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## Capturing the quantity and location of adult wh-words in the preschool classroom using a sensing tool system --Manuscript Draft--

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| <b>Abstract:</b>             | <p>The use of wh-words, including wh-questions and wh-clauses, can be linguistically, conceptually, and interactively challenging to preschoolers. Young children develop mastery of wh-words as they formulate and hear these words during daily interactions in contexts such as preschool classrooms. Observational approaches limit researchers' ability to comprehensively capture the classroom conversations, including wh-words. In the current study, we report the results of the first study using the automated speech recognition (ASR) system coupled with location sensors designed to quantify teachers' wh-words in the literacy activity areas of a preschool classroom. We found that the ASR system is a viable solution to automatically quantify the number of adult wh-words used in preschool classrooms. Our findings demonstrated that the most frequently used adult wh-word type was "what." Classroom adults used more wh-words during time point 1 compared to time point 2. Lastly, a child at risk for developmental delays heard more wh-words per minute than a typically developing child. Future research is warranted to further improve the efforts to automatically quantify the use of wh-questions in preschool classrooms.</p> |

### **Highlights**

- Automated Speech Recognition (ASR) is a viable solution to automatically quantify the number of adult wh-words used in preschool classrooms.
- The most frequently used wh-words classroom adults used were "what" and "how," and the least frequently used ones were "who" and "why."
- Both children heard more adult wh-words during time point 1 compared to time point 2.
- A child at risk for developmental delays heard more wh-words per minute than a typically developing child.

# **Capturing the quantity and location of adult wh-words in the preschool classroom using a sensing tool system**

## **Abstract**

The use of wh-words, including wh-questions and wh-clauses, can be linguistically, conceptually, and interactively challenging to preschoolers. Young children develop mastery of wh-words as they formulate and hear these words during daily interactions in contexts such as preschool classrooms. Observational approaches limit researchers' ability to comprehensively capture the classroom conversations, including wh-words. In the current study, we report the results of the first study using the automated speech recognition (ASR) system coupled with location sensors designed to quantify teachers' wh-words in the literacy activity areas of a preschool classroom. We found that the ASR system is a viable solution to automatically quantify the number of adult wh-words used in preschool classrooms. Our findings demonstrated that the most frequently used adult wh-word type was "what." Classroom adults used more wh-words during time point 1 compared to time point 2. Lastly, a child at risk for developmental delays heard more wh-words per minute than a typically developing child. Future research is warranted to further improve the efforts to automatically quantify the use of wh-questions in preschool classrooms.

**Keywords:** Wh-words, Automated Speech Recognition (ASR), Ubisense, Preschool Classrooms

## **Capturing the quantity and location of adult wh-words in the preschool classroom using a sensing tool system**

Wh-words in conversations can be used as wh-questions or wh-clauses (Chomsky, 1977; Koutsoudas, 1968). Wh-questions are questions that include "what", "where," "when," "who", "why", and "how" words, (e.g., *when did you eat?*) and wh-clauses are the statements connected to the subject or object of the main sentence by the above-listed wh-words (e.g., *I am not sure where the truck is*). Wh-words are challenging to preschoolers as the acquisition, production and comprehension of these words require advanced linguistic, conceptual and interactive skills (Kidd, 2011; Rowe et al., 2017). Young children construct the mental representations of linguistic, interactive and conceptual patterns of wh-words in daily conversations by processing the amount, variation and complexity of wh-word input that was experienced up to a certain point in development (Fitz et al., 2011). Hence, young children's successful engagement with wh-words is often a byproduct of the frequency, variation and complexity of wh-words, mostly used by adults.

At the intersection of linguistic, conceptual and interactive complexities, children's acquisition of wh-questions and wh-clauses has been in the interest of linguistics, developmental psychologists, speech language pathologists and educators. For example, since the beginning of the last half century, psycholinguistic researchers have investigated the acquisition of wh-clauses (Limber, 1973), their grammatical complexities (e.g., syntactical or propositional) (Diessel & Tomasello, 2001), and processing and comprehension difficulties experienced by young children using wh-clauses (de Villiers et al., 1979). However, until recently much of this research was conducted in laboratory settings, often priming young children without providing a discourse context (Corrêa, 1995). Research conducted providing a discourse context shows that young

children's acquisition of wh-clauses improves gradually, mainly as a function of experience with language containing wh-clauses (Kidd, 2011). However, there is a limited number of studies investigating the effects of intervention programs promoting the syntactic complexity of adult talk (e.g., wh-clauses) on preschoolers' comprehension and production of wh-clauses (Hadley, Barnes, & Hwang, 2022). The limited emphasis on wh-clauses might be related to technical, methodological and implementation difficulties to record, transcribe and code adult-child interactions in naturalistic contexts such as preschool classrooms.

Despite methodological limitations, since at least the beginning of the 20<sup>th</sup> century, researchers have been investigating elementary and high school teachers' use of wh-questions in classroom dialogues (Stevens, 1912). This work expanded in the 1970s to examine teacher verbal behaviors in preschool classrooms (Cazden, 1970). In line with the findings from the literature examining teachers in primary and secondary classrooms, researchers observed that preschool teachers used a limited number of wh-questions in their daily interactions with preschool children (Girolametto et al., 2000; O'Brien & Bi, 1995). Since then, several researchers have sought strategies and intervention programs to increase the quality of teachers' child-directed speech and the use of wh-questions to provide young children with learning opportunities (Valdez-Menchaca & Whitehurst, 1992; Wasik & Bond, 2001) and to promote children's early inquiry and exploration of their environment. Without an automated method for examining teacher-student dialogues, this research has relied on the high-cost effort of live or video coding by humans.

In this article, we present the results of our efforts to measure speech, time, and location information of educators' and children's use of wh-words using automated systems in literacy areas of a pre-K classroom. Our study is one of the first attempts to investigate the use of an ASR

system coupled with location sensors to quantify teacher wh- words. The long-term goal of this line of research is develop an efficient progress monitoring system for educators that will inform their use of wh-words to augment teachers' child-directed speech.

### **Preschool classroom as a context for child language development**

Key to early development of young children's language skills are their interactions and conversations with others. Early in their development, children use non-extended and colloquial language with caregivers and other family members to share concrete messages in their immediate context (e.g., This is a truck!) (Grøver et al., 2019; Rowe & Snow, 2020). As their language develops, children gradually shape their language in response to the tasks at hand or environmental contexts. Preschool classrooms are often the initial settings where young children engage in linguistically complex and semantically challenging decontextualized, extended academic language. Academic language is a field-specific, decontextualized type of language that requires learners to process high cognitive loads when making predictions, connections, and comparisons, often in response to cognitively challenging wh-questions or wh-clauses (Snow & Uccelli, 2009). While young children enhance their language skills from using language with here-and-now references to there-and-then references, or from more colloquial home language to more academic school language, preschool classrooms may function as hybrid locations where young children can both employ the colloquial home language practices and respond to the demanded and challenging classroom conversations that will pave the way for later academic proficiency (Hadley, Barnes, & Hwang, 2022; Hadley, Barnes, Wiernik, et al., 2022; Uccelli et al., 2019).

### **Quality of adults' child-directed speech and wh-words**

Much of the current literature on adult language practices in early childhood focuses on the quantity of child-directed adult input (Gilkerson et al., 2017; Hart & Risley, 1995). Recent research suggests that the *quality* of an adult's child-directed input plays a significant role in child language outcomes—above and beyond *quantity* (Goldin-Meadow et al., 2014; Rowe et al., 2017). Conceptual (e.g., abstractness), linguistic (e.g., the variety of words and syntax), and interactive (e.g., containing many conversational turns) language features determine the quality of child-directed talk and can increase the likelihood of improved child language outcomes (Rowe & Snow, 2020).

Wh-questions and wh-clauses are types of child-directed language that may promote conceptually, linguistically, and interactively rich language. Wh-words often challenge young children in conversations as they may require integrating several pieces of language knowledge (Chouinard et al., 2007). For example, to master the use of wh-words, young children need to develop linguistic proficiency of auxiliaries in relation to the tense, subject-object agreement, modals (e.g., can and will), verbs such as have and be, and the concept of syntactic embeddedness (Valian & Casey, 2003). According to Chomsky (1977), although wh-clauses are quite different than wh-questions on the surface level in English, they share similar underlying grammatical properties. These properties require young children to connect the displaced fillers (e.g., wh-words) with the gaps (e.g., an empty syntactic position) to comprehend the sentence meaning. Further, wh-questions might be conceptually challenging for young children because they may need to change their perspectives in dialogues, particularly when wh-questions are combined with mental verbs (e.g., think, want, or know) (de Villiers et al., 2011). Also, wh-clauses expand sentences conceptually by adding novel information. Lastly, wh-questions promote engagement and conversational turns for preschoolers because these questions often

require multi-word responses and elicit multi-turn conversations (Rowe et al., 2017); and wh-clauses help specifying referents in the sentences yielding a more unified joint attention in the conversation.

### **Teachers' wh-words in preschool classrooms and their effect on child literacy outcomes**

A growing body of research demonstrates associations between caregivers' use of wh-words and child literacy outcomes. When caregivers pose more wh-questions and use wh-clauses in home and classroom settings, children produce more speech with better syntactic complexity (Huttenlocher et al., 2002; Rowe et al., 2017) and an increased number of unique words (Leech et al., 2013), which results in better vocabulary (Vernon-Feagans et al., 2020), inferencing (Van Kleeck et al., 2006), storytelling and story comprehension skills (Strouse et al., 2013). When teachers use pedagogic questioning coupled with direct instruction, preschoolers demonstrate greater memory for story details, improved psychosomatic reasoning, and enhanced learning skills (Daubert et al., 2020; Yu et al., 2018). In pedagogic questioning, the teacher, as a knowledgeable adult, purposefully poses a question and provides an answer before waiting for the child to respond with the intention of teaching information. This teaching strategy models to children various ways to ask and respond to wh-questions, helps children track the methods teachers use to make inferences and reasonings, and facilitates child engagement with instructional content.

Unfortunately, preschool teachers tend to use a limited number of wh-words in classroom dialogues, and the quantities often differ distinctively across classroom contexts and activities (Hadley, Barnes, Wiernik, et al., 2022; Huttenlocher et al., 2002; Meacham et al., 2014). During social-dramatic play, mealtime, and science activities, preschool teachers tend to use closed-ended questions instead of open-ended questions (Barnes et al., 2020; Meacham et al., 2014).

Shared book-reading is a classroom context for which researchers reported a higher number of wh-questions (Deshmukh et al., 2019). Also, during whole-class book-reading, teachers tend to pose more high-level, open-ended questions (Deshmukh et al., 2019; Hadley, Barnes, Wiernik, et al., 2022). In general, teachers use more academic language with more wh-questions during whole-group activities compared to other group settings such as small-group activities or outdoor playtime (Dickinson & Porche, 2011; Tompkins et al., 2013). Among the wh-questions used in classroom contexts, the least frequently used question types were why- and how-questions (Deshmukh et al., 2019). However, it is precisely these questions that are typically the most challenging because the child's response requires varied vocabulary and multi-word sentences with complex grammatical structures, which are important for preschoolers to practice advanced language and literacy skills.

### **Measuring child-directed speech**

In evaluations of the quantity and quality of teacher questioning practices and their effects on child literacy outcomes, a common approach is direct or delayed observations using limited durations of audio- or video-recorded dialogues across preschool activity areas (Dickinson & Porche, 2011; Perlman et al., 2016). To transcribe and code these recordings, most researchers use hand-coding, Systematic Analysis of Language Transcripts (SALT) (Miller & Iglesias, 2012), or CHAT conventions of the Child Language Data Exchange System (CHILDES) (MacWhinney, 2000). Despite the frequent use of these approaches, recording, transcribing, and coding adult-child conversations is cumbersome and requires considerable time, resources, and effort from research teams. Human coding may also introduce bias, and researchers may struggle with lengthy training procedures and inter-rater reliability issues (Campbell & Ronfeldt, 2018; Irvin et al., 2017).

There has been a growing interest in developing automated sensing tool systems to capture preschool classroom interactions and the precise locations of these locations within the classroom. To this end, researchers have utilized and validated the use of Ubisense (Irvin et al., 2018), Language ENvironment Analysis (LENA), and other automated speech and location/movement sensing systems (Greenwood et al., 2018; Messinger et al., 2022). LENA is an automatic speech processing system that includes a device that can record up to 16 hours of adult-child speech and report the number of adult words spoken, child vocalizations, and conversational turns. LENA devices, considered an industry standard, have been widely used across a number of contexts (e.g., home and classroom), languages (e.g., Chinese and Korean), and disability status of young children (e.g., hearing loss and autism) (Greenwood et al., 2018). However, LENA cannot report counts of specific words.

Ubisense is a digital sensing technology that records second-by-second data on individuals' and/or objects' location and movement within a designated space. Although initially developed for industry, the device has been used by researchers in health and rehabilitation settings to understand movement in individuals with dementia or a traumatic brain injury (Jasiewicz et al., 2011; Kearns et al., 2008). Recently, the tool has been used in the preschool classroom to identify the activity areas children occupy (Irvin et al., 2018; Irvin et al., 2017), their movement patterns (Wallisch et al., 2021), and their proximity to peers (Irvin et al., 2021; Messinger et al., 2020). There are several advantages of using Ubisense compared to video recording or direct observation approaches (Irvin et al., 2018). For one, Ubisense can provide second-by-second child and teacher location and movement information during a full day and track the activity areas they occupy as well as the time they spend in specific locations in the preschool classroom. Additionally, combined with speech processing applied to LENA-recorded

audio, it can help identify specific areas—such as activity areas of the classroom—where literacy learning typically takes place. Eventually, as described by Irvin et al. (2017), combining automated speech and location tracking systems could lead to a more in-depth evaluation of early intervention programs that provide real-time feedback on teacher and child behavior and language.

Other researchers have used sensors (e.g., cameras, tags, recorders, and microphones) to continuously measure classroom interaction and content of these interactions. For example, Messinger et al. (2019) collected one hour of free play location data from 16 five-year-old children using Ubisense and LENA systems. In their calculations, they depicted the interaction locations using illustrative coordinate mapping to determine when children were interacting at greater than chance levels using the radial distribution function. Using automated data collection and advanced data computation approaches (Messinger et al., 2022), this group investigated child-to-child and teacher-to-child reciprocal interaction patterns, interaction patterns of girls and boys, the directionality of classroom interactions with children with autism, and how these interactions predict child language outcomes. Another study to advance the development of automated quantification of child-directed speech was carried out by Gonzalez Villasanti et al. (2020). In their system, they used head-mounted cameras to capture four hours of child-directed speech per child in a preschool classroom of 20 children. Using Amazon's Transcribe (speech-to-text) service and Matlab's text analytic toolbox, they transcribed and coded the number of utterances, number of words, number of different words, mean length of utterance, and type-token ratio (the total number of different words [types] divided by the total number of words [tokens]).

In the current study, we expand our previous work by quantifying the number of wh-words produced in the literacy area of a preschool classroom using data both from Ubisense and ASR systems. **This is the first demonstration of a proof-of-concept approach for capturing the quantity of adult wh-words in the early childhood classroom without the need for live or video coding.** More specifically, our research questions were:

- What rate per minute of adult wh-words were identified by the ASR models in literacy areas across two-time points?
- What was the difference in the frequency (per minute) of adult wh-words identified by the ASR models between a typically developing child and a child at risk for developmental delays in literacy areas?

## **Method**

### **Participants and Setting**

This study uses secondary data from a study comparing speech processing and Ubisense tools to measure global classroom measures of quality (i.e., Early Childhood Environment Rating Scale [ECERS], Infant/Toddler Environment Rating Scale [ITERS]). The data used for this proof-of-concept study were collected from a classroom of a center-based program in a large urban community in a Southern state. Participants (teachers and primary caregivers of children) consented to the use of de-identified data from the pilot for secondary analysis. Before data collection, we instructed teachers to go about their typical morning activities and routines. Participants wore the LENA device and Ubisense tag during daily activities and routines across two days. This classroom measured 7.35 meters (24.11 feet) wide and 7.6 meters (24.15 feet) in length.

When selecting audio files for analysis, we chose audio files from two separate days to avoid overlapping audio files. We selected audio files of a female and a male student, one of whom was a typically developing child and one of whom was at-risk for developmental delays. Both children spent considerable time in literacy areas compared to other children. Eva was a white female, five-year-old child with typical development. Joe was a white male, 5.3-year-old child at risk for developmental delays (i.e., All names are pseudonyms.). All children had mothers with college degrees.

## **Measures**

### ***Demographic Survey***

The childcare director completed a standard demographic form on each child's characteristics (e.g., gender) that was collected at the time of enrollment. This measure also included questions about the families of participating children (e.g., mother's education, child disability status).

### ***Location Data collected using the Ubisense (RTLS)***

The Ubisense real-time location system simultaneously uses ultra-wideband radio transmission to provide second or multi-second (rates of 1-10 Hertz as set by the user) location estimates for multiple individuals in indoor environments (e.g., each Ubisense ID tag contains a unique code which allows for monitoring of multiple subjects simultaneously). The networked sensors and wearable, lightweight transponder tags (see <https://ubisense.com/dimension4/>) relay data to a networked PC running the Ubisense Location Engine, creating a digital map of tag movements within the local environment. The system's precision ranges from 15-30 cm (6 to 12 inches), depending upon local environmental conditions and the number of installed sensors. The reliability and accuracy of the tool have shown to be acceptable for use in industrial (e.g., Phebey

et al., 2010) and health-related settings (e.g., Kearns et al., 2016) and, as noted earlier, the early childhood classroom (Irvin, Crutchfield, Greenwood, Kearns, & Buzhardt, 2017).

### ***Data extraction, cleaning & analysis***

The main steps for setting up the Ubisense system include: (a) accurately locating sensors in the four corners of the space to provide maximum movement assessment coverage, (b) networking the sensors via a Category 5 cord to a laptop computer, (c) minimizing electronic interference caused by other devices (i.e., Wi-Fi routers), (d) establishing the dimensions of the classroom based on laser distance measurements, and (e) precisely calibrating the real-time location system sensors to their surveyed locations based on laser distance measurements. Following set-up, we used the Geometry feature of Ubisense to create boundaries around individual literacy areas in the classroom which subsequently helped identify when children wearing a transponder tag were in these literacy areas, included book and listening areas. With Ubisense set up and calibrated, the scanning rate was set to 1 Hertz to increase the manageability of the large amount of data produced by the real-time location system. The location data of children wearing transponder tags were then extracted into an Excel file from the system. Durations of each "enter time" and "exit time" for literacy areas were included in the analysis if they had a duration of  $\geq 20$  seconds.

In order to prepare data for analysis, the location and speech data was combined by aligning the recording times for each file from both the LENA and Ubisense systems. The alignment included a conversion of time units and time zones. Once the alignment of time was ensured, a MATLAB routine was used to extract speech data into a spreadsheet to match the timing of the location information.

### ***Acoustic and language models***

A customized ASR solution was developed specifically for identifying wh-words in adult-classroom speech. Seven hours and 6 minutes of adult speech from the dataset described above was used to train the ASR model during the development phase, and an additional 2 hours and 16 minutes of adult speech was used as supplemental data intended to *improve* the ASR model. This represents the system baseline model for ASR for both child and adult speech. Finally, for open system evaluation, the current ASR models were tested using a total of 58 minutes and 29 seconds of audio files captured by Eva's recorder and 66 minutes and 26 seconds of audio files captured by Joe's recorder when they were in the literacy areas. Adult sentences included a "what," "where," "who," "when," "why," and "how," were considered wh-words.

The ASR approach employed a state-of-the-art neural network-based acoustic model. It was expected that this structure would allow the team to further explore improvements and test for the End-to-End transformer model (e.g., with an optional language model component). The approach can be defined as extracting features speech, developing statistics from these features, and comparing these to a neural network to recognize text content from the audio, as demonstrated in Figure 1.

Figure 1.

#### *Block Diagram for End-to-End ASR model*

Acoustic Models (AMs) use audio input to calculate the probability that a phoneme has been uttered. Our End-to-End ASR system includes Sequence-to-Sequence (S2S) models to predict the temporal sequence of phonemes. Within the S2S models, we chose to use Transformers and the Factorized Time Delay Neural Network (TDNN-F), as they outperform methods such as Recurrent Neural Networks (RNN) on several public datasets (Potamianos & Narayanan, 2003). In other words, transformers were used to predict data patterns and contexts

of phenomes such that we could predict the use of wh-words in literacy centers. Language Models (LMs) are available but optional in End-to-End ASR models and they are being used with an RNN Architecture trained on text transcripts of the training data.

### **Performance of the ASR Models**

We evaluated the performance of the ASR models by calculating the F1 score. The F1 score is a harmonic sum of model precision (i.e., how well the ASR models' predictions actually predict wh-word types) and model recall (i.e., how well it recalled wh-word types and avoided mislabeling them). The maximum value of F1 is one, and the lowest value is zero. A zero value for F occurs when either precision or recall (or both) is zero. The ASR models' performance of predicting wh-words correctly in the current study averaged .75 (range= 0.5 – 1).

### **Results**

*What rate per minute of adult wh-words were identified by the ASR models in literacy areas across two time points?* We calculated the number of wh-words used by classroom adults as the rate per minute. More specifically, we divided the total number of wh-words by the total number of minutes spent in the literacy areas and tabulated the results across the two time points of two children: Joe and Eva. Joe wore the audio recorder from 9:40 am to 3:48 pm during time point one. He spent 29 minutes 28 seconds in the literacy area during this time and heard 2.00 wh-words per minute. During time point two, between 9:23 am to 12:09 pm, Joe was in the literacy area for 31 minutes and 47 seconds, and he heard 2.83 wh-words per minute. Across two time points, Joe's most frequently heard wh-word was "what" (time point one: 0.68 per minute, and time point two: 1.79 per minute), followed by "how" (time point one: 0.71 per minute, and time point two: 0.47 per minute.) Joe's least frequently heard wh-words were "who" (time point one: 0.03 per minute, and time point two: 0.09 per minute) and "why" (time point one: 0.10 per minute, and time point two: 0.06 per minute.) Also, "where" was used 0.27 per minute on time

point one and 0.22 per minute on time point two, and the wh-word "when" was used 0.20 per minute on time point one and 0.19 on time point two.

Eva spent 37 minutes and 34 seconds in the literacy areas during time point one from 10:38 am to 11:32 am, and, during this time period, she heard 2.26 wh-words per minute. During time point two, from 10:55 am to 12:26 pm, Eva spent 32 minutes and 38 seconds in the literacy area and heard 2.82 wh-words per minute. Similar to Joe's recordings, Eva's most frequently heard wh-word for both time points was "what" (time point one: 1.17 per minute, and time point two: 1.87 per minute), and the second most frequently heard word for both time points was "how" (time point one: 0.53 per minute, and time point two: 0.49 per minute). The least frequently heard wh-words by Eva for both time points were "who" (time point one: 0.03 per minute, and time point two: 0.09 per minute) and "why" (time point one: 0.11 per minute, and time point two: 0 per minute). "Where" was heard by Eva 0.19 times per minute on time point one and 0.21 times per minute on time point two, and, finally, Eva heard "when" 0.24 times per minute on time point one and 0.15 times per minute on time point two.

Additionally, we categorized the data based on the time Joe and Eva spent in two literacy areas: cozy book and listening. During time point one, Joe and Eva did not spend any time in the cozy book area. During the second time point, Joe stayed 4 minutes 46 seconds, and Eva stayed 2 minutes and 46 seconds in the cozy book area. However, there was no wh-words during the time spent in the cozy book area for either child. All wh-words produced by classroom adults took place when Joe and Eva were in the listening area.

***What was the difference in the frequency (per minute) of adult wh-words identified by the ASR models between a typically developing child and a child at risk for developmental delays in literacy areas?*** We selected two time-points to compare the frequency of adult speech

heard by a typically developing and a child at risk for developmental delays. These time points did not include overlapping speech but included considerable time spent in the literacy area. Hence, we tabulated data from Eva's time point one and Joe's time point two. Classroom adults used 59 wh-words during the 29 minutes and 28 seconds that Eva, a typically developing female child, was in the literacy center. When Joe, who is at risk for developmental delays, was in the literacy area during the 32 minutes and 38 seconds, he heard 92 wh-words used by the classroom adults. Calculating the rate per minute, Eva heard 2.00 wh-words per minute, and Joe heard 2.82 wh-words. As indicated in Table 1, we further tabulated the results per day and calculated the rate per minute for each type of wh-word using the frequencies reported by the ASR model. The most frequently used adult wh-word heard by Eva was "how" (0.71 per minute) and by Joe was "what" (1.87 per minute). The second most frequently heard adult wh-word by Eva was "what" (0.65 per minute), and by Joe was "how" (0.49 per minute). The third most frequently heard wh-word by Eva (0.31 per minute) and by Joe (0.22 per minute) was the word "where." "When" was the fourth most frequently heard wh-word by Eva (0.20 per minute) and by Joe (0.15 per minute). "Why" was the fifth most frequently heard wh-word by Eva (0.1 per minute), and "who" was the fifth most frequently heard wh-word by Joe (0.09 per minute). The least frequently heard wh-word by Eva was "who" (0.03 per minute), and by Joe was "why" - it was not used at all during the audio file.

## **Discussion**

Current approaches to document language quantity and quality in preschool classrooms almost exclusively rely on resource-intensive direct or delayed observational or transcription approaches. In the current proof of concept study, we modeled the use of commercially available devices to capture location and speech (i.e., Ubisense and LENA recorder) to develop an ASR

system for use in preschool classroom settings. We illustrated an examination of automatically quantifying wh-words used by classroom adults while Eva, a typically developing child, and Joe, a child at risk for developmental delays, were in the literacy area during two-time points. Recent advancements in audio and location systems have enabled researchers to precisely measure where, when and with whom the social interactions and dialogues occur in preschool classroom settings (Gonzalez Villasanti et al., 2020; Irvin et al., 2021; Messinger et al., 2022). Our approach adds to the existing work by expanding the use of continuous data to broaden our understanding of "what is being said" and where in preschool classrooms – and is the first step toward automatically capturing quality of adult talk experienced by children in the pre-k classroom.

Our results indicated that the ASR system identified that, when Joe and Eva were in the literacy area, classroom adults used more wh-words per minute at time point one compared to time point two. Across the wh-word types, "*what*" and "*who*" words were used more frequently during time point two compared to time point one. Meanwhile, "*how*," "*when*," "*who*," and "*why*" words were used more frequently during time point one than during point two. Also, the ASR results from Eva's audio files showed that the "*where*" word was used more frequently during time point two than in time point one, whereas results from Joe's audio files included more "*where*" words per minute in time point one compared to time point two. Considering that the ASR models' performance of predicting wh-words correctly averaged 75%, the ASR model developed for the current study is a viable solution to automatically quantify the wh-words heard by a specific child in a preschool activity area.

Our findings are somewhat incongruent with previous reports on data collected by humans, indicating that "why" questions are among the least frequently used question types in

classrooms (Deshmukh et al., 2019). Unlike the results of previous studies (Zucker et al., 2010), our results showed that "how" words constituted 36% of wh-words from Eva's audio files and 17% of wh-words from Joe's audio files. Note that our results included the frequencies of both wh-questions and wh-clauses. The literature on quantifying preschool teachers' use of wh-questions has mainly focused on the number and proportion of questions across classroom activities and contexts (Hadley, Barnes, Wiernik, et al., 2022), whether or not the questions are open versus closed-ended, or low-demand versus high-demand (Barnes et al., 2020; Meacham et al., 2014). However, to our knowledge, no study has examined teachers' use of wh-words (including both questions and clauses) in their daily classroom interactions. Our findings on the frequency of wh-words, including wh-clauses and wh-questions, used by preschool teachers expands current literature to further understand how preschool teachers use wh-words in daily classroom conversations.

Our second objective was to compare the frequency of wh-words heard by Eva, a typically developing child, to Joe, a child at risk for developmental delays. To eliminate the possibility of including overlapping speech, we chose the audio files from two different data points and calculated the rate by the minute. Our results showed that Joe heard 2.82 wh-words per minute, and Eva heard 2.00 wh-words per minute. Several contextual factors (e.g., classroom schedules at different time points) and the disability status of children may contribute to why Joe heard wh-words more frequently than Eva. We know that language profiles of children with various disabilities (e.g., autism, Down's syndrome, attention deficit disorder, or specific language impairment) demonstrate more differences than similarities (Goodwin et al., 2015; Joffe & Varlokosta, 2007). The use of wh-words is particularly difficult for them as they are required to combine multiple language features (e.g., linguistic, conceptual, and interactive) to

comprehend or use wh-words. For example, Goodwin et al. (2015) found that preschool children with autism experience difficulties using auxiliary verbs in wh-questions while typically developing children's use of wh-questions are linked to their caregiver's use of wh-questions. Another investigation (Joffe & Varlokosta, 2007) compared the use of wh-questions among children with Down's syndrome (DS), Williams syndrome (WS), and typically developing children. This investigation showed that children with DS and WS experienced significant difficulties producing wh-questions because of poor syntactic abilities. Our approach to quantifying the number and types of wh-questions might be particularly useful in the intervention programs/approaches designed to promote the use of wh-question types with children with (at-risk for) developmental delays; this would allow, preschool teachers could to monitor the number and types of wh-words used or heard by children at risk for developmental delays across various classroom areas without human transcription or coders, which up to this point has been the only option (Sanders et al., 2016).

### **Limitations**

Our study is transformative in that it represents the first time a quality indicator, wh-words of classroom adult speech, has been automatically measured in a preschool classroom. However, there are limitations in analyzing naturalistic audio streams using ASR models. For example, in spontaneous daily speech, there were wh-questions not only at the beginning but also at other parts of the sentences. Further, although the ASR model could classify if the speech is from adults versus children, due to limitations in our ASR approach, we did not identify wh-words by individual classroom adults. Future research that combines speaker diarization with our ASR approach could shed light on individual classroom adult speakers. Also, since this is a

proof-of-concept study with a small sample size, the findings are meant to be exploratory and are not representative of preschool classrooms in general or specific populations of children.

### **Future Directions**

Despite these promising findings, much more work is needed to make this combination of ASR and location technologies feasible for use in research and practice. Demonstrating that an ASR engine can quantify wh-words automatically within the context of a busy and often noisy preschool classroom leads to the possibility of counting other targeted words. For example, words could be identified for counting based on the curriculum used by a preschool or even a specific section of the curriculum to help inform how much focus is being devoted to a targeted content area.

#### ***Identifying wh-questions from wh-clauses***

A future direction is to refine our ASR model to identify wh-questions and wh-clauses in order to distinguish between and measuring both wh-clauses and wh-questions. Both wh-words are indicators of the complexity of adult speech and, like wh-questions, wh-clauses are challenging for preschoolers. For example, to understand and use wh-words in sentences, preschool children require integrating a number of linguistic and semantic rules such as auxiliaries, subject-object agreement, the position and animacy of antecedents, filler-gap dependency and semantic shifts in the meaning when wh-words are used. Capturing and identifying wh-clauses and wh-questions would help preschool teachers to monitor their use of these words and implement intervention programs to boost their use of both wh-clauses and wh-questions in meaningful classroom contexts.

#### ***Wh-words in other preschool areas***

In the current study, we investigated the use of wh-words in the literacy areas of a preschool classroom. A future direction for this line of research might be examining the use of wh-words in other classroom activity areas, such as the science area. Responding to wh-questions, preschool children use verbal reasoning, predictions, and recalling skills (Deshmukh et al., 2019). These skills are important for promoting fundamental scientific thinking skills in the science area of preschool classrooms (Hamel et al., 2021). Hence, examining the use of wh-questions in the science area could help broaden our understanding of the quantity and quality of language children are prompted to use in science areas of preschool classrooms.

### ***Wh-words in the interactions of preschool children***

Preschool children spend more than half of their school day in free-choice time, outdoor time, and mealtime (Fuligni et al., 2004). During these times, young children are more likely to interact with their peers than with their classroom teachers. In these interactions, young children incorporate their peers' opinions through conversations with wh-words when making joint decisions (Köymen & Lieven, 2017). However, although our current investigation did not include the wh-words used by children, the current literature reports the ASR results for children are significantly worse than the results for adult speech (Potamianos & Narayanan, 2003), given variability in children's speech rate, the use of pitch, and the frequency of using grammatically correct sentence structures. That said, work is underway to improve our ability to capture words, such as WH-words, in children's speech (Tao et al., 2022), and we anticipate being able to capture wh-words in children's speech which is indicative of child oral language skills.

### ***Wh-words in experimental designs***

The use of ASR and Ubisense technology to collect data and quantify wh-words could broaden the array of research that requires continuous observations of classroom interactions and

movements in experimental studies. Early intervention programs developed to enrich teacher language during daily classroom conversations constitute a large portion of studies aiming to improve young children's language outcomes. For example, *Literacy 3D* (Greenwood et al., 2021) or a *Classwide extension of the Story Friends curriculum* (Seven et al., 2020) are intervention programs that enrich pre-kindergarten teachers' literacy-related interactions through training, professional development, and ongoing coaching. Researchers have conducted lengthy continuous classroom observations to evaluate the efficacy of these intervention programs on daily classroom interactions. Using our speech-location measurement systems, evaluating the impact of these intervention programs on daily classroom conversations might be automated and efforts to train observers could be reduced.

## **Conclusion**

We have described the use of automated speech and location tracking systems to quantify the number of wh-words in a naturalistic preschool classroom environment: literacy areas. Our findings replicated previous research indicating that teachers use more "what" words and fewer "why" words during classroom interactions. This was the first step toward automatically measuring a quality indicator of classroom adults' speech. With this automated method, a tool that provides teachers with feedback on their use of wh-words can help move beyond live or video human coding. Future investigations may use this tool to map the frequencies and patterns of using wh-words in classroom conversations with larger datasets.

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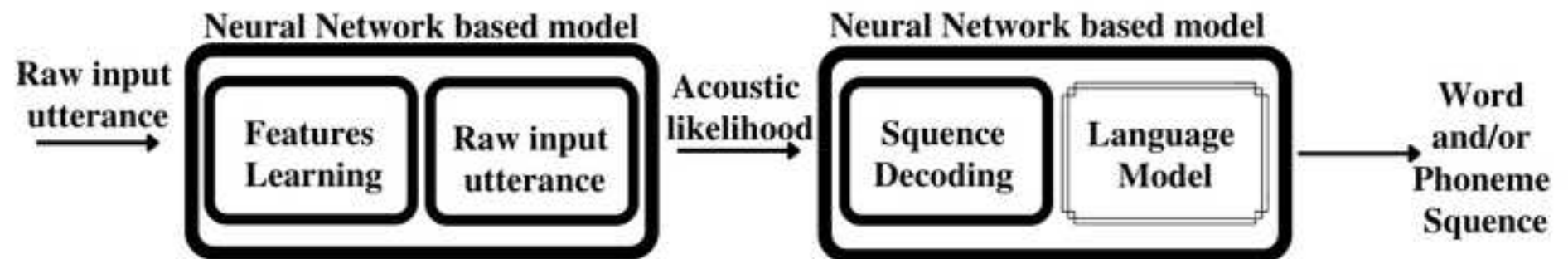


Table 1.

*Rate of adult wh-words and wh-word types per minute heard by each child and across time points*

|              | What | Where | When | Who  | How  | Why  | Total |
|--------------|------|-------|------|------|------|------|-------|
| Eva          |      |       |      |      |      |      |       |
| Time point 1 | 0.68 | 0.27  | 0.20 | 0.03 | 0.72 | 0.10 | 2.00  |
| Time point 2 | 1.79 | 0.22  | 0.19 | 0.09 | 0.48 | 0.06 | 2.83  |
| Joe          |      |       |      |      |      |      |       |
| Time point 1 | 1.18 | 0.19  | 0.24 | 0.03 | 0.53 | 0.11 | 2.26  |
| Time point 2 | 1.88 | 0.21  | 0.15 | 0.09 | 0.49 | 0    | 2.82  |