigdata in society]. *Seisan Gijyutsu.* 67, 46–52.
Google Scholar

Greene, R. W., Beszterczey, S. K., Katzenstein, T., Park, K., and Goring, J. (2002). Are students with ADHD more stressful to teach?: Patterns of teacher stress in an elementary school sample. *J. Emot. Behav. Disord.* 10, 79–89. doi: 10.1177/10634266020100020201

Crossref Full Text | Google Scholar

Hendrickx, M. M. H. G., Mainhard, T., Boor-Klip, H. J., and Brekelmans, M. (2017). Teacher liking as an affective filter for the association between student behavior and peer status. *Contemp. Educ. Psychol.* 49, 250–262. doi: 10.1016/j.cedpsych.2017.03.004

Crossref Full Text | Google Scholar

Heravi, B. M., Gibson, J. L., Hailes, S., and Skuse, D. H. (2018). "Playground social interaction analysis using bespoke wearable sensors for tracking and motion capture," in *Proceedings of the 5th International Conference on Movement and Computing*, (New York, NY: Association for Computing Machinery), doi: 10.1145/3212721.3212818

Crossref Full Text | Google Scholar

Hirose, Y., Tojo, Y., and Terayama, C. (2001). Tsuujyou no gakkyuu niokeru jiheishouji no kyouiku no genjyou [The present situation of education for children with autism in regular classes]. *Natl. Institute Special Needs Educ. Bull.* 28, 77–85. doi: 10.1266/ggs.19-00050

PubMed Abstract | Crossref Full Text | Google Scholar

Hodge, C., Chandler, K. D., Melton, K. K., Hoke, K. L., and Blodgett, J. (2020). Real-time, passive measurement of communication during family leisure: An exploratory study of wearable sociometric badges. *J. Leisure Res.* 53, 132–138. doi: 10.1080/00222216.2020.1795013

Crossref Full Text | Google Scholar

Hodgens, J. B., Cole, J., and Boldizar, J. (2000). Peer-based differences among boys with ADHD. *J. Clin. Child Psychol.* 29, 443–452. doi: 10.1207/S15374424JCCP2903_15

PubMed Abstract | Crossref Full Text | Google Scholar

Hoglund, W. L. G., Klingle, K. E., and Hosan, N. E. (2015). Classroom risks and resources: Teacher burnout, classroom quality and children's adjustment in high needs elementary schools. *J. Sch. Psychol.* 53, 337–357. doi: 10.1016/j.jsp.2015.06.002

PubMed Abstract | Crossref Full Text | Google Scholar

Imanishi, M., Kawanishi, M., and Tamamura, K. (2014). Gakkyuukeiei seitoshidou ni ikasu tîchâ torêningu no kokoromi [A program of the teacher training for class management and students behavioral guidance in regular schools]. *Bull. Cent. Educ. Res. Dev. Nara Univ. Educ.* 23, 219–225.

Google Scholar

Irvin, D. W., Stephen, A. C., Charles, R. G., Richard, L. S., Abhijeet, S., and John, H. L. H. (2017). Exploring classroom behavioral imaging: moving closer to effective and data-based early childhood inclusion planning. *Adv. Neurodev. Disord.* 1, 95–104. doi: 10.1007/s41252-017-0014-8

Crossref Full Text | Google Scholar

Ishii, A., and Okuno, H. (2020). Tsuushinsei koutougakkou (toukougata) ni okeru hattatsushougai keikou wo motsu seito no tantoukyouin eno ennkakushiki tîchâ torêningu puroguram no yuuyousei no kentou [Usefulness of remote teacher training for teachers of students with developmental

disabilities in a correspondence high school (weekday course): Through a video conference system]. *J. Child Brain Dev.* 11, 17–27. doi: 10.34572/JCBD.11.1_17

Crossref Full Text | Google Scholar

Ishii, A., Okuno, H., Nakaoka, T., Iwasaka, H., and Taniike, M. (2020). Effectiveness of a teacher training program for students with symptoms of developmental disorders: Data from a correspondence high school in Japan. *Int. J. Environ. Res. Public Health* 17:3100. doi: 10.3390/ijerph17093100

PubMed Abstract | Crossref Full Text | Google Scholar

Ito, T., Nakajima, T., and Kawata, M. (2020). What do sensor-based human activity recognition technologies bring to the field of developmental psychology? *J. Behav. Med.* 31, 190–200. doi: 10.11201/jjdp.31.190

Crossref Full Text | Google Scholar

Ito-Masui, A., Kawamoto, E., Nagai, Y., Takagi, Y., Ito, M., Mizutani, N., et al. (2020). Feasibility of measuring face-to-face interactions among ICU healthcare professionals using wearable sociometric badges. *Am. J. Respir. Crit. Care Med.* 201, 245–247. doi: 10.1164/rccm.201904-0779LE

PubMed Abstract | Crossref Full Text | Google Scholar

Iwasaka, H., Ikejima, T., Ono, M., Hisamatsu, S., and Fujiwara, T. (2005). Gakkou genba niokeru pearento torêningu kyoushi ban no kokoromi: Tokubetsu na nîzu noaru kodomo eno taio [A new approach of parent training program in school setting: as a coping with children with special needs]. *Bull. Cent. Educ. Res. Dev. Nara Univ. Educ.* 14, 141–145.

Google Scholar

Iwasaka, H., Maeda, Y., Fujiwara, T., Miyata, F., Tanaka, A., Okuno, H., et al. (2012). *Pearento Torêningu Gaidobukku [Parent Training Guidebook]*. Tokyo: Barlow Pub.

Google Scholar

Iwasaka, H., Shimizu, C., Iida, J., Kawabata, Y., Chikaie, M., Onishi, T., et al. (2002). Chuui ketsujo tadousei shougai (AD/HD) ji no oya kunren puroguramu to sono kouka nitsuite [Efficacy of a parenting training program as attention deficit/hyperactivity disorder (AD/HD) therapy]. *Jpn. J. Child Adolesc. Psychiatry* 43, 483–497.

Google Scholar

Kasari, C., Locke, J., Gulsrud, A., and Rotheram-Fuller, E. (2011). Social networks and friendships at school: Comparing children with and without ASD. *J. Autism Dev. Disord.* 41, 533–544. doi: 10.1007/s10803-010-1076-x

PubMed Abstract | Crossref Full Text | Google Scholar

Kawamoto, E., Ito-Masui, A., Esumi, R., Imai, H., and Shimaoka, M. (2020a). How ICU patient severity affects communicative interactions between healthcare professionals: A study utilizing wearable sociometric badges. *Front. Med.* 7:606987. doi: 10.3389/fmed.2020.606987

PubMed Abstract | Crossref Full Text | Google Scholar

Kawamoto, E., Ito-Masui, A., Esumi, R., Ito, M., Mizutani, N., Hayashi, T., et al. (2020b). Social network analysis of intensive care unit health care professionals measured by wearable sociometric badges: Longitudinal observational study. *J. Med. Internet Res.* 22:e23184. doi: 10.2196/23184

PubMed Abstract | Crossref Full Text | Google Scholar

Khosravi, S., Bailey, S. G., Parvizi, H., and Ghannam, R. (2022). Wearable sensors for learning enhancement in higher education. *Sensors* 22:7633. doi: 10.3390/s22197633

PubMed Abstract | Crossref Full Text | Google Scholar

Kim, Y. S., Leventhal, B. L., Koh, Y. J., Fombonne, E., Laska, E., Lim, E. C., et al. (2011). Prevalence of autism spectrum disorders in a total population sample. *Am. J. Psychiatry* 168, 904–912. doi: 10.1176/appi.ajp.2011.10101532

PubMed Abstract | Crossref Full Text | Google Scholar

Kumar, P. C., Chetty, M., Clegg, T. L., and Vitak, J. (2019). "Privacy and security considerations for digital technology use in elementary schools," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, Vol. 307, (New York, NY: Association for Computing Machinery), 1–13. doi: 10.1145/3290605.330053

Crossref Full Text | Google Scholar

Lederman, O., Mohan, A., Calacci, D., and Pentland, A. S. (2018). Rhythm: A unified measurement platform for human organizations. *IEEE MultiMedia* 25, 26–38. doi: 10.1109/MMUL.2018.112135958

Crossref Full Text | Google Scholar

Majoko, T. (2016). Inclusion of children with autism spectrum disorders: Listening and hearing to voices from the grassroots. *J. Autism Dev. Disord.* 46, 1429–1440. doi: 10.1007/s10803-015-2685-1

PubMed Abstract | Crossref Full Text | Google Scholar

Ministry of Education, Culture, Sports, Science, and Technology. (2012). *Tsuujou no Gakkyuu ni Zaisekisuru Hattatsushougai no Kanousei Noaru tokubetsuna Kyouikutekishien o Hitsuyoutosuru Jidou Seito Nikansuru Cyousakekka Nitsuite [The Results of a Survey on Students with Special Educational Needs with Possible Developmental Disabilities Enrolled in Regular Classrooms]*. Available online at: https://www.mext.go.jp/a_menu/shotou/tokubetu/material/1328729.htm (Accessed March 20, 2024).

Google Scholar

Nakajima, T., Kawamoto, T., and Takahashi, M. (2019). Chuugakkou taiiku ni okeru kyoushi eno gengoteki komyunikêshon dêta no fîdobakku niyoru jyugyou kaizen no kokoromi: Dansu jyugyou niokeru seito no taiwateki gakushuu katsudou ni chakumoku shite [Experiment of class improvement by feedback of verbal communication data to teacher in junior high school physical education: focusing on students' interactive activities in dance classes]. *Hokkaido J. Phys. Educ. Health Sport*

Sci. 54, 125–132.
Google Scholar
Nakajima, T., Takahashi, M., Kawamoto, T., and Takase, J. (2020). Chuugakkou taiiku niokeru timutichingu jyugyou kaizen no kokoromi: Wearaburu sensing tsûru niyoru jyugyousha eno kashika dêta no fîdobakku [Attempts to improve team-teaching classes in junior high school physical education: Feedback of visualization data to teachers by wearable sensing tool]. *Hokkaido J. Phys. Educ. Health Sport Sci.* 55, 9–18.
Google Scholar
Ogan, A. (2019). Reframing classroom sensing: Promise and peril. *Interactions* 26, 26–32. doi: 10.1145/3358902
Crossref Full Text | Google Scholar
Okuno, H., Nagai, T., Sakai, S., Mohri, I., Yamamoto, T., Yoshizaki, A., et al. (2011). Effectiveness of modified parent training for mothers of children with pervasive developmental disorder on parental confidence and children's behavior. *Brain Dev.* 33, 152–160. doi: 10.1016/j.braindev.2010.03.007
PubMed Abstract | Crossref Full Text | Google Scholar
Onishi, T., Muto, Y., and Iwasaka, H. (2015). Tîchâ torêningu puroguramu niyoru hoikusha shien ni kansuru kenkyuu dai ippou [A study of teacher training program for supporting early childhood teachers]. *Bull. Cent. Educ. Res. Dev. Nara Univ. Educ.* 1, 83–90.
Google Scholar
Pianta, R. C., and Hamre, B. K. (2009). Conceptualization, measurement, and improvement of classroom processes: Standardized observation can leverage capacity. *Educ. Res.* 38, 109–119. doi: 10.3102/0013189X09332374
PubMed Abstract | Crossref Full Text | Google Scholar
Roorda, D. L., Koomen, H. M. Y., Spilt, J. L., and Oort, F. J. (2011). The influence of affective teacher–student relationships on students' school engagement and achievement: A meta-analytic approach. *Rev. Educ. Res.* 81, 493–529. doi: 10.3102/0034654311421793
PubMed Abstract | Crossref Full Text | Google Scholar
Rotheram-Fuller, E., Kasari, C., Chamberlain, B., and Locke, J. (2010). Social involvement of children with autism spectrum disorders in elementary school classrooms. *J. Child Psychol. Psychiatry* 51, 1227–1234.
Google Scholar
Rucinski, C. L., Brown, J. L., and Downer, J. T. (2018). Teacher–child relationships, classroom climate, and children's social-emotional and academic development. *J. Educ. Psychol.* 110, 992–1004. doi: 10.1037/EDU0000240
Crossref Full Text | Google Scholar

Sayal, K., Prasad, V., Daley, D., Ford, T., and Coghill, D. (2018). ADHD in children and young people: Prevalence, care pathways, and service provision. *Lancet Psychiatry* 5, 175–186. doi: 10.1016/S2215-0366(17)30167-0

PubMed Abstract | Crossref Full Text | Google Scholar

Stefanini, A., Aloini, D., Gloor, P., and Pochiero, F. (2021). Patient satisfaction in emergency department: Unveiling complex interactions by wearable sensors. *J. Bus. Res.* 129, 600–611. doi: 10.1016/j.jbusres.2019.12.038

Crossref Full Text | Google Scholar

Torii, M., Komeda, H., Kamio, Y., and Nishiyama, T. (2017). *Nihon ban SRS-2 Taijin Outousei Shakudo Manyuaru [Manual of Japanese Version of Social Responsiveness Scale*, 2nd Edn. Tokyo: Nihon Bunka Kagakusha.

Google Scholar

Whitham, C. (1991). *Win the Whining War & Other Skimishes: Family Peace Plan.* London: Perspective Publishing.

Google Scholar

Wubbels, T., and Brekelmans, M. (2005). Two decades of research on teacher–student relationships in class. *Int. J. Educ. Res.* 43, 6–24. doi: 10.1016/j.ijer.2006.03.003

Crossref Full Text | Google Scholar

Yamamoto, S., and Hanai, T. (2015). Bijinesukennbikyou wo mochiita youji no ningenkankei no kashika no shikou:Youchien nenchou gosaiji kurasu wo taishou to shita baai [Attempt of visualization of infant relationships with Business microscope®: The case of 5-year-old kindergarten class]. *Jpn. J. Sports Health Sci.* 38, 25–34.

Google Scholar

Yamamoto, T., Okuno, H., Tatsumi, A., Sakai, S., Mohri, I., and Taniike, M. (2021). Use of a sensing device to visualizes group participation in social skills learning groups. *Front. Psychiatry* 12:642949. doi: 10.3389/fpsyt.2021.642949

PubMed Abstract | Crossref Full Text | Google Scholar

Zendarski, N., Haebich, K., Bhide, S., Quek, J., Nicholson, J. M., Jacobs, K. E., et al. (2020). Student–teacher relationship quality in children with and without ADHD: A cross-sectional community based study. *Early Child. Res. Q.* 51, 275–284. doi: 10.1016/J.ECRESQ.2019.12.006

Crossref Full Text | Google Scholar

Table 1. Participants' characteristics

Group	Class	Teacher			Class of the participating teachers				Student chosen by the participating teachers	
		Age	sex	Experience as a teacher (years)	Grade (Age)	Class size; number of students	Number of boys (%)	Number of students with special needs (%)	Number of the students	Primary problems of the students (diagnosis)
TT	a	49	woman	14	1st grade (6-7)	23	13 (57)	3 (13)	1	Hyperactivity and inattention (No diagnosis)
TT	b	31	woman	8	5th grade (10-11)	37	18 (49)	5 (14)	2	Aggressive behaviors (No diagnosis), Aggressive behaviors (No diagnosis)
TT	c	33	woman	12	6th grade (11-12)	30	13 (43)	6 (20)	2	Difficulties in social interaction and communication problem (ASD), Hyperactivity and inattention (ADHD)
Control	d	32	man	3	1st grade (6-7)	24	13 (54)	5 (21)	1	Difficulties in social interaction and communication problem (ASD)
Control	e	53	woman	28	3rd grade (8-9)	22	13 (59)	6 (27)	1	Difficulties in social interaction and communication problem (ASD)
Control	f	24	woman	1	3rd grade (8-9)	23	14 (61)	5 (22)	1	Difficulties in social interaction and communication problem (No diagnosis)

Table 2. Interaction time of teachers based on video recording

Group	TT					
Class	a		b		c	
Measurement	Pre	Post	Pre	Post	Pre	Post
Count/120 seconds [a)]	63.3	44.1	75.6	66.7	71.3	85.9
Group	Control					
Class	d		e		f	
Measurement	Pre	Post	Pre	Post	Pre	Post
Count/120 seconds [a)]	56.7	98.7	71.5	108.7	84	73.2

TT: Teacher training

[a)] The number in cells shows individual time during the activity for pre or post measurement.

Table 3. Pre and post comparisons of interaction time of teachers using the sociometric device and video recording

Class	Directions of change (pre vs. post)	
	Business microscope	Video recording
a	−	−
b	−	−
c	+	+
d	+	+
e	−	+
f	−	−

+: count of interactions increased at post measurement,

−: count of interactions decreased at post measurement

Figure Captions

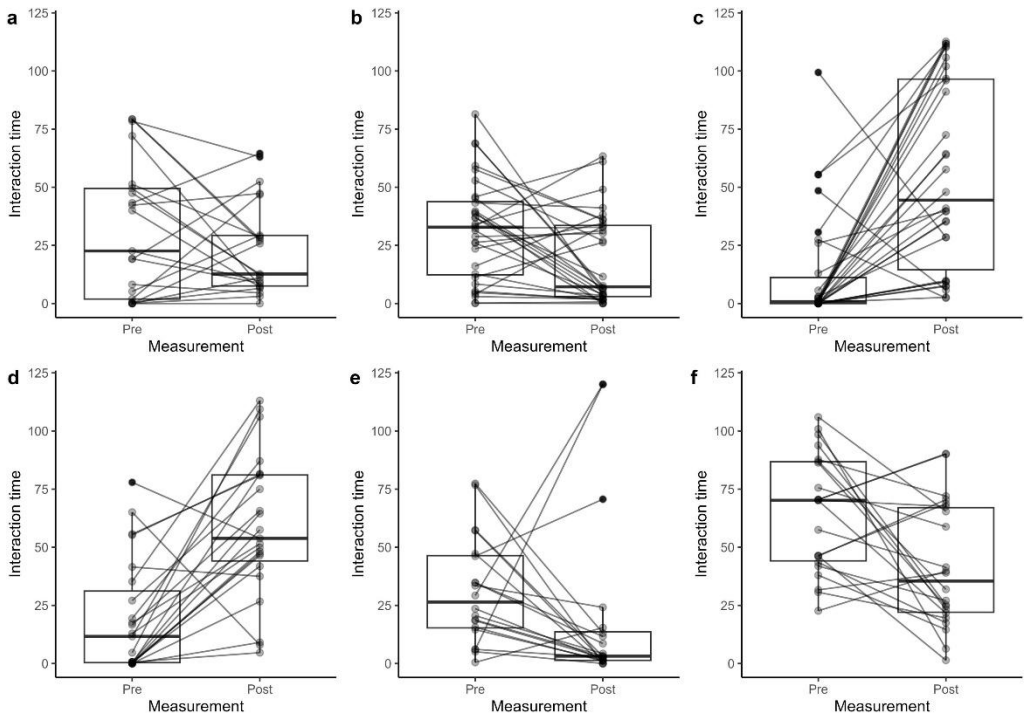


Figure 1. Individual pre-post changes in each student in each class. The letters indicate the classes: teachers in a-c received the TT intervention; teachers in d-f did not receive the intervention.

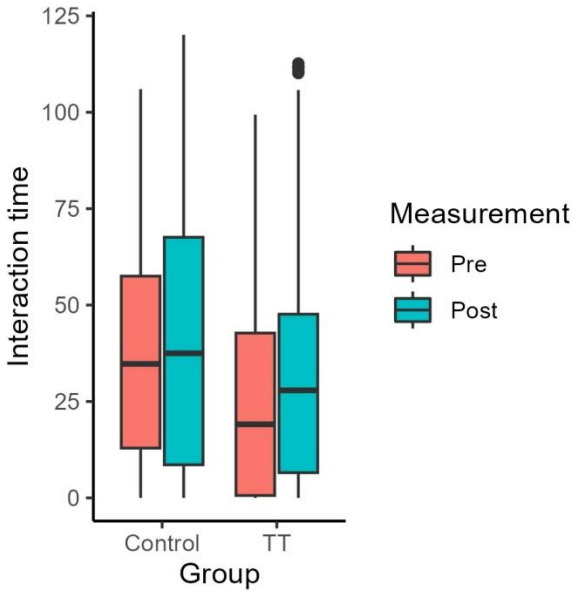


Figure 2. Pre-post changes between groups in teacher–student interaction time

Supplemental Table S1. Changes in teachers' confidence

Group	TT						
Class		a		b		c	
Measurement		Pre	Post	Pre	Post	Pre	Post
Item							
	Q1	4	5	4	3	4	4
	Q2	5	5	4	4	4	4
	Q3	4	4	5	4	4	4
	Q4	4	3	4	2	3	3
	Q5	4	3	3	3	3	3
	Q6	3	4	3	3	4	4
	Q7	3	3	2	2	4	3
	Q8	3	3	2	2	3	4
	Q9	3	3	5	4	3	4
	Q10	4	4	5	4	4	4
	Q11	4	4	5	5	3	3
	Q12	3	4	3	3	4	4
	Q13	4	3	4	4	3	3
	Q14	4	4	5	5	3	3
	Q15	4	4	4	4	3	3
	Q16	4	3	5	4	3	4
	Q17	4	4	3	2	3	4
	Q18	4	5	4	1	5	5
	Total	68	68	70	59	63	66
Group	Control						
Class		d		e		f	
Measurement		Pre	Post	Pre	Post	Pre	Post
Item							
	Q1	4	4	4	4	4	4
	Q2	5	4	4	4	4	4
	Q3	5	4	5	4	4	4
	Q4	5	4	5	4	4	4
	Q5	4	3	3	4	4	3
	Q6	4	4	3	4	3	3
	Q7	4	3	5	4	3	3
	Q8	4	3	4	2	3	2
	Q9	4	3	5	4	3	3
	Q10	4	3	5	5	3	3
	Q11	4	3	5	4	3	3
	Q12	3	3	4	4	4	4
	Q13	4	2	5	3	4	2
	Q14	4	4	5	5	4	5
	Q15	4	4	5	5	4	4
	Q16	4	4	5	3	4	4
	Q17	4	4	4	4	3	4
	Q18	4	5	4	5	4	4
	Total	74	64	65	63	80	72

TT: Teacher training

Supplemental Table S2. Changes in questionnaire scores of each teacher

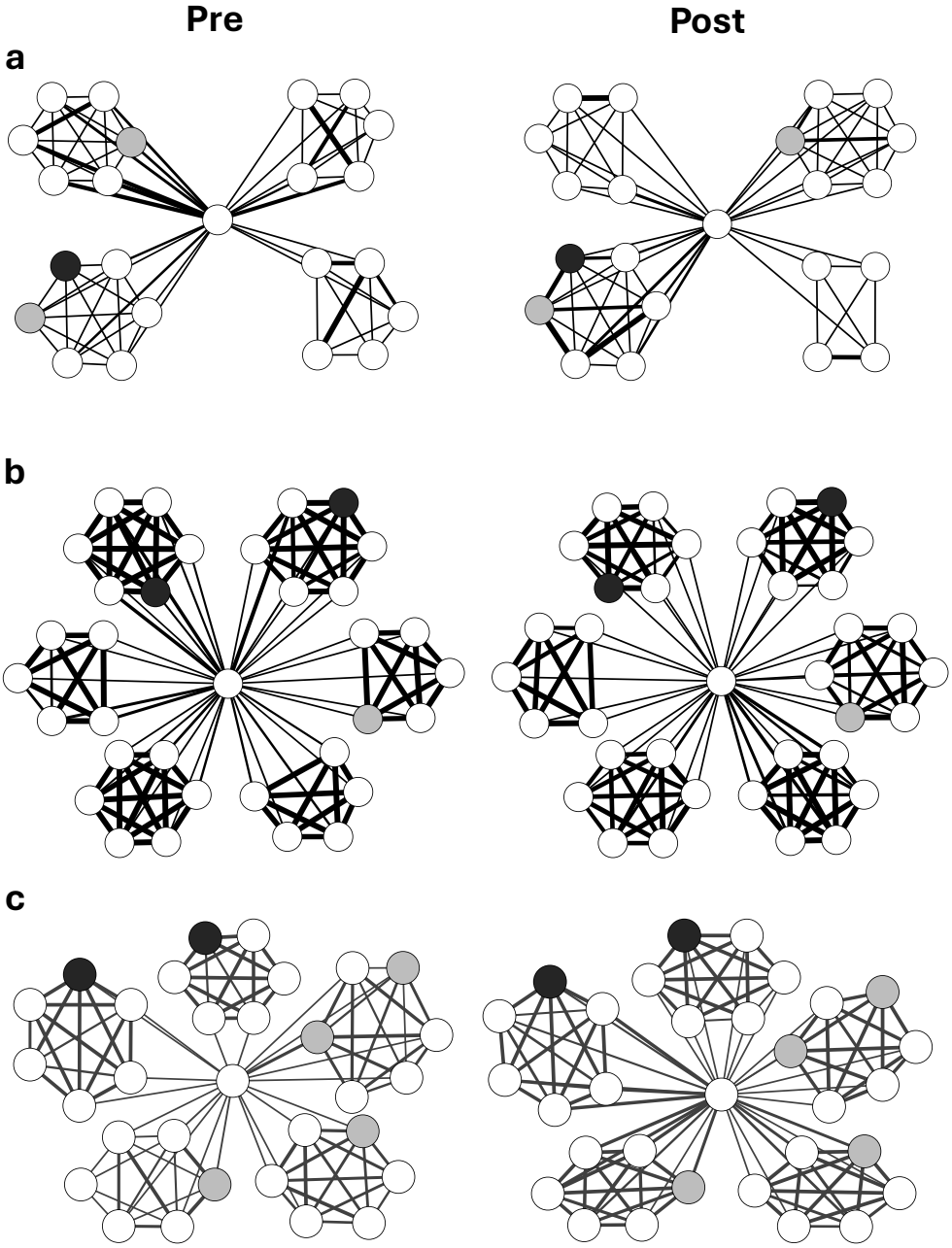
Group	TT						
Class		a		b		c	
Measurement		Pre	Post	Pre	Post	Pre	Post
Measures							
	SRS-18 Total	37	38	44	39	39	38
	GHQ Total	1	5	6	10	4	0
	Work engagement	54	52	48	47	47	41
	Self-efficacy	54	53	49	50	46	44
Group	Control						
Class		d		e		f	
Measurement		Pre	Post	Pre	Post	Pre	Post
Measures							
	SRS-18 Total	54	56	44	40	40	57
	GHQ Total	7	11	3	8	3	10
	Work engagement	42	41	28	32	28	40
	Self-efficacy	48	41	43	41	39	40

TT: Teacher training; SRS-18: Psychological Stress Response Scale; GHQ: General Health Questionnaire

Supplemental Table S3. Changes in students selected by the teachers

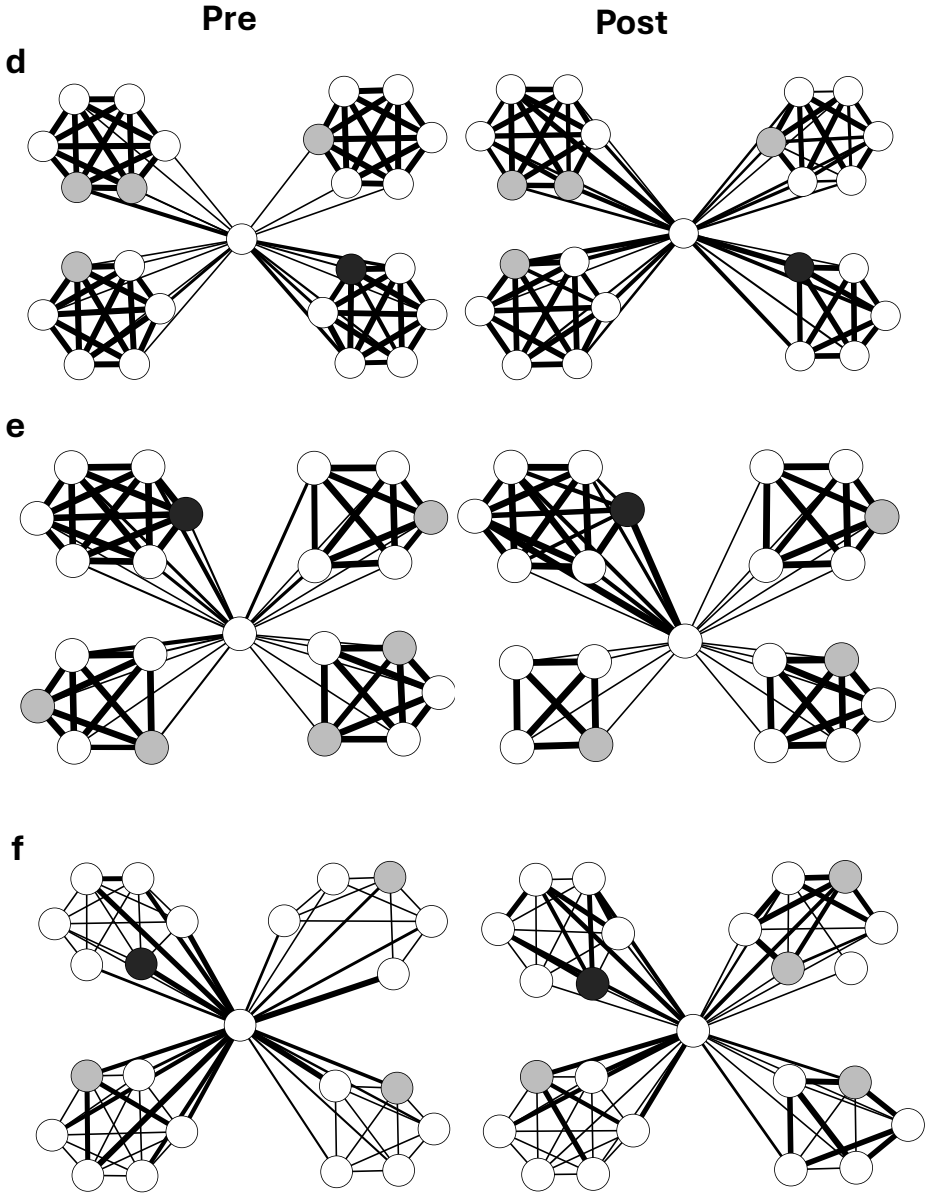
Group	TT										
Class		A		B1		B2		C1		C2	
Measurement		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Measures											
TRF	Total	65	66	62	65	59	54	65	58	64	64
	Internal	65	59	59	62	54	51	62	49	66	67
	External	65	65	65	67	65	60	61	59	63	64
SRS-2	Total	60	67	46	59	47	42	65	53	72	73
	SCI	59	64	44	57	48	42	65	53	71	72
	RRB	60	73	54	66	45	45	60	52	75	75
Group	Control										
Class		D		E		F					
Measurement		Pre	Post	Pre	Post	Pre	Post				
Measures											
TRF	Total	66	63	63	65	59	64				
	Internal	66	64	62	63	57	63				
	External	64	61	60	62	57	63				
SRS-2	Total	65	63	73	65	51	54				
	SCI	64	62	74	64	52	56				
	RRB	68	64	64	64	45	45				

TT: Teacher training; TRF: Teacher's Report Form of the Child Behavior Checklist; SRS: Social Responsiveness Scale-2.



Supplemental Figure S1. Face-to-face interaction between the teacher and students pre- and post-teacher training (class a, b, and c).

Note. In the face-to-face interaction network diagram, the nodes (individuals) are indicated by circles, with the central node representing the teacher (T) and the surrounding nodes representing individual students. The straight lines connecting the nodes indicate face-to-face interaction and were drawn such that the longer the face-to-face time, the thicker the line. The black circles show students selected by the teachers (Supplemental Table S3). The grey circles show students with special needs.



Supplemental Figure S2. Face-to-face interaction between the teacher and students pre- and post-teacher training (class d, e, and f).

Note. In the face-to-face interaction network diagram, the nodes (individuals) are indicated by circles, with the central node representing the teacher (T) and the surrounding nodes representing individual students. The straight lines connecting the nodes indicate face-to-face interaction and were drawn such that the longer the face-to-face time, the thicker the line. The black circles show students selected by the teachers (Supplemental Table S3). The grey circles show students with special needs.