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Research paper

Promoting rich discussions in mathematics classrooms: Using personalized, automated feedback to support reflection and instructional change

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HIGHLIGHTS

- The [blinded for review] application provides automated, personalized feedback on teachers' talk moves.
- Teachers generally found the application simple to use, valuable, and moderately accurate.
- Teachers primarily attended to the quantity of their talk, rather than the quality.
- Teachers increased the frequency of their talk moves over a short period of time.
- Automated tools hold promise for supporting reflective noticing and instructional change.

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ABSTRACT

Talk moves can promote conversations that enable students' equitable participation in a rigorous learning environment. This study examined teachers' perceptions of the usability, utility, and accuracy of a web-based application that provides automated feedback on their use of talk moves. Pilot data from 21 teachers indicates mainly positive perceptions, with a trend of increasing talk moves despite variability in teachers' use of the application. A case study of the most frequent user illustrates an ideal use case. Overall, these findings point to the promise of automated tools to support meaningful professional learning opportunities for teachers, leading to instructional change.

1. Introduction

1.1. The importance of rich discussions in mathematics classrooms

There is widespread agreement that students' understanding should be constructed through the process of interacting within a learning community, and that discussions should be a prominent and normative feature within K-12 classrooms (Brenner, 1994; Franke et al., 2015; Sherin, 2002). The Common Core State Standards for Mathematical Practice, which have been adopted by the majority of states in the US, emphasize verbal communication as a means of promoting argumentation and reasoning, and engaging students in the intellectual work of mathematics by vocalizing their own thinking and making sense of other's ideas (National Governors Association, 2010). Mathematically proficient students are expected to communicate and justify their conclusions, and respond to the arguments and reasoning of others. Developing fluency with these practices requires teachers to engage their

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students in what has been labeled "dialogic pedagogy," where students' ideas, reasoning, and multiple points of view play a central role and become conversational norms (Hofmann & Ruthven, 2018; Kim & Wilkinson, 2019).

In an effort to delineate specific dialogic practices that teachers can use to orchestrate the types of discussions encouraged by the standards, researchers developed an approach to classroom discourse called "accountable talk" (O'Connor et al., 2015). At the heart of accountable talk is the notion that teachers should organize discussions that promote students' equitable participation in a rigorous learning environment where their thinking is made explicit and publicly available. There is a strong theoretical and empirical basis for encouraging students' active participation in inquiry-based and socially constructed classroom environments (Saxe, Gearhart et al., 2002; Vygotsky, 1978; Webb et al., 2008; Yackel & Cobb, 1996). By scaffolding conversations in which students play a central and purposeful role, teachers help to socialize children to a particular academic enterprise in which they are legitimate and essential participants (O'Connor & Michaels, 1996). As Resnick et al. (2010) explain:

> Discussion-based classroom practices that combine rigorous tasks with carefully orchestrated, teacher-led discussion can support the growth of both disciplinary knowledge and the capacity to engage in reasoned discussion. Evidence is now accumulating that these ways of learning produce broad capacities that we label "growing the mind." (pg. 173).

1.2. Accountable talk moves that promote rich discussions

Over the past decade, a robust literature on accountable talk, and in particular the talk moves that promote rich discussions, has emerged. By using talk moves, teachers place the "intellectual heavy lifting" and balance of talk toward students and help ensure that classroom conversations will be purposeful, coherent, and productive (Michaels et al., 2010). Boston (2012) explains that accountable talk moves support discourse to go beyond the ubiquitous linguistic sequence in which the teacher initiates a question, a student briefly responds, and the teacher evaluates their response (IRE; Mehan, 1979); namely, by replacing the act of evaluating with discourse practices that support a collaborative understanding and that build on or extend students' mathematical ideas (Michaels & O'Connor, 2015). In this way, talk moves enable dialogue shifts from teacher-directed recitation to "true discussions" in which knowledge is informally shared and constructed rather than transmitted (Cazden, 2003).

Talk moves can be used by both teachers and learners to construct conversations in which students share their thinking, actively consider the ideas of others, and engage in sustained reasoning. Talk moves are essentially linguistic tools or actions that are intended to elicit a response by another member of the class (O'Connor & Michaels, 2019). Teacher talk moves include questions that press students to justify their thinking or to consider the contributions made by other students. They also include moves to monitor and promote equity by inviting a variety of talk formats (e.g., think-pair-share), positioning students as capable mathematics learners, and scaffolding language use for English learners (Hand, 2012; Moschkovich, 2012).

Accountable talk moves have been incorporated into a variety of frameworks intended for use by both researchers and practitioners, including the Accountable Talk Sourcebook (Michaels et al., 2010) which offers definitions, categorizations and examples of talk moves, NCTM's Principles to Action Toolkit (Candela et al., 2020) which includes videos and other materials to showcase talk moves in actual mathematics lessons, and the Instructional Quality Assessment (Boston, 2012; Boston & Wolf, 2006) which is a widely used classroom observation measure (Wilhelm & Kim, 2015). These types of frameworks and materials signal to teachers, instructional leaders, and professional development providers that using talk moves is a highly valued instructional practice (Boston, 2012) and an important topic to foreground in both collaborative professional learning experiences and in targeted self-reflection (Boston & Candela, 2018).

1.3. Talk moves promote learning and equity

A large body of research over the past several decades provides strong evidence that participating in rich classroom discussions has positive links to student learning (e.g., Resnick et al., 2010; Walshaw & Anthony, 2008; Webb et al., 2019). In particular, several studies have documented that using accountable talk moves in mathematics classes is associated with increased student achievement. For example, Project Challenge (Chapin et al., 2009; Chapin & O'Connor, 2012) followed cohorts of elementary schoolers longitudinally across multiple years and documented dramatic changes in their classroom discussions (including consistent use of accountable talk moves) along with significant increases in their mathematics achievement. Further, the researchers documented a transfer to English language arts, as students' achievement rose significantly in that area even though their mathematics classrooms were the target of the intervention.

A more recent experimental study provides more definitive evidence of a relationship between the use of talk moves and students' learning gains. O'Connor et al. (2015) examined students' mathematics achievement during short units when they were taught by a teacher who intentionally incorporated talk moves compared to units taught by the same teacher using primarily IRE discourse (teacher Initiates, student Responds, teacher Evaluates). When the teacher used talk moves, she implemented strategies to encourage discussions such as having students "turn and talk" to their neighbor, asking students to provide the reasoning behind their ideas, prompting students to indicate whether they agreed or disagreed with other students, and revoicing students' contributions. The comparison lessons involved "direct instruction" methods with very few talk moves. The researchers found significant learning benefits for students taking part in the units with talk moves, speculating that discourse-intensive classrooms may have both short and long term effects on students' motivation, self-efficacy, cognition, and linguistic ability (O'Connor & Michaels, 2019).

In addition to improving student learning outcomes, using talk moves can be understood as an equity-focused endeavor (O'Connor & Michaels, 2019). Michaels et al. (2008) argued that accountable talk looks "striking similar to the norms of discourse called for in theories of deliberative democracy" (pg. 285). Specifically, accountable talk supports a classroom community with the underlying expectation that all students have equal access to participation, subject matter content, and developing appropriate habits of mind (Michaels et al., 2010). In a discursive classroom, the environment is constructed such that every student is afforded the potential to contribute to ongoing rationale discourse, and that potential is continually nurtured and socialized (Bielaczyc et al., 2013; Hufferd-Ackles et al., 2004; Resnick et al., 2010).

Forming and sustaining such a learning environment can be particularly beneficial for girls and students from home backgrounds where risk-taking and modeling of similar talk patterns may be less common, enculturating them into the norms of democratic discourse that can later be realized in wider civic spheres (Lampert et al., 1996; Michaels et al., 2008). Shifting away from

traditional discourse patterns towards accountable talk makes space for students' contributions, especially for English Language Learners (ELLs), through a focus on communicating mathematically and presenting arguments rather than acquiring vocabulary and other low-level linguistic skills (Khisty & Chval, 2002; Moschkovich, 1999; 2013). Furthermore, increased participation by ELLs and students from nondominant groups can foster dispositions in which attention is given to competencies and resources rather than deficits and obstacles (Hand, 2012; Moschkovich, 2002).

1.4. Professional development to support teachers' use of accountable talk

There is little debate that the intentional use of instructional strategies to facilitate rich classroom discussions is an essential component of high quality or "ambitious" mathematics teaching (Lampert et al., 2010; Stein et al., 2008). In fact, Correnti et al. (2015) argued that orchestrating productive conversations is an "important and universally recognized dimension of teaching" (pg. 306). Yet, many teachers are ill-prepared to routinely create and sustain mathematically-rich and productive discourse in their classrooms, particularly those serving high-poverty communities (Banilower et al., 2018; Boston, 2012; Malzahn et al., 2020). These instructional skills are not easily developed and require extensive practice, coupled with timely feedback to support reflection and inform adjustments in instruction (Herbel-Eisenmann et al., 2013; Nathan & Knuth, 2003; Resnick, Asterhan, & Clarke, 2018, b). There remains a strong need for impactful and scalable professional learning tools, materials, and approaches to support mathematics teachers in their improvement efforts (Heck et al., 2019).

The specific discursive techniques suggested by accountable talk theory serve as well-defined, research-based practices for teachers striving to facilitate discourse-rich classroom environments. A number of professional development models have emerged to support preservice and inservice teachers in their efforts to learn about and use talk moves, in a variety of subject areas (e.g. Heyd-Metzuyanim et al., 2019; Hofmann & Ruthven, 2018; Kershner et al., 2020). For example, inspired by Project Challenge's success at the elementary school level (Chapin & O'Connor, 2012), Herbel-Eisenmann et al. (2013; 2015; 2017) designed professional development materials for secondary school mathematics teachers with talk moves as the centerpiece. These materials include artifacts of practice – such as classroom video, mathematics tasks, lesson plans, and student work – organized into a set of modules, "constellations of activities" and a capstone project that are intended to be used as part of a year-long teacher study group led by a facilitator. The PD encourages teachers to notice and discuss particular talk moves, and consider how they foster students' opportunities to communicate and learn. To date there has been relatively little published about the impact of these materials, however an exploratory case study described one participating teacher's efforts to become more purposeful in her classroom discourse practices (Cavanna et al., 2015) and another study reported that teachers' conversations during PD increased in their focus on developing facility with the mathematics register (Herbel-Eisenmann et al., 2015).

Another promising PD effort aimed at supporting teachers' use of accountable talk moves is the Classroom Discourse Analyzer (CDA), a web-based platform that provides discourse information to teachers based on their classroom video-recordings (Chen, 2020; Chen et al., 2015, 2020). The CDA enables teachers to visualize their use of specific discourse moves such as turns, speakers, amount of talk within a turn, and classification of the talk within a turn. Although some of the discourse information is automatically extracted, the higher-inference classifications must be carried out manually by trained human coders. Researchers conducted a randomized controlled trial that enrolled secondary mathematics teachers to study the efficacy of a year-long PD program using the CDA. Teachers in both the treatment and control groups participated in workshops in which they learned about accountable talk strategies, however those in the treatment group also received personalized feedback from the CDA. Treatment group teachers experienced significant increases in their use of certain talk moves along with changes in their beliefs and self-efficacy related to classroom talk that were sustained over time (Chen, 2020). Moreover, students of the treatment teachers significantly increased their mathematics achievement relative to the control group (Chen et al., 2020).

1.5. The promise of automating feedback on classroom discourse

Currently, most approaches to providing teachers with detailed feedback about their discourse strategies require highly trained observers to hand code transcripts of classroom recordings using qualitative research methods to identify talk moves (e.g., Correnti et al., 2015; Wolf et al., 2005) and/or one-on-one expert coaching (e.g., Robertson et al., 2014). These approaches are time-consuming and expensive, rely on considerable human expertise, and simply do not scale to large numbers of teachers (Ogan, 2019). Tools capable of automating this complex coding and analysis process would enable more teachers to access reliable, personalized feedback on critical aspects of their classroom talk (Song et al., 2020).

A number of research teams have made considerable progress in developing automated "intelligent agents" that are trained to emulate the role of the teacher and prompt students using designated aspects of accountable talk, such as revoicing and asking students to agree/disagree with another student. These intelligent agents typically act as facilitators or tutors during small group, text-based, online settings, taking part in and helping to focus the discussion at opportune moments (e.g. Adamson et al., 2013; Hmelo-Silver, 2013; Tegos et al., 2015). The fact that automated agents can be successfully programmed to learn and appropriately implement talk moves has important technological implications for automated approaches to supporting teacher learning of accountable talk practices. For example, the processes involved in the automated detection of talk move labels, such as annotating large numbers of examples based on well-articulated definitions to serve as training data, has proven a surmountable task. Applying these same processes to the detection of talk moves in actual classroom speech in order to provide feedback to teachers about their discourse practices is a realistic next-step (Sionti et al., 2011).

Recent research has shown that it is possible to fully automate the generation of information regarding teachers' discourse patterns by building on advances in automatic speech recognition, natural language processing, and deep learning (e.g., Demszky et al., 2021, pp. 21–483; Song et al., 2020). For example, working from recordings of speech from real classroom environments, D'Mello's research team developed models to reliably detect discursive features such as instructional talk, authentic teacher questions, elaborated evaluation, and uptake (Jensen et al., 2020; Kelly et al., 2018). Furthermore, Wang et al. (2013) highlight the promise of providing teachers with automated feedback on their discourse practices. They found that teachers who received automated feedback regarding the amount of teacher talk relative to student talk in their mathematics lessons significantly increased the quantity of student talk, suggesting that even basic information about teachers' discursive patterns, displayed in a readily accessible format, can produce changes in the desired directions.

This article presents pilot data on teachers' experiences with an online application that provides automated feedback on their

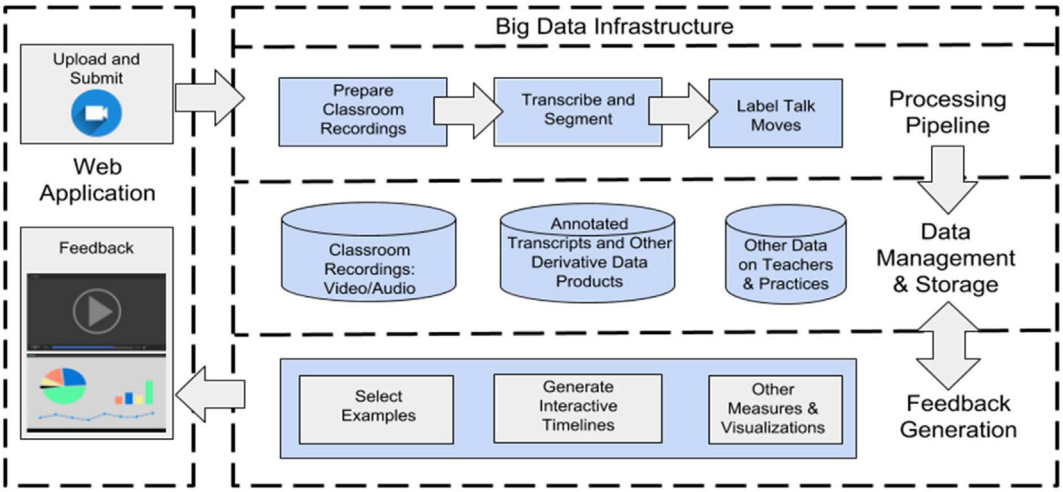

Fig. 1. The system architecture of the TalkMoves pipeline.

classroom discourse patterns, including the prevalence of talk moves. The study explores teachers' perceptions of the application's usability, utility, and accuracy, as well as the frequency with which they used talk moves over time. Results from the full group of pilot teachers suggest "typical" patterns as well as variation in their perceptions and impact, while a case study of the teacher who most frequently used the application paints a picture of an "ideal" use case. The next section describes this application, including its architecture and interface.

2. The TalkMoves application

The TalkMoves application (Suresh, 2019; 2021) was designed to automate and scale up the process of detecting talk moves, along with other classroom discourse practices, enabling teachers to receive immediate and accessible information about their mathematics lessons.[1] The application consists of three interrelated components: a cloud-based big data infrastructure for managing and processing classroom recordings, deep learning models that reliably detect the use of talk moves, and an interface that provides teachers with personalized feedback on their use of discussion strategies during individual teaching episodes and longitudinally over multiple episodes.

The system architecture of the TalkMoves pipeline is summarized in Fig. 1. Teachers generate and upload classroom recordings, which can consist of entire lessons or portions of lessons. The TalkMoves system collects the files, processing one video at a time through the pipeline. The audio is converted into a written transcript, which is then broken into sentences. Each sentence is designated as originating from the teacher or a student. Deep learning models determine whether there is a talk move corresponding to each teacher sentence. Additional analytics are applied to calculate other discursive features, such how much talk came from the teacher versus the students. Finally, the system generates feedback based on output from the models, which is visually displayed on personalized dashboard using a web interface. The entire system is fully automated and requires no human processing beyond the initial uploading of classroom recordings.

2.1. Talk moves included in the application

The TalkMoves application provides feedback on a set of six teacher talk moves, as shown in Table 1. These talk moves were selected due to their relatively high frequency in our training set, the ability of human coders to establish high interrater reliability, and based on suggestions from experts in accountable talk (Suresh, 2021). This set of talk moves is not exhaustive; there are other important talk moves including those that have (and potentially have not yet) been identified and labeled as such in the research literature (O'Connor & Michaels, 2019). The talk moves can be organized within three categories[2] based upon their instructional purpose (Resnick, Asterhan, & Clarke, 2018, b): (1) accountability to the learning community, (2) accountability to content knowledge, and (3) accountability to rigorous thinking.

2.2. Feedback interface

The initial feedback interface for the TalkMoves application was generated using a collaborative design (co-design) process (Penuel et al., 2007). A group of teachers, mathematics educators, and computer scientists contributed their expertise by brainstorming ideas, generating and reacting to designs, and considering how the application would likely be utilized by a range of potential users (e.g. teachers with varying amounts of classroom experience and knowledge of talk moves). A primary consideration was that users should be able to independently navigate the application with little or no upfront training, meaning that the talk moves should be clearly defined and the feedback presented in an easily interpretable manner. The co-design process resulted in several guiding principles related to the development and design of the application: filming and uploading the recordings should not take up valuable class time, the feedback should be presented in a non-evaluative manner, and the interface should be intuitive with minimal text.

[1] Although full access to the TalkMoves application is currently restricted to teachers participating in the pilot study, a public facing version of a portion of the application is available at talkmoves.com.

[2] There have been slight variations in the wording of the accountable talk categories in the research literature. The wording selected for the TalkMoves application was based on recommendations from experts in the field.

Table 1
The teacher talk moves incorporated in the TalkMoves application.

Category	Talk move	Description	Example
Learning Community	Keeping everyone together	Prompting students to be active listeners and orienting students to each other	"What did Eliza just say her equation was?"
Learning Community	Getting students to relate to another's ideas	Prompting students to react to what a classmate said	"Do you agree with Juan that the answer is 7/10?"
Learning Community	Restating	Repeating all or part of what a student said word for word	"Add two here."
Content Knowledge	Pressing for accuracy	Prompting students to make a mathematical contribution or use mathematical language	"Can you give an example of an ordered pair?"
Rigorous Thinking	Revoicing	Repeating what a student said but adding on or changing the wording	"Julia told us she would add two here."
Rigorous Thinking	Pressing for reasoning	Prompting students to explain, provide evidence, share their thinking behind a decision, or connect ideas or representations	"Why could I argue that the slope should be increasing?"

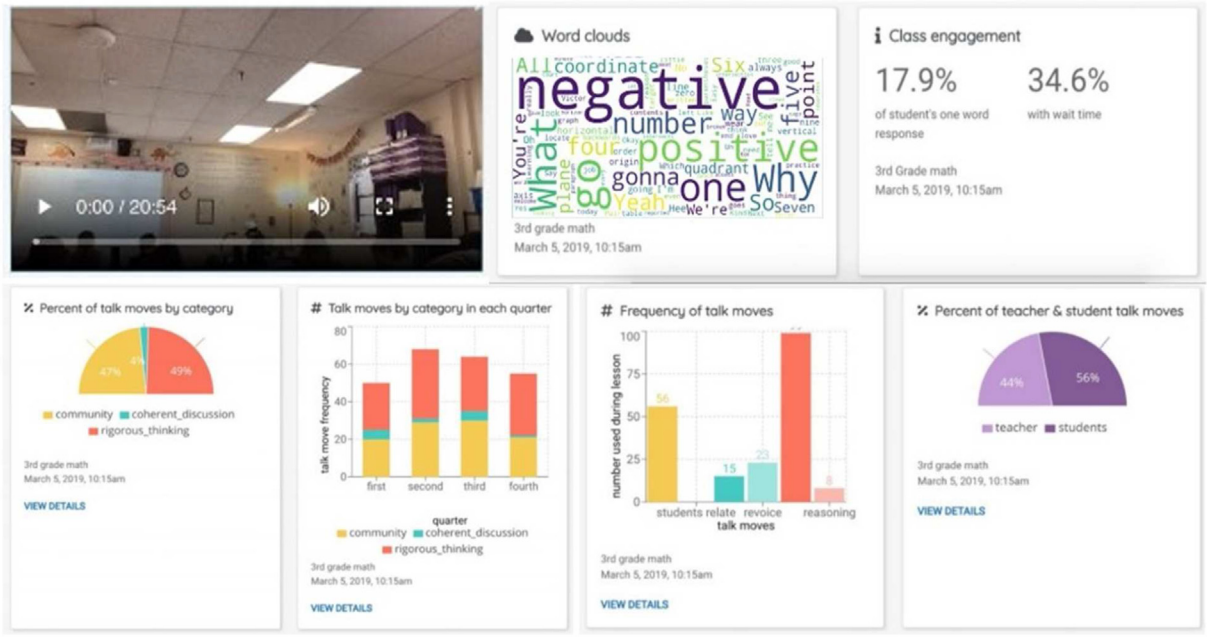

Fig. 2. A screenshot of the feedback interface for a single classroom recording.

Fig. 2 shows the feedback dashboard that was used in the pilot study.[3] For each uploaded recording the dashboard displays (1) video of the lesson, (2) the frequency of each teacher talk move, (3) the relative percentage of teacher and student talk, (4) the percentage of talk moves within each accountable talk category, (5) the amount of talk moves by category during each quarter of the lesson, (6) a word cloud showing the most frequently used words, and (7) the percentages of students' sentences containing only one word and teacher sentences with at least 3 s of wait time. The interface also includes a "teacher guide" that contains information about accountable talk theory and examples of each talk move.

3. Method

3.1. Participants

A group of 21 teachers from two school districts in the western United States voluntarily consented to participate in the pilot study during the 2019–2020 school year, providing important insights related to the design and impact of the TalkMoves application. The teachers spanned grades 4–12 with the majority teaching upper elementary school (71%). The participants were a relatively experienced group of teachers, with a range of 4–32 years classroom teaching experience (M = 15). All but two teachers had at least one colleague at their school who was also taking part in the study, enabling the possibility of formal or informal collaboration related to their participation in study activities. Tables 2 and 3 provide additional demographic information by teacher and by school.

3.2. Recording lessons

Each teacher was provided with an iPad and a Swivl robotic camera base that enables self-recording of high-quality video and audio in noisy classroom environments (Franklin et al., 2018; McCoy et al., 2018). Teachers were also given five "markers" or audio recording microphones that accompany the Swivl; one marker was intended to be worn by the teacher and the other four distributed around the classroom (e.g. on students' desks). Teachers were asked to record math lessons approximately once per week,

[3] The feedback dashboard has since been updated based on feedback from the pilot study. The current version includes additional discourse analytics (such as student talk moves), the analytics presented across lessons, numerous design modifications, and more resources for teachers to learn about talk moves.

Table 2
Background of teachers (n = 21) participating in the pilot study (2019–2020).

Elem school teachers	Middle school teachers	High school teachers	4–10 years experience	11–20 years experience	21+ years experience
15 (71%)	4 (19%)	2 (10%)	5 (24%)	13 (62%)	3 (14%)

Table 3
School demographics for teachers participating in the pilot study (2019–2020).

School	District	# teachers in study	Grade level of students in study	% free and reduced lunch	% Caucasian	% Hispanic	% ELL
School A	1	4	5th	24	60.25	26.02	10
School B	1	7	4th & 5th	10	67.44	20.33	5.50
School C	1	4	4th & 5th	73	18.71	77.62	46.40
School D	1	1	6th	22	65.21	24.61	9.50
School E	1	2	9th – 12th	16	65.24	21.92	7
School F	2	1	6th	25	66.41	22.45	15.20
School G	2	2	7th	12	78.56	10.72	3.80

although it was entirely their choice which lessons to film and how frequently. Each recording was uploaded to Swivl's secure cloud storage and then processed by the TalkMoves application. Typically within a few hours after recording, teachers receive an email from the application notifying them that their lesson has been processed and providing a direct link to that lesson's feedback. To ensure the privacy of both the teachers and their students, the application is password protected and structured such that teachers can only view the feedback on their own lessons.

3.3. Procedure

At the start of the study, teachers completed a brief online survey requesting demographic information, their familiarity with talk moves and accountable talk, and their individual goals related to classroom discourse practices. Once they had recorded at least two classroom lessons, researchers sent a user survey to each teacher to find out whether they were experiencing any challenges with the recording equipment or with the TalkMoves application, and followed up with any participants who reported concerns or had questions.

Next, after teachers recorded a few more lessons, the researchers sent a more extensive user survey asking about their perceptions of the usability, utility, and accuracy of the feedback provided by the TalkMoves application. Usability refers primarily to the ease with which teachers can learn to use the system ("How easy is it to find the information you want?" "How easy is it to interpret the graphs and charts?"). Utility refers to the usefulness of the application for its intended audience ("How useful is the feedback?" "How likely are you to change your instruction based on the feedback?"). The survey included a mix of open and closed-ended questions and offered teachers the opportunity to provide suggestions and raise questions related to the application.

Lastly, each teacher participated in an individual, semi-structured interview with a member of the research team. The interview began with a think-aloud protocol in which teachers shared their process for viewing their feedback, including what they looked at in the application and why, as well as their thinking when engaging with the application. Additional segments of the interview included questions about: 1) usability, 2) perceived utility, 3) confusion or questions, 4) trustworthiness of the feedback, and 5) goals and familiarity with talk moves. Researchers also asked teachers to elaborate on their responses to previous survey questions, responded to any questions and concerns, and talked through features of the application that teachers indicated they were not familiar with.

3.4. Analytic approach

The results presented in this paper are primarily descriptive in nature and based on qualitative analyses (Miles et al., 2014), with the aim of providing a general overview of the participants' perceptions and experiences during their initial use of the TalkMoves application. Data from the teachers' surveys and interviews offer insights regarding their familiarity with and goals related to talk moves, their perceptions of the usability, usefulness, and accuracy of the application, and the nature of their classroom discourse as captured by the application. An open-coding approach (Given, 2008) was applied to teachers' answers to open-ended survey and interview questions. Two researchers independently classified each teacher's response(s), obtaining inter-rater agreement of at least 80%; the researchers discussed and reconciled any differences in their classifications.

A qualitative case study (Creswell & Poth, 2016) of one frequent and enthusiastic user's engagement with the TalkMoves application enables a deeper consideration of the potential impacts on teachers' inquiry and reflection into their discourse practices. The case study description was generated through an iterative examination of the teacher's survey, interview, and TalkMoves application data, with several members of the research team individually writing notes and descriptive memos, and then coming to consensus by sharing, discussing and revising these descriptions.

3.5. Findings

3.5.1. Teachers' Initial Familiarity with talk moves and discourse goals

Initial Familiarity with Talk Moves. Prior to their use of the TalkMoves application, most of the pilot teachers were largely unfamiliar with talk moves or the specifics around the foundational principles of accountable talk. At baseline, most teachers reported that they were not at all or not very familiar with talk moves (see Fig. 3). The teachers expressed somewhat more familiarity with the term "accountable talk" than with talk moves. However, from their interviews it seems clear that teachers generally had a different understanding of accountable talk than the research team. As one teacher explained when asked about accountable talk, "We've had a lot of training on how to give immediate feedback in lessons and use cooperative learning structures to foster students giving each other immediate feedback" (T11). Nevertheless, as voluntary participants in this pilot study, the teachers generally expressed an eagerness to learn more about effective discourse strategies.

Initial Discourse Goals. Teachers' stated goals highlight their interest in improving the discourse in their own mathematics

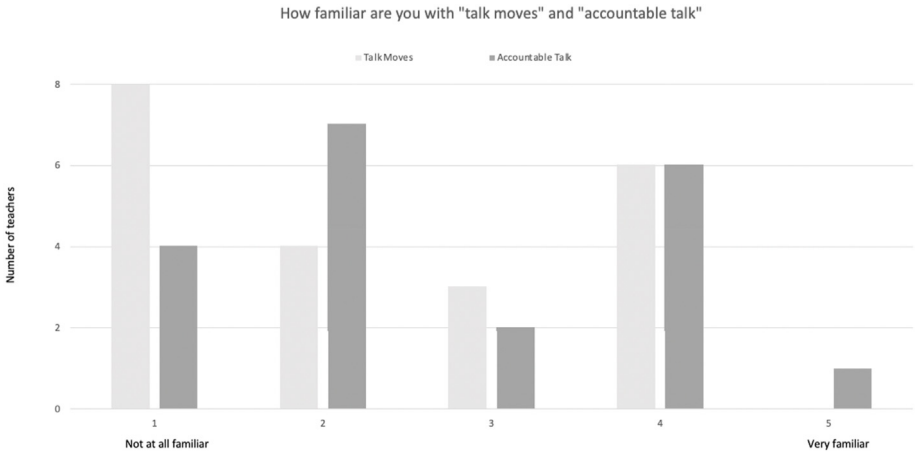

Fig. 3. Teachers' initial familiarity with talk moves and accountable talk.

lessons, particularly with respect to learning about talk moves and using them to elicit student thinking and contributions to class discussions. Teachers' answers to the question, "What aspect of your instruction would you like to know more about or change related to talk moves?" were coded into five response categories, shown in Table 4. Perhaps aligned with their relative lack of prior knowledge about talk moves, most teachers simply wanted to learn more about talk moves. As one teacher explained when asked what they wanted to learn, "All of it. I've not heard of talk moves before, but am searching the internet today" (T20). Other teachers had goals that referred to increasing student engagement, such as a teacher who shared, "I want to be better at questioning techniques. I tend to just talk too much to get through things and do not engage students in the lesson enough" (T15).

Table 4
Teacher's goals by category.

Goal Categories	# Teachers
Gaining Knowledge Related to Talk Moves	6
Better Supporting Student Thinking and Engagement	5
Increase Student Talk and Peer Collaboration	4
Getting Feedback on Their Instructional Practices	3
Other	3

3.5.2. Teachers' perceptions of the usability, utility, and accuracy of the TalkMoves application

Lesson Recordings. Within the first month of the study, 15 of the pilot teachers self-recorded and uploaded a total of 51 math lessons. Six teachers had not yet started filming, though their reasons varied from needing more time to collect consent forms to difficulty with the recording equipment. Over the four month pilot period, from mid-November 2019 and mid-March 2, 020,[4] all 21 teachers recorded and uploaded at least 3 of their lessons. Altogether the teachers recorded a total of 233 math lessons,[5] ranging from 3 to 21 lessons per teacher, with the average number of recordings being 10.

Table 5 shows the characteristics of teachers who recorded lessons below and above the group average. In general, these teachers did not vary in terms of their baseline familiarity with talk moves. On average, both groups reported that they were not very familiar with talk moves, suggesting that teachers' motivation for recording and using the application was not related to differences in their initial knowledge of classroom discourse strategies. The teachers who recorded more often tended to teach at the elementary school level, and they were slightly more experienced than their colleagues.

Perceptions of Usability. The TalkMoves application was designed for teachers to learn to navigate independently, with no training related to either talk moves or the feedback displays. Encouragingly, teachers generally found the application straightforward and easy to use, though some initially had questions about the recording equipment and accessing their feedback. Most of these early questions were related to challenges using the Swivl device or early bugs in the application that the programming team endeavored to troubleshoot and fix. In the second survey administered to teachers (after they had recorded multiple lessons), the majority reported that the recording equipment was easy or relatively easy to use (84%) and that it was easy or relatively easy to find the information they wanted on the application (68%). When asked about the graphs and charts in the application, almost all of the teachers (89%) said they were easy or relatively easy to interpret, despite the application's minimal surrounding text. One teacher enthusiastically described the functionality of the application by saying, "It's very user friendly, very intuitive. I mean, it's a plug and play, which is great for me" (T14). Another noted with a bit more hesitancy, "I wouldn't say that it's something that I feel 100% confident using or navigating, but I feel like I've been able to play around with it to figure some things out" (T17).

Teachers varied in the amount of time they spent engaging with their personalized feedback on the recorded lessons. Teachers reported spending between 2 and 30 min reviewing their feedback, with most saying that they typically used the application for about 5–10 min at a time. T19 explained, "I go back and look at it a couple times. Like the first time … it's just a minute or two, just kind of scanning over it and clicking it … And then later I'll go back and maybe spend another like five or 10 min looking through it."

Only a few teachers described consistently reviewing the video footage from their classes, with most choosing to look primarily at the charts and tables in their personalized dashboard. Several

[4] Due to COVID-19, face-to-face classroom instruction ceased in the two participating school districts in mid-March 2020 and teachers did not record any more lessons that school year.

[5] Recordings under 5 min were not processed by the application. Based on a careful review, the researchers found that most appeared to have been recorded unintentionally or filming was deliberately stopped (e.g. because the class had not yet started, there was an unexpected interruption). Analyses of these recordings were unlikely to be an accurate reflection of the teachers' instruction and they were removed from the dataset.

Table 5
Characteristics of teachers with lesson recordings below and above the group average.

	Below average # of recordings (<10 recordings)	At or above average # of recordings (≥10 recordings)
# teachers (total)	9	12
Familiarity with talk moves at baseline (average, scale 1–5)	2	2
# elementary teachers (grades 4–5)	5	10
# middle school teachers (grades 6–8)	3	1
# high school teachers (grades 9–12)	1	1
Years teaching experience	4–19 years (avg = 13)	4–32 years (avg = 17)

teachers expressed a particular appreciation for the simplicity of the word cloud feature of the application, which captures the most frequently spoken words by the teacher and students during class. One teacher reflected, "Based on the word cloud, I noticed that I did not use as much academic language in earlier lessons" (T12). Although the word cloud does not refer specifically to talk moves, it offers a way for teachers to easily glance at a visual display of the common vocabulary used in a lesson.

Perceptions of Utility. One of the main reasons teachers found the TalkMoves application useful and relevant was that it provided feedback on the amount of student talk relative to teacher talk. Yet the teachers did not appear particularly attentive to a key function of the application: providing information about the frequency and types of talk moves used during a math lesson. Although most teachers reported they wanted to learn about or receive feedback on their talk moves, in practice the teachers expressed more interest in feedback on *the quantity* of teacher and student talk, rather than feedback on *the quality* of the talk. The interviews revealed that 72% of the teachers first looked at the visualization showing the percentages of teacher and student talk. Many were still uncertain or had questions about the individual talk moves, which they discussed with a member of the research team during interview.

Most teachers (63%) reported in the second user survey that they were likely to change their instruction based on the feedback they received from the TalkMoves application. In their interviews, teachers elaborated on what aspects of their instruction they hoped to change and why. About half the of teachers who reported they were making an effort to change explained that they were especially focused in talking less often during class. Teachers made comments such as, "I have tried to change and give more time to student talk" (T25) and "I would like to talk less in math and let the kids have more discussions. More learning will take place" (T22). Other teachers noted they were striving to provide wait time more often and they were becoming more attentive to the language used in their classrooms based on the feedback on these topics, including the vocabulary listed in the word cloud.

Though not as common as making an effort to talk less, some teachers did start to become more intentional with their use of talk moves after receiving feedback from the TalkMoves application. In particular, two teachers reported that they were increasingly thoughtful about implementing talk moves. One teacher commented, "The data is awesome to look at, and there are times that I will make a conscious effort to increase my evidence of a certain talk move" (T26). In another case, a teacher who had initially reported not having any familiarity with talk moves started scripting her lessons when planning, writing out ahead of time what she wanted to say so that she could not only learn the talk moves but then use them with her students (T22).

Perceptions of Accuracy. A number of teachers expressed concerns regarding the accuracy of the feedback, with most teachers (58%) rating the application as only moderately accurate (ie., 3 on a 5-point scale) and almost a fifth felt that it was somewhat inaccurate or not accurate. These concerns regarding accuracy may have led to some teachers' underuse of the application. In particular, teachers correctly noted the system was limited in its ability to accurately detect and automatically transcribe student speech, likely resulting in lower performance in some areas. As one teacher shared, "I'm not sure the mics are picking up the students. I feel like they are talking more than the TalkMoves app says" (T21). At the same time, some teachers conveyed that the feedback correctly reflected the overall essence of what they did in their classrooms, while recognizing that any given percentage may not be entirely accurate. One teacher clearly expressed her mixed feelings: "I do trust it. But I'm also a skeptic in life. So I'm always going to go back and watch the footage myself and see if I agree with it … it's causing me to think about those things. So even if I don't trust it, 100% I trust it enough to go back and see it" (T14).

3.5.3. Teachers' use of talk moves and changes over time

Most Commonly Used Talk Moves. Examining the average frequency with which teachers used each of the six talk moves in their mathematics lessons reveals several discernible patterns (see Table 6). Teachers primarily used two talk moves: keeping everyone together and pressing for accuracy. Teachers frequently requested that students participate in the lesson by making a contribution or by actively listening to others (*keep everyone together*) and they encouraged students to provide mathematical information (*press for accuracy*). However they only occasionally encouraged students to respond to each other's ideas (*get students to relate*), restated or revoiced students' contributions, or prompted students to share their reasoning (*press for reasoning*).

Changes in Talk Moves Over Time. Table 6 provides information as to how much teachers' use of talk moves changed over the course of the (partial) school year. For each teacher, their recorded lessons were split into two halves by date recorded. When teachers had an odd number of lessons, the additional lesson was grouped with their later lessons. Paired samples t-tests were used to analyze changes over time, comparing the first to the second half of their lessons. Although there were no statistically significant changes for any of the six talk moves, there was an increasing trend for each. On average, teachers used each of the six talk moves more often in the second half of their recorded lessons compared to the first half, likely signaling a shift in their attention to these moves and an intentional effort to use them more often in their mathematics instruction. Although the increase in frequency for any individual talk move was not particularly large, overall teachers used an average of 6.5 more talk moves in their later lessons relative to their earlier lessons.

Talk Move Categories. Accountable talk theory supports the notion that teachers' use of talk moves should be more or less evenly distributed across three co-occurring categories (Michaels et al., 2008): accountability to the learning community, accountability to content knowledge, and accountability to rigorous thinking. During the pilot study, on average about half of teachers' talk moves fell in the learning community category, with the content knowledge category being the second most frequently used (see Table 7). Talk moves in the rigorous thinking category were

Table 6
Average[a] frequency of each teacher talk move (2019–2020).

Talk Move	Average frequency across all lessons	Average frequency in first half of lessons	Average frequency in second half of lessons	Change from first half to second half
Keeping everyone together	47.95	46.61	49.61	3
Getting students to relate	2.68	2.35	3.01	0.66
Restating	0.85	0.62	1.09	0.47
Pressing for accuracy	32.90	32.25	33.72	1.47
Revoicing	3.12	2.78	3.48	0.7
Pressing for reasoning	1.60	1.5	1.71	0.21
All Talk Moves	89.10	86.12	92.62	6.5

[a] Averages were calculated by first determining the average for each teacher, and then averaging across teachers. All data were normalized for a 55 min lesson.

much less common, at under 10% per lesson on average. These distributions directly correspond to teachers' heavy use of the individual talk moves *keep everyone together* (learning community) and *press for accuracy* (content knowledge) and reflect their infrequent use of the two talk moves in the rigorous thinking category (*revoicing* and *press for reasoning*). As Table 7 shows, there was an increase in the average frequency of each category over time. None of the increases were statistically significant, but they generally map onto the increases in frequencies of the individual talk moves.

4. Case study of Lanette: An in-depth look at one teacher's experience using the TalkMoves application

4.1. Lanette's background

The case study of Lanette (a pseudonym) is intended to unpack the experiences and perceptions of a teacher who was highly committed to both recording classroom lessons and reviewing her feedback from the TalkMoves application. Lanette was a 5th grade elementary school teacher with 16 years of experience at the time she joined the pilot study. She had earned a Bachelor's degree in Elementary Education as well as a Master's in Education Administration. The entire 5th grade team at Lanette's school elected to take part in the study, as well as one 4th grade teacher and the instructional coach for their 4th and 5th grade teachers. The grade level teams at this school were highly aligned in the sense that they taught the same lessons (from the same curriculum) at more or less the same pace. Further, they jointly agreed that taking part in the study would be beneficial, and frequently had informal conversations regarding their participation.

4.2. Familiarity with talk moves and discourse goals

Lanette reported on her background survey that she had no familiarity with talk moves, but she was eager to learn about and implement them. Lanette noted that she was "intrigued" by the idea that using talk moves might encourage her students to do more of the talking and thinking during classroom lessons. Her stated goal was to use talk moves "to enhance my students understanding and to increase rigor." During her interview, Lanette added that her entire 5th grade team was focused on collectively improving their practice, especially using accountable talk to "get higher levels of understanding with our kids … [and asking ourselves] how are our talk moves leading to conceptual understanding for kids." These goals were very much in line with those conveyed by the other 5th grade teachers at Lanette's school.

4.3. Lesson recordings and perceptions of ssability

Lanette was an early adopter and frequent user of the TalkMoves application. During the four month period when teachers were able to film in-person lessons during the 2019–2020 school year, she recorded her math classes 21 times, which is more than any other participant in the study. Lanette found the technology simple to use, with the only minor challenge occurring when she first began using the Swivl device. Lanette and another participating teacher at her school were not able to get the Swivl robotic base to automatically rotate and follow them as they moved around the classroom. They eventually determined that a switch on the device had been inadvertently turned to the "off" position and simply needed to be moved to "on" for the Swivl to work as expected.

4.4. Perceptions of utility

Lanette communicated her enjoyment of the process of using the TalkMoves application. She engaged in ongoing experimentation with ways to apply what she learned from the feedback on a given lesson, intentionally changing her instruction to see whether that prompted changes in the feedback on her next lesson. Lanette rated the personalized feedback as "very useful" (the highest rating). Like most of the teachers in the study, she was especially interested in the quantity of her talk relative to her students. Lanette was concerned that she did not allow her students to talk enough and noted the feedback motivated her to "become more of a student driven classroom in regards to learning and teaching."

At the time of her interview, Lanette had recorded 9 math lessons and she reported spending 15–20 min looking at the feedback for each lesson. She explained, "I've been trying to film everyday …

Table 7
Average frequency of each teacher talk move category (2019–2020).

Talk Move	Average frequency across all lessons	Average frequency in first half of lessons	Average frequency in second half of lessons	Change from first half to second half
Learning Community	50.71	48.91	52.51	3.60
Content Knowledge	31.49	30.96	32.02	1.06
Rigorous Thinking	7.28	6.88	7.69	0.81

Just because I keep looking back at this feedback, trying to figure out where I need to change... . What kinds of things do I need to be saying to make it [i.e. the visualizations] change." However, Lanette acknowledged that she was still uncertain about what some of the talk moves were, and she also expressed confusion about what the talk move categories meant. For example, Lanette asked whether the talk moves referred to just teacher talk or whether they also included student talk moves. Further, she did not realize that the talk moves categories were compilations of individual talk moves, and instead assumed that they provided wholistic information as to the extent of her students' involvement in the lesson. At the same time, Lanette shared that she had been attempting to learn more about talk moves by reading materials provided by the research team, including the Teacher Guide included within the application. Lanette's questions and misunderstandings suggest that teachers would likely benefit from receiving more detailed explanations about the meaning of each talk move and category, as well as links to online resources on accountable talk and talk move examples.

4.5. Perceptions of accuracy

Lanette commented that she trusts the TalkMoves application gives her "very accurate information," with the exception of feedback on the proportion of teacher and student talk. Lanette explained that although she had been actively working to decrease the amount of time she spoke during class, the percentages of teacher and student talk provided by the application did not reflect this effort. In fact, Lanette went so far as to use a stopwatch to keep track of how much time she spent talking, to determine for herself how often she talked. Lanette questioned whether there was a problem with how well the Swivl microphones were capturing student talk, especially during small group discussions. The researchers responded with several suggestions to improve the audio capture and better ensure the accuracy of the automated transcription and discourse analysis processes, including placing the teacher microphone closer to her face and only recording one small group of students when they were working independently.

4.6. Use of talk moves

Like most teachers in the study, Lanette primarily used the talk moves *keeping everyone together* and *pressing for accuracy*, with the other four talk moves occurring much less frequently in her recorded lessons (see Table 8). Lanette's efforts to increase her use of talk moves clearly paid off, as she shifted from an average total of 78 talk moves per lesson in her first 10 lessons to 96 talk moves per lesson in her last 11 lessons. Lanette's lessons increased in all of the talk moves except restating, suggesting that as she became more attentive to and knowledge about these discourse strategies, she implemented moves in each accountable talk category more often in her math instruction (see Table 9).

4.7. Professional learning plans

Lanette shared that her 5th grade teammates were all enthusiastic about the feedback they were getting from the TalkMoves application and they often talked informally about the videos they recorded and what the data revealed about their classroom discourse. Lanette was eager for the 5th grade team to look at their feedback together more systematically during their weekly professional learning community meetings, perhaps by all recording the same math lesson and comparing their data for that lesson. She suggested, "When we have our weekly meetings, we need to pick one lesson. Because we each teach the same math lesson every day, and if we don't we're within a day apart. We can actually compare those lessons, so that we're comparing apples to apples …. We've got an example here of a class being taught. Now let's look at the information that's given back. And let's be able to dig into this data to see what it is showing us." Lanette further proposed that such conversations would encourage her grade level team to intentionally plan for the use of specific talk moves when they created lesson plans and instructional resources. Unfortunately these more formal conversations did not ended up taking place as Lanette envisioned, perhaps due to COVID requiring their school to shift to remote learning in the spring of 2020, just a few months after they first began using the application. However Lanette remained enthusiastic about and dedicated to using the TalkMoves application to improve her teaching, even using it during the 2020-21 school year to record and gather information on her online mathematics lessons.

5. Discussion

The TalkMoves application developed as part of this study provided teachers with detailed feedback on their use of research-based discourse practices, presented in a quantifiable and non-evaluative manner. The pilot data indicate that the TalkMoves application can be successfully navigated by teachers, working on their own, to engage in reflective noticing (Sherin & Dyer, 2017) of patterns in their classroom discourse that may be targets for self-guided improvement. The pilot teachers approached and utilized the technology in somewhat varying ways, for example by using it for different lengths of time and for differing purposes (e.g., to talk less, to use more of certain talk moves). There was a trend for teachers to increase their use of talk moves over time, even given the short duration of the study period.

Due to the small sample size and limited time frame for data collection during the 2019–2020 school year, additional research is needed to determine whether the trends observed in this study hold true for each of the individual talk moves and for the total number of talk moves used in a lesson. It is important to caution that it may not always be appropriate for teachers to increase their use of all six of the talk moves included in the TalkMoves

Table 8
Average frequency of each teacher talk move in Lanette's lessons.

Talk Move	Average frequency across all lessons	Average frequency in first half of lessons	Average frequency in second half of lessons	Change from first half to second half
Keeping everyone together	47.09	42.2	51.36	9.16
Getting students to relate	2.56	1.53	3.49	1.96
Restating	0.37	0.69	0.08	−0.61
Pressing for accuracy	33.64	30.47	36.53	6.06
Revoicing	1.68	1.47	1.87	0.4
Pressing for reasoning	2.27	1.76	2.74	0.98
All Talk Moves	87.62	78.33	96.07	17.74

Table 9
Average frequency of each teacher talk move category in Lanette's lessons.

Talk Move	Average frequency across all lessons	Average frequency in first half of lessons	Average frequency in second half of lessons	Change from first half to second half
Learning Community	33.64	44.42	54.93	10.51
Content Knowledge	57.75	30.47	36.53	6.06
Rigorous Thinking	3.95	3.23	4.61	1.38

application. It is likely the case that knowing which talk move to use at opportune moments in a lesson, how to pair talk moves with cognitively demanding mathematics tasks, and numerous other pedagogical decisions that involve talk moves come into play when considering the relationship between accountable talk and student learning (Murata et al., 2017; O'Connor & Michaels, 2019; Sohmer et al., 2009).

Becoming adept in the application of new discourse practices such as talk moves is likely to require a good deal of time, effort, and structured professional development for many teachers. O'Connor and Michaels (2019) delineate two important challenges in this work: embedding accountable talk within high quality content-based instruction and shifting from a decades-long focus on recitation to a culture of reasoning. The TalkMoves application can serve as an important tool by providing reliable feedback for teachers to study, reflect on, and track over time. An important future direction in this line of research is preparing for collaborative use of the TalkMoves application, such as in an instructional coaching environment, during school-based professional learning community meetings, or as part of a larger professional development course focused on accountable talk. Working on their own and without additional support from experts or colleagues, the pilot teachers were often unsure how to distill what the feedback on specific talk moves actually meant for them.

The teachers in this study were most interested in and attentive to data regarding the amounts of teacher and student talk and other discursive features unrelated to talk moves (such as vocabulary displayed in the word cloud). It is possible that attending to these more readily interpretable discursive practices are entryways to teachers learning about and thoughtfully attending to talk moves (Chapin et al., 2009). Understanding and reflecting on the talk moves used during a lesson is likely a more challenging cognitive process than simply noting how often students talk during that lesson. Further research is needed to explore when and why teachers begin to shift their attention and instruction to intentionally incorporate talk moves, especially compared to other discourse patterns.

Future research should also attend to improvements in both the design and accuracy of the TalkMoves application, including the ability to capture and automatically transcribe student speech in noisy classrooms. The teachers' perceptions of the application as only moderately accurate were generally tied to concerns about the recording of student talk, with the frequent assumption that student speech was underestimated. These technological limitations have been noted by others similarly attempting to capture high quality classroom audio without using more invasive and distracting recording equipment (e.g., D'Mello et al., 2015; Jenson et al., 2020). As improvements occur in audio and video capture, together with more accurate automated child speech recognition algorithms, it is likely that applications making use of such technology will become more ubiquitous and smoothly integrated into a variety of professional learning toolkits.

6. Conclusions

Online platforms like the TalkMoves application can amplify and democratize teachers' access to high quality feedback, and have the potential to transform professional development experiences for teachers. The feedback can be utilized to support individualized and collaborative teacher learning, motivate instructional change, and generate more discursive classroom learning environments. In addition, because the targeted talk moves highlight student engagement in equitable discourse practices, understanding and acting on this feedback has important implications for teachers' ability to provide opportunities to learn mathematics for all students, including those who historically have been marginalized and less engaged in discussion-based learning (Moschkovich, 2018).

The participating teachers in this pilot study of the TalkMoves application initially were not very familiar with accountable talk or talk moves. However they perceived the application as being straightforward to use and providing valuable feedback relevant to their mathematics instruction. Although the teachers were especially attentive to the quantity of their talk rather than the frequency of their talk moves, they showed a trend of increasing their talk moves over a relatively short amount of time. On average the teachers used 6.5 more talk moves in their later lessons relative to their earlier lessons, with the most frequent user of the application having an increase of 18 talk moves per lesson.

This line of research invites a variety of follow-up questions such as: do the teachers sustain their interest and engagement with the application over time, do they continue to show improvements in their classroom discourse, and to what degree would related collaborative professional learning experiences enhance their knowledge and instruction practices. Overall, the study shows the promise of automated, personalized online applications to support teachers by encouraging them to review, notice, and reflect on specific discourse patterns.

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