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RESEARCH ARTICLE

Automated measures of vocal interactions and engagement in inclusive preschool classrooms

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Abstract

Classroom engagement plays a crucial role in preschoolers' development, yet the correlates of engagement, especially among children with autism spectrum disorder (ASD) and developmental delays (DD), remains unknown. This study examines levels of engagement with classroom social partners and tasks among children in three groups ASD, DD, and typical development (TD). Here, we asked whether children's vocal interactions (vocalizations to and from peers and teachers) were associated with their classroom engagement with social partners (peers and teachers) and with tasks, and whether the association between classroom engagement and vocal interactions differed between children in the ASD group and their peers in the DD and TD groups. Automated measures of vocalizations and location quantified children's vocal interactions with peers and teachers over the course of the school year. Automated location and vocalization data were used to capture both (1) children's vocal output to specific peers and teachers, and (2) the vocal input they received from those peers and teachers. Participants were 72 3–5-year-olds (M_{age} = 48.6 months, SD = 7.0, 43% girls) and their teachers. Children in the ASD group displayed lower engagement with peers, teachers, and tasks than children in the TD group; they also showed lower engagement with peers than children in the DD group. Overall, children's own vocalizations were positively associated with engagement with social partners. Thus, although children in the ASD group tend to have lower engagement scores than children in the TD group, active participation in vocal interactions appears to support their classroom engagement with teachers and peers.

Lay Summary

We examined associations between automated measures of preschoolers' vocal interactions and their classroom engagement with peers, teachers, and tasks in inclusive classrooms. Children with autism spectrum disorder (ASD) showed lower engagement levels than children without ASD. Overall, however, children's own vocalizations were positively associated with engagement with peers and teachers, shedding new light on behaviors supporting engagement in children with ASD.

KEYWORDS
autism spectrum disorder, automated measures, classroom engagement, developmental disabilities, inclusion classrooms, objective measurement, vocal interactions

INTRODUCTION

Classroom engagement, the ability to successfully participate in classroom tasks and with social partners, plays a crucial role in preschoolers' self-regulation, cognition, and school readiness abilities (Bohlmann & Downer, 2016; Coolahan et al., 2000; Fantuzzo et al., 2004; Williford et al., 2013; Zigler et al., 2004). Children's language abilities, as measured by standardized assessments, are positively associated with classroom engagement (Bohlmann & Downer, 2016). This association may exist not because language supports engagement, but because for example, children with better cognitive skills have both stronger language abilities and higher levels of engagement. Alternately, scores on language assessments may reflect children's tendency to talk to peers and teachers in the classroom, and talking in the classroom helps children stay engaged (Bohlmann & Downer, 2016). However, it remains unknown if classroom engagement actually is associated with children's real-time talking in the classroom or if the previously documented association with general language abilities exists for some other reason.

Further, it is also unknown whether children with developmental disabilities or delays such as children with autism spectrum disorder (ASD)[1] or developmental delay (DD), differ from children with typical development (TD) in their classroom engagement. ASD is a pervasive neurodevelopmental disorder characterized by deficits in communication and social interaction (American Psychiatric Association, 2013). Here, we use DD to identify children who have a have a delay in one or more developmental domains, such as language or cognition, but do not have ASD. Many children with ASD and DD have language delays, which can impede successful communication (Camargo et al., 2014; Charman et al., 2003; Delehanty et al., 2018; Merrell & Holland, 1997). Additionally, children with ASD often experience specific difficulties with pragmatics (Geurts & Embrechts, 2008) and conversational turn-taking (Laghi et al., 2018). These difficulties with language use, may be associated with lower levels of positive engagement with peers and teachers, and with tasks. The current study examines levels of engagement with social partners and classroom tasks among children with ASD, children with DD, and children with TD. We combined longitudinal automated measurement of vocal interactions (vocalizations to and from peers and teachers) with expert observations of engagement, while controlling for assessed language ability, to examine whether vocal interactions support preschoolers' classroom engagement.

[1]When we reference the literature, rather than this study's participants, we use person-first language for all three groups of children. We made this choice aware that many verbal adults on the autism spectrum prefer identity-first language (i.e., "autistic individual"). However, it is not clear that this is most appropriate for young children in inclusion classrooms. Our decision to use person-first language allows consistency in how we discuss all three groups of children as person-first nomenclature is the only accepted terminology for children with DDs. This discussion is part of larger debate in which we opt to use the scientific language we deem most clear, communicative, appropriate, and respectful (Amaral, 2023)."

CLASSROOM ENGAGEMENT

Nearly all work on classroom engagement has focused on preschoolers and young children with TD. This work suggests that children's engagement with different social partners and with tasks is related to a wide array of developmental outcomes. Engagement with teachers in preschool and early elementary school has been linked to children's expressive and receptive language abilities, academic success, and social competence through late elementary school (Huttenlocher et al., 2002; Wasik et al., 2006; Welsh et al., 2001). Peer engagement during preschool is related to children's self-esteem, language abilities, and adjustment to kindergarten (Ladd & Price, 1987; Schechter & Bye, 2007). Task engagement during preschool is linked to academic success and prosocial behavior (Coolahan et al., 2000; Fantuzzo et al., 2004). As classroom engagement is related to future language abilities and school readiness (Bohlmann & Downer, 2016; Coolahan et al., 2000; Fantuzzo et al., 2004; Hirsh-Pasek et al., 2008; Sabol et al., 2018), lower classroom engagement during preschool could compound existing delays.

Measuring classroom engagement

Much of our knowledge of classroom engagement comes from observational measures, such as the individualized classroom assessment scoring system (inCLASS; Downer et al., 2010). The inCLASS, designed for use with preschoolers (3–5 years old), entails a trained researcher observing one child at a time during the school day over 10-min observation cycles focusing on children's positive interactions with peers (e.g., playing with peers) and teachers (e.g., smiling at teachers), positive task engagement (e.g., staying focused on a task), and negative classroom engagement (e.g., hitting a peer). Using the inCLASS, researchers have found that children's classroom engagement is associated with children's language abilities (Bohlmann & Downer, 2016; Sabol et al., 2018) and emotion regulation (Williford et al., 2013).

Here we use the inCLASS in inclusive classrooms, where children with ASD and other developmental disabilities are educated alongside children without these disorders, to assess engagement in different groups of children. The inCLASS has previously been used in studies focused on children with TD, and, to our knowledge, none have used the inCLASS to measure engagement of children with developmental disabilities or delays. In fact, there have been few studies, using any measure, to study children with ASD or DD's engagement with tasks, peers, and teachers in the classroom.

CLASSROOM ENGAGEMENT FOR CHILDREN WITH DEVELOPMENTAL DISABILITIES

The small number of prior observational studies on engagement in children with ASD and DD have yielded mixed findings. However, there is reason to hypothesize the possibility of lower engagement among children with ASD and DD compared to children with TD. For example, Kemp et al. (2013) found that children with ASD were significantly less engaged during free-play than children with DD. However, others have found no differences in free-play engagement between children with ASD and DD, and only small differences between children with ASD and TD (Odom, 2002). One explanation for these contradictory findings was differing definitions of engagement (see Sam et al., 2016). Researchers have not examined the behavioral correlates of engagement in children with ASD. In particular, while language abilities, particularly vocal interaction, have been proposed to support classroom engagement (Bohlmann & Downer, 2016), this idea has not been tested. The inCLASS is a validated measure of engagement and provides clear definitions and rating anchors to quantify engagement, facilitating comparison to other behavioral measures, such as children's classroom vocal interactions.

CAPTURING VOCAL INTERACTION IN PRESCHOOL CLASSROOMS

We captured vocal interactions using two automated tools, the language environment analysis (LENA) system and Ubisense (ultrawide band radio frequency identification [RFID] technology). LENA digital language processors (DLPs) are lightweight, child-worn audio recorders that allow for efficient, automated measurement of individual children's language experiences in the classroom. LENA software provides estimates of the number of child and adult vocalizations (Gilkerson & Richards, 2008), and is valid for children with and without disabilities (Richards et al., 2017; Trembath et al., 2019). LENA measures of child vocalizations in preschool classrooms are associated with standardized assessments of language abilities (Dykstra et al., 2013; Perry et al., 2018).

Coupling LENA with Ubisense indicates when children vocalize in proximity to specific peers and teachers. The Ubisense system involves child- and teacher-worn tags that allow for efficient location tracking throughout the classroom, indicating when child–child and child-teacher pairs are in proximity (Irvin et al., 2018, 2021; Messinger et al., 2019). When participants wear two tags (a left and right), their relative orientation to partners (e.g., who is facing whom) can be measured (Altman et al., 2020; Fasano et al., 2021; Irvin et al., 2021). Combining measures of proximity and orientation indicated when children vocalized in *social contact* with a partner (Altman et al., 2020; Fasano et al., 2021). Together, the observational and automated methods allowed us to understand the association between real-time vocal interactions and classroom engagement among children with ASD, DD, and TD.

RATIONALE FOR THE CURRENT STUDY AND HYPOTHESES

Vocal interaction may help promote children's positive classroom engagement, including the ability to initiate and maintain conversations with social partners and actively participate in classroom activities and tasks. This study examined whether differences in children's real-time classroom vocal interactions were associated with classroom engagement in eight inclusive preschool classes for children with ASD, children with DD, and children with TD. Downer et al.' (2010) factor analysis of inCLASS scores identified four domains of engagement: peer, teacher, task, and negative engagement, which served as our outcome variables of interest. We employed automated measures (LENA and Ubisense) to quantify children's real-time vocal interactions with peers and teachers, which were used to measure vocal interaction differences among children with ASD, DD, and TD as well as to predict children's classroom engagement. Children's assessed language abilities were employed as predictors/covariates in predicting engagement as previous studies indicated that there are associations between children's assessed language abilities and classroom engagement (Bohlmann & Downer, 2016).

We first examined group (ASD, DD, and TD) differences in children's vocal interactions and classroom engagement. Group was determined from children's designations on their Individual Education Program (IEPs). For example, children with an ASD designation on their IEPs are referred to as the ASD group. We hypothesized that children in the ASD group would engage in fewer vocal interactions and score lower on all four observed classroom engagement domains than children in the DD and TD groups. We then asked whether objectively measured vocal interactions were associated with observed classroom engagement scores. We hypothesized that, for all children, higher rates of vocal interactions with peers and teachers would be positively associated with the four domains of classroom engagement, above and beyond any group differences and children's assessed language abilities.

METHODS

Participants

Participants included 72 preschoolers (32 girls or 43%) enrolled in eight inclusive classes in a large metropolitan area in the Southeastern United States Although there

were 72 participants, the enrollment in these eight classes was 98 children. Our participant number is small than this for several reasons. First, 15 of these participants were enrolled in two classes (AM and PM sessions in the same classroom), leave 83 unique children. Of these 83, five additional children enrolled after the completion of inCLASS observations but were present during LENA/Ubisense data collection (these five children contributed peer vocal input data and were potential recipients of child vocal output but were not included as target children). Of these 78, three children were not present during LENA/Ubisense data collection, and were removed from analyses. Of these 75, three children did not consent, for a total of 72 participants. The overall consent rate was 96%. See online appendix A, Table A1 for demographic information and online appendix C for a flowchart depicting participant numbers.

Of the 72 preschoolers, 63 were Hispanic (61 White, 1 Black, and 1 multiracial) and 9 were non-Hispanic (8 White, 1 Black). Based on teacher or parent report, 41 of the children were monolingual English learners, 26 were bilingual English-Spanish learners, three were monolingual Spanish learners, and 2 were bilingual learners of English and a Romance language other than Spanish. Children's mean age at enrollment was 48.6 months (SD = 7.0). Qualifying children in the ASD and DD groups received an Individualized Education Program (IEP), determining their category of eligibility for special education services as legislated by the Individuals with Disabilities Education Act (IDEA; United States Department of Education, 2021). Eligibility group (hereafter "group") was determined based on parent report or child IEP. Two participants had IEP eligibility of DD, but parent–reported ASD diagnoses; these children were included in the ASD group. No parent of a child *without* an IEP indicated any developmental delay or disability. ASD group ($n = 21$) membership was determined by either children's IEP or parent report indicating that the child had ASD; DD group membership ($n = 22$) was determined by both sources indicating DD. The TD group ($n = 29$) included children without an IEP.

Across the eight classes there were 10 unique teachers/paraprofessionals[2] (10 female; consent rate 100%) who were included as social partners in our vocalizations analyses. Each class included one lead teacher and 1–2 paraprofessionals, for a total of four lead teachers and six paraprofessionals across all classes and years.

All study protocols were approved by the University Institutional Review Board. Parents provided consent for children's participation and teachers/paraprofessionals provided consent for their own participation. Fifty-six of the participants were also included in a 2021 study of social networks (Fasano et al., 2021).

[2]Although each classroom has 2–3 teachers, there are only 10 unique teachers as some teachers were in both the AM/PM sessions of classes, and/or participated across multiple years.

Data collection

Location data were collected using the Ubisense Dimension4 system. Audio was recorded using LENA DLPs (version H). Audio recordings were collected monthly during school-day-long observations in each class ($M = 2.08$ h, SD = 0.85 h), excluding times when children were not in the classroom (e.g., outdoor play). School days ranged from ~2.5 (half-day)—5 h (full day). Classes were observed 2–5 times each ($M = 4.36$) audio recordings per child (SD = 2.43), yielding 314 individual audio recordings and over 650 h of total audio and location data ($M = 9.07$ h per child, SD = 3.66, range 1.56–17.83 h per child; Table 1).

Measures

Children's and teachers' vocalizations

Each child wore a LENA recorder in an altered LENA vest. Audio files were analyzed using LENA Pro V3.4.0 pattern recognition software. The software distinguishes children's own speech-like vocalizations from the vocalizations of other speakers using Gaussian mixture models. Vocalization refers to speech-like vocalizations, ranging from pre-linguistic sounds to full-word production and excludes non-speech sounds (e.g., crying). Teacher vocalizations were quantified using the adult word count (AWC) variable from LENA. Vocalization counts were derived from LENA's Interpretive Time Segment files, which contain the onset and offset of each vocalization made by the child wearing the recorder and the onset and offset of the adult vocalizations that each child was exposed to.

LENA has been used to quantify speech in both English (Soderstrom & Wittebolle, 2013) and Spanish (Weisleder & Fernald, 2013). Previous studies have shown high reliability between humans and LENA coding of adult versus child speech in classroom audio recordings (Fasano et al., 2021; Mitsven et al., 2021; Perry et al., 2022). In the current study, trained coders blind to LENA classifications coded approximately 5% of the vocalizations (2100 total vocalizations) as either adult or child speech. There was 87% agreement (SD = 0.07; $K = 0.74$, SD = 0.15), suggesting the reliability of LENA categorization of child and adult speech in the sample. Of the 2100 vocalizations coded in this study, 1500 had previously been coded for Fasano et al. (2021).

Children's and teachers' location

The Ubisense system tracks children's location at 2–4 Hz to an accuracy of 15–30 cm (Phebey, 2010). The system consists of one sensor in each corner of the classroom

TABLE 1 Group ratios and average recording time of each class.

		Class time	Consented children/ total in class	Ratio ASD:DD:TD	Ratio girls:boys	Number of teachers	Number of observations	Avg. recording length (h)
Room 1	Class 1, 2018–2019	AM	12/12	4:0:8	5:7	3	5	2.35
	Class 2, 2018–2019	PM	11/12	3:0:8[a]	5:6	3	5	2.27
	Class 3, 2019–2020	AM	11/11	4:0:7	7:4	3	5	1.78
	Class 4, 2019–2020	PM	11/11	3:0:8[b]	8:3	3	5	2.13
Room 2	Class 5, 2018–2019	AM	11/13	3:7:1	1:10	2	5	2.12
	Class 6, 2019–2020	AM	9/9	1:4:1	2:4	2	4	1.99
Room 3	Class 7, 2019–2020	Full-day	10/10	2:6:2	5:5	2	2	3.77
Room 4	Class 8, 2019–2020	Full-day	20/20	4:6:10	11:9	2	4	4.33

Note: Room column indicates which classes occurred in same physical space. Classes 1–4 did not enroll students with DD. "Number of teachers" includes paraprofessionals in the classrooms. There are 10 unique teachers across classes/years, as some teachers were in both the AM/PM sections of classes and/or participated during multiple years. Class ratios include total number of children who participated in the study from each class. Because five of these children did not contribute inCLASS data, they were included as partners (i.e., in the peer input variable), but they were not included as subjects. Across all eight classes, there were only three children who did not consent (one student in Class 2, and two students in Class 5).

[a]These are the same eight TD students from Class 1 and are included separately in both counts of total consented children for classes 1 and 2.

[b]These include the seven TD students from Class 3 and one additional TD student not enrolled in AM. The seven children in both classes are included separately in both counts of total consented children for classes 3 and 4.

(8.97 × 8.86 m, 8.76 × 8.93 m, 9.58 × 8.70 m, and 8.39 × 11.12 m),[3] a dedicated server, and active tags worn by children and teachers. Each child wore two tags (in the left and right pockets sewn into a vest housing the LENA recorder) as did each teacher (in the left and right pockets of a fanny pack). The tags' ultra-wide-band RFID signals were used to calculate child and teacher location and orientation by means of triangulation and time differences in arrival.

Social contact (proximity and orientation)

RFID measures of child and teacher position and orientation in the classroom were used to detect instances of social contact based on children's proximity to and mutual orientation toward peers and teachers.[4] The radial distribution function indicates distances at which pairs of individuals are closer than expected by chance ($g(r) > 1$). Chance refers to the likelihood of two individuals being located at a particular distance given their overall location preferences. The radial distribution function indicated that co-location between both child–child and child-teacher dyads was greater than chance between 0.2 and 2 m (Figure 1). Within this range, we examined the relative orientation of each dyad by measuring θ_1, the angle of child A relative to child B, and θ_2, the angle of child B relative to child A. We defined social contact as instances in which children and their social partners were within 0.2–0.2 m and both oriented within ±45° toward an imaginary line connecting each other. For example, if child A was facing child B (and the imaginary line connecting the two) but child B was not roughly facing the line connecting the two (within ±45°), the two would not be in social contact. Colloquially, each of the two children needed to be roughly facing each other for there to be social contact. The same process was repeated to calculate the relative orientation of children to teachers.

Data integration

Location data were interpolated at 0.10 s intervals and synchronized with vocalization data to quantify how much child–child and child-teacher pairs vocalized to one another during periods of social contact. When a child was in social contact with a peer, the child's own vocalizations were tabulated from their own recorder while their peer's vocalizations were tabulated from the peer's recorder. When a child was in social contact with a teacher, both the child's and teacher's vocalizations were tabulated from the child's own recorder. We summed the number of vocalizations made by each child during periods of social contact with each of their peers/teachers to index *which* child–child and child-teacher dyads were speaking to each other (e.g., how much child A spoke to child B and child B spoke to child A). These sums were divided by the length of time both partners were in the classroom at the same time. Thus, we calculated the rate of vocalizations *per peer* per hour given the amount of time in which a child *could* have been in social contact with a peer.

Individual child observations

Researchers rated engagement in four engagement domains—peer interaction, teacher interaction, task orientation, and negative engagement—using the

[3]The sample consisted of eight distinct classes who were observed in four physical classrooms (Table 1).

[4]Visualizations of social contact are available on Databrary for those with authorized accounts https://nyu.databrary.org/volume/1464 and on OSF https://osf.io/gn6ar/?view_only=fd70d2fcee7d47bda12967921d903350.

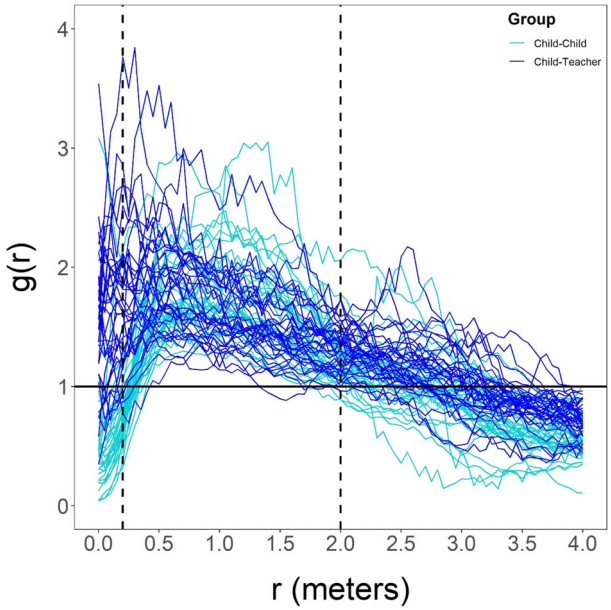

FIGURE 1 The radial distribution function $g(r)$ indicates distances at which the probability of child–child and child–teacher pairs being in contact exceeds chance ($g(r) = 1$). The area between the vertical dashed lines (from 0.2 to 2 m) index the proximity criterion of social contact across observations for each of eight classes for child–child and child-teacher dyads.

INdividualized CLassroom Assessment Scoring System (inCLASS; Downer et al., 2010). The peer domain comprises three dimensions: sociability (e.g., playing with peers), communication (e.g., talking to a peer and the complexity of the conversation), assertiveness (e.g., initiating a game). The teacher domain comprises two dimensions: positive engagement (e.g., smiling at the teacher), communication (e.g., talking to the teacher and the complexity of the conversation). The task domain comprises two dimensions: task engagement (e.g., staying focused on a task), self-reliance (e.g., asking for help when necessary). The negative domain includes negative peer interaction (e.g., hitting a peer), negative teacher interaction (e.g., crying), and behavioral control (e.g., talking at an appropriate volume inside the classroom).

Researchers attended a 2-day intensive observation training directed by an inCLASS-certified trainer and were certified after achieving >80% agreement with master codes on a series of five 10-min video clips. Each child was observed once in the middle of the school year. It is important to note that the inCLASS assessments were not collected simultaneously with automated vocalization and location data. During each child's inCLASS assessment, a researcher observed that child for four 10-min cycles over the course of a single school day. The researcher scored each dimension on a 7-point scale: low range (1–2), mid-range (3–5), and high range (6–7). The negative teacher and negative peer interaction dimensions were reverse scored for analyses (e.g., 1 becomes 7). Thus, higher scores indicate more positive teacher, peer, and task engagement and better (less negative) classroom engagement. Scores for each dimension within domains were summed, resulting in one total score for the four domains. Total domain scores were averaged over observation cycles. Peer and negative domains include three dimensions, with final aggregate scores ranging from 3 to 21. Teacher and task domains include two dimensions, ranging from 2 to 14. Fifteen percent of the inCLASS assessments were double coded for reliability, with >90% agreement across coders, where scores within ±1 of each other are counted as in agreement, as outlined in the original inCLASS protocol (Downer et al., 2010). We also calculated the ICC for inter-observer agreement in R (RStudio, 2018) with the ICC function in the psych package (Ravelle, 2022). Using a one-way random effects model, we obtained relatively high inter-rater reliability, 0.87, with a 95% confidence interval of 0.85–0.89.

Standardized assessments of language abilities

Trained researchers administered the Preschool Language Scales, Fifth Edition (PLS-5, Zimmerman et al., 2011) during the middle of the school year to obtain a standardized measure of each child's receptive, expressive, and overall language abilities. The measure of overall language abilities was used as a control variable due to previously reported associations between assessed language abilities and classroom engagement (Bohlmann & Downer, 2016). Ten children (two from the ASD group, six from the DD group, two from the TD group) were administered the bilingual Spanish-English form of the PLS-5, based on their language background (i.e., Spanish-dominant bilingual or monolingual Spanish-speaker). There were no differences in PLS-5 scores administered using the bilingual Spanish-English or monolingual English form, *p*s >0.30.

Analytic plan

To explore group differences in classroom vocal interactions, assessed language abilities, and classroom engagement, we used mixed effects regression analyses with the lme4 package in RStudio (Bates et al., 2014; RStudio, 2018). Then, in our primary analyses, we used mixed effects regressions to predict classroom engagement scores from group, vocalizations to and from social partners, and PLS scores. For example, the model predicting peer engagement was:

Peer Engagement ~ Vocalizations to Peers + Vocalizations from Peers + Group + PLS-5 score + (1|class).

In all models, children were nested within classes, and children's vocal interactions were averaged across partners and observations. The ASD group was the reference

group for contrasts with the DD and TD groups. We did not have hypotheses about the DD group relative to the TD group, as our hypotheses centered on differences between (1) the ASD group and DD group and (2) the ASD group and the TD group. Thus, we chose not to conduct additional comparisons between the DD group and TD group to avoid multiple comparisons. Significance was determined using the *lmertest* function, which provides summaries via Satterthwaite's degrees of freedom (Kuznetsova et al., 2017). Continuous predictors (e.g., children's vocalizations to peers) were mean centered within class. R code and datasets are available on OSF at https://osf.io/gn6ar/?view_only=fd70d2fcee7d47bda12967921d903350.

RESULTS

Descriptive statistics for children's vocalizations to and from peers and teachers, standardized language scores, and inCLASS domain scores are presented in Table 2. All inCLASS domain scores were significantly correlated with each other, apart from the peer and negative engagement domains (Table 3). Likewise, the PLS-5 total and subscale scores were significantly correlated with each other and every inCLASS domain, except the negative domain.

Group differences in classroom vocal interactions and assessed language abilities

First, we examined group differences in children's language abilities by comparing their scores on the PLS-5. The ASD group had lower PLS-5 total scores than both the TD group, $B = 32.90$, SE $= 5.95$, $t = 6.65$, $p < 0.001$, and the DD group, $B = 16.62$, SE $= 5.61$, $t = 2.96$, $p = 0.004$ (Table 2). This pattern held for the auditory comprehension subscale, with the ASD group scoring lower than the TD group, $B = 28.16$, SE $= 4.64$, $t = 6.07$, $p < 0.001$, and the DD group, $B = 14.37$, SE $= 5.21$, $t = 2.76$, $p = 0.007$; and the expressive communication subscale, with the ASD group scoring lower than the TD group, $B = 33.02$, SE $= 5.30$, $t = 6.23$, $p < 0.001$ and DD group, $B = 15.61$, SE $= 6.01$, $t = 2.60$, $p = 0.012$. Given the similar pattern across subscales, we include only the total score as a covariate in subsequent analyses.

We ran mixed effects regressions to assess group differences in children's vocalizations to peers while accounting for children's total PLS-5 score, a measure of their standardized language abilities (Table 2). In this model, the ASD group did not differ from the TD group, $B = 1.35$, SE $= 0.83$, $t = 1.64$, $p = 0.11$ or the DD group, $B = 0.58$, SE $= 0.79$, $t = 0.73$, $p = 0.47$. However, children's vocalizations to peers were associated with their PLS-5 scores, $B = 0.05$, SE $= 0.16$, $t = 3.16$, $p = 0.002$, such that children with higher language abilities vocalized more to their peers. In their vocalizations to teachers, the ASD group did not significantly differ from the TD group, $B = 0.42$, SE $= 0.99$, $t = 0.43$, $p = 0.67$, or the DD group, $B = 0.23$, SE $= 0.92$, $t = 0.25$, $p = 0.80$. PLS-5 scores were not significantly related to children's vocalizations to teachers, $B = 0.02$, SE $= 0.02$, $t = 0.97$, $p = 0.34$.

As described in Table 2, the ASD group did not differ from the TD group, $B = 0.76$, SE $= 0.44$, $t = 1.75$, $p = 0.09$, or from the DD group, $B = 0.38$, S|E $= 0.43$, $t = 0.88$, $p = 0.38$, in peer vocal input. PLS-5 scores were also not significantly related to peer vocal input, $B = 0.01$, SE $= 0.01$, $t = 1.63$, $p = 0.11$. The ASD group also did not differ from their peers in vocal input from teachers (TD group contrast, $B = 1.41$, SE $= 2.03$, $t = 0.70$, $p = 0.50$, DD group contrast, $B = 0.91$, SE $= 2.02$, $t = 0.45$, $p = 0.65$). However, PLS-5 scores were significantly, negatively related to children's vocal input from teachers, $B = -0.08$, SE $= 0.04$, $t = -2.08$, $p = 0.04$, suggesting that teachers provide more vocal input to children with lower language abilities.

Associations between real-time vocal interactions and classroom engagement

Separate mixed effects regression models predicted scores in each of the four inCLASS domains from group, vocal input and output, PLS-5 total score, and a random class intercept.

Peer domain

Children's vocalizations to peers were positively associated with peer engagement, even when controlling for peer input, group, and PLS-5 score, $p = 0.002$ such that children who vocalized more to peers had higher peer engagement domain scores (Table 4). In this model, vocalizations from peers were *negatively* associated with peer engagement, $p = 0.040$. There was also a main effect such that the ASD group had significantly lower peer engagement scores than the TD group, $p < 0.001$, and DD group, $p = 0.018$. PLS-5 total score was not significantly related to peer engagement, $p = 0.34$.

Teacher domain

Vocalizations to teachers were positively related to teacher engagement domain scores, $p = 0.036$, even when controlling for teacher input, group, and PLS-5 scores. However, there was no significant effect of vocalizations from teachers, $p = 0.217$. There was also a main effect of group such that the ASD group had significantly lower teacher engagement scores than the TD group $p = 0.006$, but did not differ from the DD group, $p = 0.16$ (Table 5).

TABLE 2 Descriptive statistics: children's vocalizations, inCLASS domain scores, and PLS-5 scores.

					Range		Comparison with ASD Group
		Group	Mean	SD	Min	Max	
Vocalizations to and from peers and teachers	Vocalizations to peers	ASD	5.02	2.46	1.86	12.08	
		TD	7.37	3.38	1.62	13.52	$p = 0.11$
		DD	5.44	2.52	2.69	11.83	$p = 0.47$
		Overall	6.09	3.02	1.62	13.52	
	Vocalizations to teachers	ASD	5.54	2.62	0.82	10.82	
		TD	5.53	2.63	0.66	9.43	$p = 0.67$
		DD	4.67	3.27	1.30	13.43	$p = 0.80$
		Overall	4.98	2.83	0.66	13.43	
	Vocal input from peers	ASD	6.08	2.37	2.64	10.99	
		TD	6.20	2.27	2.51	10.29	$p = 0.09$
		DD	5.78	1.84	2.82	8.94	$p = 0.38$
		Overall	6.03	2.16	2.51	10.99	
	Vocal input from teachers	ASD	32.59	15.75	8.66	65.47	
		TD	28.72	10.57	9.05	54.66	$p = 0.50$
		DD	33.26	22.57	8.02	82.03	$p = 0.65$
		Overall	31.24	16.40	8.02	82.03	
inCLASS Domains	Peer engagement	ASD	4.37	1.30	3.00	8.00	
		TD	8.83	2.08	4.25	14.50	**$p < 0.001$**
		DD	5.81	2.74	3.25	12.00	**$p = 0.02$**
		Overall	6.61	2.85	3.00	14.50	
	Teacher engagement	ASD	3.93	1.66	2.00	7.50	
		TD	5.31	2.23	2.25	7.00	**$p = 0.01$**
		DD	4.10	1.52	2.25	10.75	$p = 0.16$
		Overall	4.54	1.96	2.00	10.75	
	Task engagement	ASD	5.48	1.32	3.25	7.50	
		TD	7.84	1.67	6.25	12.50	**$p = 0.01$**
		DD	6.30	1.66	3.75	9.5	$p = 0.24$
		Overall	6.68	1.85	3.25	12.50	
	Negative engagement	ASD	17.77	1.82	14.00	21.00	
		TD	18.98	1.11	16.50	20.75	**$p = 0.01$**
		DD	18.38	1.73	14.25	20.75	$p = 0.14$
		Overall	18.44	1.60	14.00	21.00	
PLS-5 Total and Subscale Standardized Scores	Total	ASD	76.86	16.22	50	102	
		TD	113.24	20.36	78	150	**$p < 0.001$**
		DD	86.68	17.32	50	112	**$p = 0.004$**
		Overall	94.51	24.10	50	150	
	Auditory comprehension	ASD	81.38	17.30	50	106	
		TD	112.31	16.24	88	140	**$p < 0.001$**
		DD	92.18	16.54	50	118	**$p = 0.01$**
		Overall	97.14	21.08	50	140	
	Expressive communication	ASD	74.90	16.17	50	98	
		TD	111.28	22.42	68	150	**$p < 0.001$**
		DD	82.82	18.65	50	116	**$p = 0.01$**
		Overall	91.97	25.28	50	150	

Note: ASD ($N = 21$); DD ($N = 22$); TD ($N = 29$). Vocalizations are mean rate per hour per peer. Children have an average of 11 peers in their class with whom they could vocalize. When we sum children's vocalizations to and from all of their peers on a given observation divided by their time in the classroom, the total rate of vocalizing to peers is 73.8 times per hour, and the total rate of input from peers is 73.0 times per hour. Possible inCLASS Peer and Negative domain scores ranged from 3 to 21 (Negative domain scores are reverse coded); possible inCLASS Teacher and Task domain scores ranged from 2 to 14. PLS-5 scores are standard scores; Total and subscale possible scores range from 50 to 150, with a mean score of 100 and standard deviation of 15. Children with scores below 85 fall 1 SD below the mean. Fourteen children (66.7%) from the ASD group, 11 children (50%) from the DD group, and three children (10.3%) from the TD group had Total scores below 85. On average, the ASD group's total language score on the PLS-5 fell in the 6th percentile; the TD group's total language score fell in the 81st percentile; the DD group's total language score fell in the 18th percentile. Comparison with ASD Group significance was determined using the *lmertest* function, which provides summaries via Satterthwaite's degrees of freedom (Kuznetsova et al., 2017).

TABLE 3 Correlations of in-CLASS domain scores and PLS-5 scores.

	1	2	3	4	5	6
1. Peer engagement domain	–					
2. Teacher engagement domain	0.46***	–				
3. Task engagement domain	0.66***	0.58***	–			
4. Negative engagement domain	0.15	0.23*	0.43***	–		
5. PLS-5 Total language score	0.55***	0.29*	0.49***	0.20	–	
6. PLS-5 Auditory comprehension score	0.53***	0.23†	0.51***	0.20	0.95***	–
7. PLS-5 Expressive communication score	0.54***	0.31**	0.46***	0.16	0.98***	0.87***

Note: All correlations are positive. For the Negative Domain, scores are reverse coded such that higher scores indicate *less* negative engagement in the classroom (more positive engagement). Thus, positive correlations with the Negative Domain indicate higher positive engagement in both domains. Scores for each dimension within domains were summed, resulting in one total score for the four domains. Total domain scores were averaged over observation cycles. Peer and negative domains include three dimensions, with final aggregate scores ranging from 3 to 21. Teacher and task domains include two dimensions, ranging from 2 to 14.
†$p = 0.050$.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

TABLE 4 Predicting the inCLASS Peer domain.

		Fixed effects					
Parameter		**B**	**SE**	***t***	**95% CI**	***p***	***d***
Vocalizations to peers		0.383	0.12	3.20	0.151, 0.612	**0.002**	0.83
Input from peers		−0.484	0.23	−2.10	−0.930, −0.046	**0.04**	−0.55
PLS-5 Total score		−0.016	0.02	−0.97	−0.047, 0.015	0.36	−0.25
Group	ASD versus DD contrast	1.687	0.69	2.44	0.296, 3.008	**0.02**	0.61
	ASD versus TD contrast	4.151	0.73	5.66	2.757, 5.672	**<0.001**	1.40
Class intercept	Random effects						
	Variance			SD			
	0.480			0.69			

Note: ASD is the reference group for both the ASD versus DD and ASD versus TD contrasts.

PLS-5 total score was not significantly related to teacher engagement, $p = 0.45$.

Task domain

We predicted children's task engagement from children's own vocalizations to peers and to teachers, their vocal input from peers and from teachers, group, and PLS-5 total score. Task engagement was only associated with group. The ASD group had significantly lower task domain scores than the TD group, $p = 0.007$, but did not differ from the DD group, $p = 0.24$ (Table 6). Neither vocalizations to and from peers or teachers, nor PLS-5 total score were significantly related to task engagement, $ps > =0.05$.

Negative domain

We predicted children's negative engagement from children's own vocalizations to peers and to teachers, their vocal input from peers and from teachers, group, and PLS-5 total score. Negative engagement was only associated with group. The ASD group had significantly lower negative engagement scores (more negative classroom behaviors) than the TD group, $p = 0.010$, but did not differ from the DD group, $p = 0.14$ (Table 7). Neither vocalizations to and from peers and teacher, nor PLS-5 total score were significantly related to negative engagement, $ps = 0.05$.

DISCUSSION

Engagement is crucial for preschoolers' development. To our knowledge, this is the first study both to utilize inCLASS engagement measures among preschoolers with ASD and to investigate the association of engagement scores with real-time classroom vocalizations. Trained researchers observed children's engagement over a single day for each child, while automated vocalization and location movement were collected once per month per class. We found that children in the ASD group had

TABLE 5 Predicting the inCLASS Teacher domain.

		Fixed effects					
Parameter		***B***	**SE**	***t***	**95% CI**	***p***	***d***
Vocalizations to teachers		0.156	0.07	2.15	0.017, 0.295	**0.036**	0.55
Input from teachers		−0.046	0.04	−1.25	−0.116, 0.025	0.217	−0.32
PLS-5 Total score		−0.009	0.01	−0.77	−0.032, 0.014	0.446	−0.19
Group	ASD versus DD contrast	0.786	0.55	1.42	−0.297, 1.838	0.159	0.35
	ASD versus TD contrast	1.587	0.56	2.88	0.507, 2.657	**0.006**	0.70
Class intercept	Random effects						
	Variance			SD			
	1.183			1.09			

Note: ASD is the reference group for both the ASD versus DD and ASD versus TD contrasts.

TABLE 6 Predicting the inCLASS Task domain.

		Fixed effects					
Parameter		***B***	**SE**	***t***	**95% CI**	***p***	***d***
Vocalizations to peers		0.125	0.12	1.02	−0.108, 0.357	0.313	0.27
Input from peers		−0.052	0.20	−0.27	−0.424, 0.319	0.790	−0.01
Vocalizations to teachers		−0.004	0.10	−0.04	−0.190, 0.182	0.966	0.06
Input from teachers		0.020	0.04	0.50	−0.056, 0.097	0.617	0.13
PLS-5 Total score		0.010	0.01	0.76	−0.015, 0.036	0.450	0.20
Group	ASD versus DD contrast	0.645	0.54	1.18	−0.525, 1.752	0.241	0.31
	ASD versus TD contrast	1.828	0.58	3.14	0.739, 2.915	**0.003**	0.79
Class intercept	Random effects						
	Variance			SD			
	0.120			0.35			

Note: ASD is the reference group for both the ASD versus DD and ASD versus TD contrasts.

lower engagement across all domains than children in the TD group, and lower scores than the DD group in the peer domain. Across all groups, children's own vocalizations to peers were a positive predictor of their engagement with peers. Likewise, children's vocalizations to teachers were a positive predictor of their engagement with teachers. In fact, vocalizations to peers and teachers predicted engagement with these partners above and beyond assessed language abilities. Moreover, vocalization and engagement measures were collected over the course of several months, rather than on the same day, and were nevertheless associated, highlighting the strength of this association. This is the first evidence that children's vocalizations to child and adult partners may support their classroom engagement.

The role of social language in supporting engagement

We found that children's PLS-5 scores were strongly associated with children's vocalizations to peers and the vocalizations they were exposed to from teachers, indicating that language use in the classroom is associated with children's assessed language abilities. Past studies have found correlations between classroom engagement and children's assessed language abilities (Bohlmann & Downer, 2016). However, in the current study, PLS-5 scores were not significantly associated with inCLASS domain scores when classroom vocalizations were also included as predictors. Together these results suggest that children's classroom *social* vocalizations are more proximal predictors/indicators of classroom engagement than assessed language abilities. These findings suggest that interventions designed to increase children's vocalizations to peers and teachers may be a pathway to foster children's engagement with social partners.

Although children's vocalizations to peers and teachers were positively associated with their peer and teacher engagement, respectively, vocal input *from* peers and teachers was not. In fact, there was a *negative* association between peer vocal input and peer engagement. Receiving high levels of peer vocal input may create fewer opportunities for a child to talk. Peer vocal input may detract from peer engagement, especially the

TABLE 7 Predicting the inCLASS Negative domain.

		Fixed effects					
Parameter		***B***	**SE**	***t***	**95% CI**	***p***	***d***
Vocalizations to peers		−0.136	0.11	−1.22	−0.346, 0.075	0.227	−0.32
Input from peers		−0.014	0.18	−0.08	−0.349, 0.322	0.936	−0.02
Vocalizations to teachers		−0.174	0.09	−1.95	−0.342, −0.006	0.056	−0.51
Input from teachers		0.019	0.04	0.52	−0.050, 0.088	0.607	0.13
PLS-5 Total score		0.014	0.01	1.15	−0.009, 0.038	0.253	0.30
Group	ASD versus DD contrast	0.753	0.50	1.51	−0.199, 1.686	0.136	0.38
	ASD versus TD contrast	1.420	0.53	2.66	0.398, 2.416	**0.010**	0.67
Class intercept	Random effects						
	Variance			SD			
	0.135			0.37			

Note: ASD is the reference group for both the ASD versus DD and ASD versus TD contrasts. Positive effects indicate *less* negative engagement in the classroom. For example, a positive effect of vocalizations to peers would indicate that increased levels of vocalizations peers are associated with decreased levels of negative engagement.

communication and assertiveness dimensions in the context of the significant association with children's own vocalizations. The lack of a significant association between teacher input and teacher engagement could be due to variations in the function of different types of teacher language. Teacher vocalizations in one-on-one interactions with children may be associated with increased child engagement with teachers. However, teachers may also vocalize more to children when their engagement with teachers is low and their behavior needs to be regulated. Future work concurrently measuring vocal interactions and engagement may help determine how different types of teacher vocalizations vary with child engagement.

We hypothesized that children's vocal interactions would support their engagement with tasks based on reported associations between language abilities and task engagement (Williford et al., 2013). However, neither children's vocalizations to partners nor vocalizations from social partners were associated with inCLASS task engagement. One aspect of inCLASS task engagement is adjusting one's behavior to meet classroom requirements, including speaking at appropriate times (e.g., when the teacher calls on the child), suggesting that task engagement may require periods of not vocalizing. Additionally, non-interactive vocalizations, such as children's self-talk, either aloud or internal, may support task engagement.

Finally, although others have found an inverse association between language ability and negative behaviors (Chow & Wehby, 2018; Petersen et al., 2013), we did not find an association between vocalizations and negative engagement. Recent studies have found that LENA measures of children's vocalizations are associated with friendship and positive interactions, suggesting that classroom vocal interactions tend to index positive rather than negative behaviors (Altman et al., 2020).

Group differences in classroom engagement

Children in the ASD group displayed lower levels of classroom engagement than children in the TD group in all domains. Children in the ASD group exhibited lower peer engagement than children in the DD group, consistent with literature documenting deficits in peer interaction among children with ASD. The ASD group's depressed peer engagement levels may reflect difficulties with pragmatics (Geurts & Embrechts, 2008), or a tendency to engage in repetitive behaviors or limit speech to a restricted set of topics (Boyd et al., 2007).

Likewise, children in the ASD group may have had lower engagement scores in the teacher, task, and negative domains than children in the TD group because ASD-specific language difficulties can inhibit high-level, collaborative communication. Likewise, higher levels of restricted interests among children with ASD may make it difficult to engage in tasks unrelated to that interest. Conflicts in this area may help explain higher levels of negative engagement among the ASD group compared to the TD group.

Finally, the ASD group may have lower engagement scores than the TD group not because of engagement *difficulties* per se, but because engagement presents differently in children with ASD. For example, teacher engagement on the inCLASS includes smiling at the teacher. Children with ASD may score lower because their facial expressions are more muted or atypical (Macari et al., 2018), regardless of their feelings toward the teacher. Nevertheless, associations between children's vocal interactions and engagement scores, even when accounting for group differences, suggest that the inCLASS captured meaningful variability in engagement even within the ASD group.

Similarities in engagement in children with ASD and DD

Although children in the ASD group had lower peer engagement scores than children in the DD group, their engagement scores did not differ from children in the DD group in other domains. One explanation for the similarly depressed engagement scores in the teacher, task, and negative domains across both the ASD and DD groups is that general developmental delays common to both groups make engagement difficult. For example, children with developmental delays and disabilities often have difficulties with executive function (EF) skills (Blijd-Hoogewys et al., 2014; Geurts et al., 2004). Such delays in EF can make it more difficult for children to stay on task, which could result in lower classroom engagement. In sum, children in the ASD and DD groups may have had low engagement scores in the teacher, negative, and task domains because of general delays in language, social, or cognitive skills.

Limitations and future directions

Findings from this paper could lead to important insights for improving the educational experiences of children with ASD and DD. Many educational interventions for children with ASD focus on increasing child talking through peer and teacher interaction as a means to support language and social development (e.g., LEAP, Boyd et al., 2013). The current findings suggest that interventions that increase child speech to their peers and teachers could, in fact, have cascading effects on classroom engagement. Future research should focus on interventions aimed at adults eliciting vocalizations from children as well as investigating what types of teacher talk (e.g., questions, commands, etc.) during which activities (e.g., small group, individual, whole group, etc.) are associated with children's vocal responses.

One limitation of the current study is that class size varies, with some classes having fewer than 10 children. An additional limitation is the absence of simultaneous measures of vocal interactions and classroom engagement. Although automated measures allowed us to capture who interacts with whom, inCLASS coding does not indicate with whom a target child is interacting. Future research using concurrent measurements of social vocalizations and engagement could reveal whether interacting with certain peers (e.g., children with stronger language abilities) especially supports children's engagement and elucidate whether vocal interactions support in-the-moment engagement. Further, we acknowledge that the TD group enrolled in the classes in the current study may not represent a general community sample of children without developmental disabilities, and thus findings about the TD group may not necessarily generalize to all populations with TD. Finally, the 45-degree (i.e., face-to-face) orientation used as a criterion of social contact in our measure of engagement is based on a priori assumptions about social contact that may reflect neurotypical social norms. Social orientation may differ for different populations, including perhaps, individuals with ASD. Future research is necessary to understand how social contact might differ between neurodivergent and neurotypical populations.

CONCLUSIONS

This study is the first to our knowledge that employs the inCLASS to measure engagement for children with ASD and DD. We utilized automated measures of vocal interaction and an observational measure of engagement to understand the role of real-time vocalizations in classroom engagement among children with ASD in inclusion classrooms. The ASD group had lower classroom engagement scores than the TD group in all domains and were less engaged than the DD group in the peer domain. Regardless of group, however, children's own vocalizations to social partners in the classroom supported their engagement with peers and teachers. Thus, although children with ASD tend to have lower engagement scores than children with TD, their vocal interactions may support positive classroom engagement.

AUTHOR CONTRIBUTIONS

Regina M. Fasano, Lynn K. Perry, Daniel S. Messinger: Conceptualization. Regina M. Fasano, Samantha G. Mitsven, Stephanie A. Custode: Data Collection. Regina M. Fasano, Lynn K. Perry, Debasish Sarker: Data Processing and Analysis. Regina M. Fasano, Lynn K. Perry: Writing (original draft). All authors: Writing (review and editing). Rebecca J. Bulotsky-Shearer was part of the writing for editing and revisions, specifically with regard to language describing the inCLASS measure and procedures in the methods.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

All participating teachers gave their informed consent. Informed consent for participating students was given by their parents. All protocols were approved by the University of Miami IRB.

DATA AVAILABILITY STATEMENT

R code and datasets are available on OSF at https://osf.io/gn6ar/?view_only=fd70d2fcee7d47bda12967921d903350.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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