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ORIGINAL ARTICLE

Managing common ground in the classroom: teachers use gestures to support students' contributions to classroom discourse

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Abstract
Maintaining shared understanding in classroom interaction is challenging for both teachers and students. In this paper, we consider the role of teachers' gestures in promoting shared understanding. Our specific aim was to document ways in which teachers use their own gestures to support students' contributions to the classroom discourse. We present three illustrative cases that represent the range of variation in teachers' use of speech (i.e., repeating the students' speech vs. not speaking at all) and variation in the spatial positioning of the teacher, the student, and the referents of the student's speech. We argue that teachers use gestures, both to ensure that they share common ground with the individual student who is speaking and to foster common ground among the class as a whole.

Keywords Gesture · Classroom discourse · Revoicing · Teachers

1 Introduction

Maintaining shared understanding, or common ground, in classroom interaction can be challenging for both teachers and students. Teachers need to communicate complex and novel ideas in ways that can be readily understood and taken up by students. Students, in turn, need to attend to the ongoing focus of attention in the classroom, activate relevant prior knowledge, and integrate new information as it becomes available. All of this occurs in settings involving many individuals, frequent interruptions, and physical spaces that are not always conducive to communication.

By *common ground*, we refer to the knowledge, beliefs and assumptions that are mutually shared among participants in an interaction (Clark & Schaefer, 1989). This shared understanding is crucial to successful social interactions (Clark, 1996; Schegloff, 1992), including interactions in which people acquire knowledge and learn skills from others (Vygotsky, 1986). New knowledge often builds on existing knowledge; therefore, it is not surprising that teachers often begin lessons by focusing on existing, shared knowledge, and they build upon this knowledge as they progress through lessons and present new ideas.

In past work, we have studied the moves that teachers make in an effort to manage common ground in mathematics classrooms (Nathan & Alibali, 2011; Nathan, Church, & Alibali, 2017). Teachers may be particularly invested in managing common ground because classroom instruction is a "high-stakes" communicative setting, in that teachers make explicit efforts to ensure that learning occurs. As such, we believe there is value in understanding the techniques that teachers use to establish and maintain common ground during instruction.

One class of such techniques involves *gestures*. A growing body of work focuses on how teachers use gestures during instruction (e.g., Flevares & Perry, 2001; Roth, 2001; Singer, Radinsky, & Goldman, 2008; Alibali & Nathan, 2012; Wilson, Boatright, & Landon-Hays, 2014; Majlesi, 2015; Richland, 2015; Shein, 2012). However, the sources and consequences of variations in teachers' gestures remain poorly understood. We suggest that considerations of common ground are one factor that shapes how teachers use gestures.

In the following sections, we review the literature on how people use gestures in managing common ground, both in

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conversational settings and in classrooms. We then review literature on gesture as a "semiotic resource" that teachers draw on during instruction. Finally, we highlight our specific focus here: teachers' use of their own gestures to support students' contributions to classroom discourse.

1.1 How people use gesture to manage common ground

People use gestures in communicating in a wide range of situations. Many studies have compared speakers' gestures in conversational settings in which they do and do not share common ground with their listeners (for a recent review, see Holler & Bavelas, 2017). This body of work uses a wide range of dependent measures, including measures that focus on the amount of gesture (e.g., gesture frequency, gesture rate per 100 words) and measures that focus on characteristics that may influence the *informativeness* of gestures, such as their location, complexity, and precision.

Studies of the effects of common ground on the amount of gesture have yielded mixed results. Some show that speakers gesture at lower rates when they share common ground with conversation partners (e.g., Holler & Stevens, 2007; Jacobs & Garnham, 2007; Schubotz, Özyürek, & Holler, 2019 [younger but not older adults]); however, a few studies have yielded the opposite pattern (e.g., Holler & Wilkin, 2009; Holler, Tutton, & Wilkin, 2011), and several studies have yielded null findings (e.g., de Ruiter, Bangerter, & Dings, 2012; Galati & Brennan, 2014; Hoetjes, Koolen, Goudbeek, Krahmer, & Swerts, 2015; Hilliard & Cook, 2016). In some studies, speakers reduced the raw frequency of their gestures when they shared common ground with their listeners, but they also reduced speech output, leading to null effects on gesture rates.

There is greater consistency in findings about common ground and gestures' informativeness. When people lack common ground, they tend to produce gestures that are larger, higher in space, more complex, and of longer duration (Galati & Brennan, 2014; Gerwing & Bavelas, 2004; Hilliard & Cook, 2016; Hoetjes et al., 2015; Holler & Stevens, 2007). Given the lack of consistent effects on the amount of gestures, the systematic patterns observed in measures of gesture informativeness are striking (see Holler & Bavelas, 2017, for discussion).

These findings about gesture in conversational settings suggest it would be valuable to investigate the role of gesture in managing common ground during instructional communication. A handful of studies have focused explicitly on how teachers use gestures to establish and maintain common ground during instruction (e.g., Nathan, Church, et al., 2017; Rasmussen, Stephan, & Allen, 2004; Zukow-Goldring, Romo, & Duncan, 1994).

In this body of work, several findings are noteworthy. First, some evidence suggests that teachers gesture at higher rates when they present new material than when they review previously presented material (e.g., Alibali & Nathan, 2007; Alibali et al., 2014). Second, teachers gesture at higher rates when students have difficulty with the material (Alibali et al., 2013). When teachers recognize that common ground has been breached, they increase their gesture rates in an effort to re-establish shared understanding. Teachers may also adjust the informativeness of their gestures in response to trouble spots. For example, in one case discussed by Alibali et al. (2013), the teacher increased the detail and specificity of his gestures following a student's expression of uncertainty.

1.2 Teachers' gestures in the semiotic system of the classroom

To understand the role of gestures in managing common ground, it is valuable to consider the semiotic properties of gestures. Clark (1996) argued that gestures are signs in the Peircean sense that they are based on a relation between the sign itself, the object or intended referent, and the interpretant (i.e., the meaning that they have for a particular individual). Peirce distinguished three classes of signs: *indices*, which refer by indicating an object; *icons*, which refer by resemblance to the object; and *symbols*, which refer by virtue of a collective agreement (Atkin, 2013). Gestures can refer in each of these ways—by indicating (pointing gestures), by resemblance (gestures that iconically represent their referents), and by "describing-as" (conventional gestures) (Clark, 1996). Teachers regularly use gestures that refer in all of these ways (Nathan, 2008).

Some scholars have considered the pedagogical value of teachers' gestures from a semiotic perspective. Gestures can be viewed as "semiotic resources" that teachers and students may draw on as they express, develop, refine and connect ideas (Rasmussen et al., 2004; Arzarello, Paola, Robutti, & Sabena, 2008; Radford, Edwards, & Arzarello, 2009).

Arzarello and colleagues (Arzarello et al., 2008; Arzarello & Robutti, 2008) describe a "semiotic game" that teachers engage in as part of their effort to guide students toward discipline-appropriate language and practices. The "game" involves a student first expressing an idea using informal or imprecise speech and spontaneous gestures, in what Arzarello and colleagues term a *semiotic bundle*. The teacher repeats the student's gestures, producing what DeFornel (1992) and Koschmann and LeBaron (2002) have called a "return" gesture, or a gesture that imitates the immediately preceding gesture of the interlocutor. At the same time, the teacher restates the idea in more precise, discipline-appropriate language. In this way, the teacher introduces the

"official" disciplinary register into the developing semiotic bundle.

Restating the student's speech in more precise terms is an example of a discursive practice called *revoicing* (Forman, Larreamendy-Joerns, Stein, & Brown, 1998; O'Connor & Michaels, 1993). Revoicing involves repeating, restating, or elaborating another person's contribution to the discourse. In the "semiotic game", the teacher revoices the student's contribution both in speech and in gesture. Thus, the teacher's "move" involves *multimodal revoicing*: mimicking the student's gesture *and* restating the student's speech. The teacher uses one semiotic resource—in this case, gesture—to demonstrate and maintain common ground, and at the same time, the teacher uses another semiotic resource—in this case, discipline-specific language—to push the student's thinking and speaking towards a discipline-appropriate form.

Some recent studies have focused on how teachers use gestures when they revoice students' contributions. In a case study of a 5th-grade teacher's use of gestures during questioning and revoicing, Shein (2012) discusses examples in which the teacher mimics students' gestures and revoices students' speech in more precise mathematical terms, as in the semiotic game described by Arzarello and colleagues. Majlesi (2015) discusses similar examples in foreign language instruction. Flood (2018) describes a case in which a teacher revoices a student's speech and *modifies* the student's gesture, in an pedagogical move aimed at highlighting one aspect of the information expressed in the gestures. These examples emphasize the multimodal nature of revoicing—an issue we return to below.

1.3 The present study

Teachers use gestures in many ways as part of their effort to communicate ideas and to establish and maintain common ground. Teachers may increase the frequency and informativeness of their gestures when common ground is threatened, such as when material is challenging or new or when students have difficulty understanding (e.g., Alibali et al., 2014). Teachers may also mimic, elaborate, or modify students' gestures while extending their speech in new directions or to new registers (e.g., Arzarello et al., 2008; Flood, 2018).

In this research, we focus on how teachers use their own gestures to support *students'* contributions to the classroom discourse. To address this aim, we reviewed classroom lessons from three corpora of videos that we collected in previous work. Our goal was not to quantify or document the frequency of such cases, but rather to gain a broad sense of the different ways in which teachers use their own gestures to support students' contributions. Thus, this work is intended to highlight a phenomenon that we believe merits deeper investigation.

We noted that there were two primary ways in which teachers supported students' contributions with their own gestures. First, teachers sometimes *repeated* students' turns at talk and *added* gestures that indicated specific referents. In typical cases of this sort, students refer to target referents (such as inscriptions) using speech alone or speech with gestures that are distant from their referents. Teachers then repeat the students' verbal utterances, adding gestures that precisely indicate the referents. Note that this situation is, in some respects, the reverse of that described by Arzarello and colleagues, in which teachers repeat students' *gestures* and modify students' *speech*; here, teachers repeat students' speech and modify or add gestures.

Second, teachers sometimes produced gestures to correspond with students' speech, while the students spoke (and teachers did not). In typical cases of this sort, students refer to target referents using speech alone or speech with gestures that are distant from their referents, and teachers gesture to those referents without speaking themselves. In previous work (Nathan, et al., 2017), we introduced the term *addressee gestures*, defined as gestures produced by addressees to correspond with other speakers' utterances, to describe such gestures.

In brief, the purpose of this paper is to characterize some of the ways people use their own gestures to support *others'* turns at talk, with a focus on teacher-student interactions in classroom settings. We present three illustrative cases, selected to represent a range of variation in the teachers' use of speech (i.e., repeating the students' speech vs. not speaking at all), as well as variation in the spatial proximity of the teacher, the student, and the referents of the student's speech. We interpret these cases from the perspective of establishing and maintaining common ground in the classroom.

2 General methodological considerations

2.1 Data sources

We reviewed three previously collected corpora of classroom lessons to identify cases in which teachers used their own gestures to support students' contributions to classroom discourse.

Corpus 1 is a multi-year corpus of 6th-grade mathematics lessons on early algebra, drawn from a single female teacher. This teacher was engaged in a professional development partnership with the researchers focusing on classroom discussions of students' mathematical strategies (French & Nathan, 2006). The lessons were filmed with a single camera, and the camera operator sought to follow the person speaking at all times. The school was located in a small city in the western US; the student body was largely middle- and upper-middle class.

Corpora 2 and 3 consist of high-school lessons from teachers who were not involved in any professional development activities with the research team. Corpus 2 focused on geometry classes and Corpus 3 on pre-engineering classes. Both corpora included multiple teachers from multiple schools, all located in the Midwestern US. The lessons in Cases 2 and 3 were from two different high schools located in the same mid-sized city. Both schools were racially, ethnically, and socioeconomically diverse. Lessons were filmed with two cameras, one focused on the students and the other on the teacher.

2.2 Selecting the cases

We selected three cases manifesting two salient dimensions of variation in teachers' use of their own gestures to support students' turns at talk. One key dimension of variation is *teachers' use of speech*. In some cases, teachers repeated students' speech (sometimes with slight modifications of wording or tone) and produced gestures along with that speech. In other cases, teachers did not speak, but produced gestures while students spoke. Given past research showing that gestures are rarely produced by listeners (McNeill, 1992), our observation that teachers sometimes produce gestures while listening is noteworthy.

A second key dimension is the *spatial positioning* of teachers and students relative to the referents of students' speech. Speakers sometimes refer to objects or inscriptions that they cannot "reach" with their hands. If they gesture toward those distal referents, their gestures are likely to be ambiguous. Thus, one might expect teachers to gesture to support students' contributions only when students are distant from the referents of their speech. However, this was not the case; we also observed teachers gesture to support students' contributions when both teacher and student were proximal to the referents.

In Cases 1 and 2, students are physically distant from the referents of their utterances, and teachers are proximal to those referents. In Case 1, the teacher revoices the student's utterance and adds proximal gestures, and in Case 2, the teacher gestures in silence while the student speaks. In Case 3, student and teacher are both proximal to the referents of the student's utterances; the teacher gestures in silence while the student speaks.

3 Case 1

3.1 Background information

This case is drawn from a 6th-grade mathematics lesson focusing on two symbolic representations of a story problem. In previous work, we presented this excerpt to illustrate the use of pointing gestures to link representations (Alibali, Nathan, & Fujimori, 2011); here, we make a different point using the same excerpt.

During this excerpt, there were two inscriptions on the board: *4 girls* × *some amount of money* + *18* = *$42* and *($42 – $18)* ÷ *4* = *($6)amount each girl paid*. These inscriptions are related in that one can be transformed into the other (although one included the solution, $6, rather than "some amount of money"). One equation, the *situation equation*, models the story as an algebraic (i.e., start-unknown) equation (Riley, Greeno, & Heller, 1983). The other, the *solution equation*, models the story as an arithmetic (i.e., result-unknown) equation, indicating the operations to be taken to reach the solution (Fig. 1). When this excerpt occurred, the teacher was leading a discussion about similarities and differences between the two equations.

3.2 Description and analysis

In this case, the focal student is physically distant from the referents of his utterances, but the teacher is proximal to those referents. In Unit 1, the student gestured toward the whiteboard at the front of the room, while sitting in his seat several feet away. Because of the distance, his gestures were ambiguous. The camera focused on the student during Unit 1, but panned to the teacher at Unit 2. In Units 2 and 5, the student used the words *there* and *over there*, which are routinely accompanied by gestures; however, his gestures with these words were not captured on video.

In this excerpt, the teacher revoices the student's utterances. The student initially stated, "timesing is there and dividing's there." The teacher immediately reiterated this verbal statement and produced gestures to indicate the relevant elements of the inscriptions (Fig. 1). Moments later, the student continued, "then plus, and then the minus over

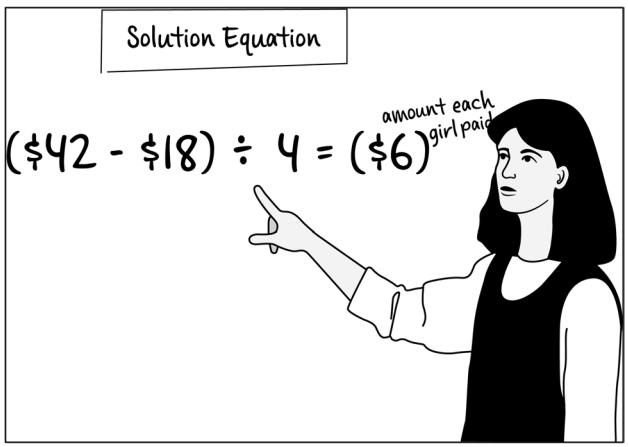

Fig. 1 Teacher gesturing to the solution equation. See Table 1, Unit 4, Gesture 1

Table 1 Transcript of Case 1

Unit	Speaker and modality	Speech and gesture transcript
1	S speech	[Uh, timesing and dividing, are –]
	S gesture	LH point toward unclear referent on whiteboard at front of room
2	S speech	Timesing is there and dividing's there
	S gesture	[off camera]
3	T speech	So [times], [times 4]
	T gesture	RH point to × sign in left (situation) equation (after having moved closer to right equation) RH distal point toward left (situation) equation
4	T speech	And then [divide by] [4], cool
	T gesture	RH point to ÷ sign in right (solution) equation RH point to 4 in right (solution) equation
5	S speech	And then plus, and then the minus over there
	S gesture	[Off camera]
6	T speech	[Plus 18] and [minus 18]. Cool.
	T gesture	RH palm face down under + 18 in left (situation) equation RH palm face down under – 18 in right (solution) equation

Within each unit, the speech transcript is in the top row and the gesture transcript is in the bottom row. The words that co-occur with each gesture are indicated by square brackets

S student, *T* teacher, *LH* left hand, *RH* right hand

there." Again, the teacher immediately reiterated the student's speech and produced gestures to indicate the relevant elements of the inscriptions. Thus, the teacher's gestures delineated the referents of the student's utterances in a way that was readily visible—and interpretable—for other students.

We argue that the teacher's gestures helped to maintain common ground in two key ways. First, her gestures helped maintain shared focus on the equations for students in the class as a whole while the focal student's contribution to the discourse unfolded. Second, her gestures helped ensure that she interpreted the student's utterance appropriately. If she had indicated the incorrect referents, the student could have corrected her.

This excerpt involves linking two representations—specifically, two different ways of symbolically representing the mathematical relations in the story problem. Such links are challenging for students at this level, and the teacher's gestures delineated the specific correspondences between the equations that the student described (e.g., "+ 18" in the situation equation corresponds to "– 18" in the solution equation) with precise pointing gestures. Given the complexity of these links and their centrality in the lesson, it was likely beneficial for students for the links to be expressed multimodally—in the student's speech, the teacher's speech, and the teacher's gesture.

The teacher's revoicing subtly modified the student's speech. She shifted the student's colloquial expression to a more mathematically precise one, and she noted the term to which the operation applied (e.g., "timesing" vs. "times 4"). In a similar way, the teacher's gestures also modified the student's gestures (some of which were off-camera). The teacher's turn involved "re-gesturing" the student's gestures in a more precise and readily interpretable way, by indicating the referents with proximal rather than distal points. In this sense, the teacher produced a *gestural revoicing* of the student's contribution. Together, her verbal and gestural revoicings comprise a *multimodal revoicing* of the student's turn.

This excerpt is reminiscent of the "semiotic game" described by Arzarello and colleagues, in that it involves the teacher repeating some elements of the student's turn—the referents of the student's gestures and many elements of the student's speech—and modifying them to express the mathematical ideas more precisely. Thus, with her turn, the teacher both supported and extended the student's contribution. In addition to maintaining shared understanding, this move may serve multiple pedagogical goals, including introducing precise mathematical language and symbols into the discourse, positioning the focal student as a valuable contributor to the mathematical discourse, and building a relationship with the student.

4 Case 2

4.1 Background information

Case 2 was drawn from a corpus of high-school geometry lessons. In previous work, we reported on a different lesson by the same teacher (Nathan, Wolfgram, Srisurichan, Walkington, & Alibali, 2017). The lesson analyzed here took place in a classroom equipped as a computer lab, which also

included a blackboard. Students were seated at computers around the room's periphery. Just before this excerpt began, they turned in their chairs to see the teacher speaking at the board.

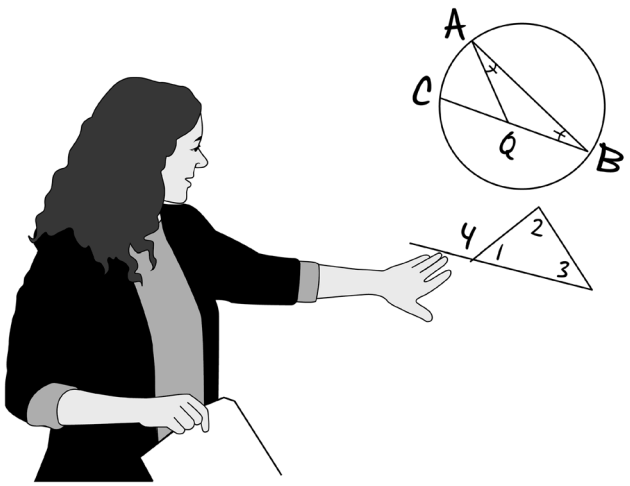

Fig. 2 Teacher producing addressee gesture in Case 2. See Table 2, Unit 5

The lesson focused on proving that the measure of an inscribed angle is half that of the intercepted arc. The relevant inscriptions are depicted in Fig. 2. The teacher led the students through identifying triangle AQB as an isosceles triangle, and noting that, because QA and QB are radii of the same circle, ∠QAB and ∠QBA must be congruent. The teacher then asked the students what they remembered about exterior angles, and she drew a triangle with an exterior angle (Fig. 2). The excerpt in Table 2 commences at this point. The teacher is holding a piece of chalk in her right hand; some of her gestures involve making marks with the chalk to indicate or highlight elements of the inscription as the student speaks (for a discussion of such *writing gestures*, see Alibali, et al., 2014).

4.2 Description and analysis

As in Case 1, in this case the focal student is physically distant from the referents of his utterances, but the teacher

Table 2 Transcript of Case 2

Unit	Speaker and modality	Speech and gesture transcripts
1	T speech	So [if this is my triangle]
	T gesture	RH point (holding chalk) traces line that is base of triangle
2	T speech	And [this is an exterior angle]
	T gesture	RH writes "4" inside exterior angle
3	T speech	And [these are the interior angles]
	T gesture	RH writes "1", "2" and "3" inside interior angles
4	T speech	[How] do you find that [exterior angle measure]?
	T gesture	RH flick hand toward students LH pinky point to "4"
5	S speech	[Measure of angle 2] plus {measure of angle 3} {equals}…
	T gesture	LH palm traces line segment under "4"
	S gesture	RH point to upper right interior angle of imaginary triangle in neutral space near his body RH point to lower right interior angle of same imaginary triangle
6	S speech	{[Measure of] angle [4]}
	S gesture	RH points to exterior angle of imaginary triangle in neutral space near his body
	T gesture	RH draws circle around "2" RH draws circle around "3"
7	T speech	Yeah. [Supplementary with 1]
	T gesture	RH point (holding chalk) to "1"
8	T speech	And using that, [in Chapter 4]
	T gesture	RH point (holding chalk) to student
9	T speech	We proved that [angle 4]
	T gesture	RH point to "4"
10	T speech	Is equal to the [sum of these two]
	T gesture	RH point (holding chalk) moves back and forth from "2" to "3" three times

Within each unit, the speech transcript is in the top row and the gesture transcript is in the bottom row(s). The words that co-occur with the *teacher's* gestures are indicated in square brackets; the words that co-occur with the *student's* gestures are indicated in curly brackets

S student, *T* teacher, *LH* left hand, *RH* right hand

is proximal to those referents. However, unlike Case 1, the teacher here gestures in silence while the student speaks. The teacher first explained the inscription (Units 1–3) and then posed a question inviting a response from students (Unit 4). A male student responded from his seat several feet away, and the teacher silently produced addressee gestures as the student spoke (starting in Unit 5).

In her first addressee gesture (Unit 5), however, the teacher produced what could be interpreted as a referential error. She seems to have anticipated that the student was going to say something about angle 4, so as the student began to speak, she began tracing part of angle 4 (Fig. 2). However, the student instead referred to angle 2, as became clear at the end of the first clause of his turn ("measure of angle 2"). This led to a potentially problematic moment when the teacher was tracing the line segment under the number 4, while the student was referring (in speech) to the measure of angle 2.

The teacher seems to have noted this "mismatch" between the student's speech and her gesture, and she quickly shifted to draw a circle around the number "2" in the apex of the triangle. By the time she did this, however, the student was speaking about adding the measure of angle 3 to get the measure of angle 4 (Units 5–6). At this point, the student also started to gesture himself, pointing to an imaginary triangle in neutral space in front of him. He first pointed to the upper right interior angle (corresponding to angle "2" in the figure) and then to the lower right interior angle (corresponding to angle "3"). It is possible his gestures were provoked by the teacher indicating the incorrect referent in her addressee gesture. He may have produced gestures in order to clarify his referents, even though he was distant from those referents.

After this initial gesture, the teacher's remaining addressee gestures accurately indicated the referents of the student's utterance. It is worth noting that her gestures followed the student's verbal mention of those referents in time. Thus, her gestures to specific referents were not produced *simultaneously* with the student's speech referring to those same referents; instead, her gestures lagged slightly behind. This is not surprising, given she could not know what he would say next. When he referred to the measure of angle 2, she was indicating part of angle 4; when he referred to angle 3, she was just beginning to shift her focus to angle 2; and finally, when he referred to angle 4, she was indicating the angles to be summed (2 and 3).

Although the teacher's gestures were not temporally aligned with the student's verbal mention of those referents (as they would be if speech and gesture were produced by the same person), the interaction as a whole does not feel "off" or mistimed. It seems natural that, if the teacher is gesturing to the referents of the student's utterance, her gestures must follow his speech. We return to the issue of timing in the general discussion.

As in Case 1, from the perspective of common ground, the teacher's gestures in this case appear to serve two functions. First, they ensure (and communicate to the focal student) that she understood his utterance appropriately. When it became clear that her expectation about his utterance was incorrect, the student began to produce gestures, as well, and the teacher quickly initiated a repair. Following her initial misunderstanding, she quickly grasped what the student intended to say, and her ensuing gestures accurately delineated his referents.

Second, the teacher's gestures indicated the referents of the student's utterance in a way that other students in the classroom could readily see and interpret. Thus, her addressee gestures contributed to a shared focus on specific elements of the inscription, not only for the focal student, but for students in the class overall. Indeed, many students who were captured on camera remained oriented towards the teacher, rather than turning toward the student as he spoke. To the extent the students attended to the teacher's gestures, her gestures may have contributed to the maintenance of common ground.

5 Case 3

5.1 Background information

Case 3 was drawn from a corpus of videos of pre-engineering classes. Portions of this lesson were discussed in Nathan, Wolfgram, et al. (2017); however, the excerpt we consider here was not analyzed in that paper.

This excerpt occurred in a lesson relating the mathematics of Boolean Logic to digital circuit design. The focal student was part of a group of four students working on a problem about a voting booth security system. According to the problem statement, "For privacy reasons, a voting booth can only be used if the booth on either side is unoccupied." In this context, an effective monitoring circuit has two outputs—one that indicates when a particular voting booth is available, and one that indicates when entry to the voting booth is denied because one of the two adjacent booths is occupied. Students constructed a working electronic circuit that implements this set of logical conditions.

Students used the binary mathematics of truth tables to translate the verbal problem statement to a set of logical propositions, and they then cast the set of logical expressions into a viable circuit design, which they constructed with logic gates, wires, resistors, capacitors, and a power source. They then tested the circuit to show that it worked for every possible combinatorial case ($2^4 = 16$ possibilities). A

successful circuit outputs a green light when all conditions are met and a red light when any condition is violated.

5.2 Description and analysis

In this case, both the focal student and the teacher were proximal to the referents of the student's speech. As in Case 2, the teacher in this case gestures in silence while the student speaks. Just prior to this excerpt, the teacher asked the other students in the class to gather around, and he asked the focal student to demonstrate the behavior of his group's circuit for every possibility. This demonstration linked the physical circuit the students had constructed (Fig. 3a) to the symbolic, truth table representation of the problem (Fig. 3b). The student was focused on the physical instantiation of the circuit, which was wired to a "breadboard,", a rigid platform used for circuit design.

Over the course of the episode, the student links each logically possible configuration of the circuit (i.e., each possible occupancy case in the voting booth) to the corresponding part of the truth table. The student called out each possible physical state of the circuit, and at some points, he turned relevant switches either ON or OFF; thus, he systematically tested his group's simulation of each set of conditions in the physical circuit. The student indicated and manipulated portions of the physical circuit with his left hand, and at the same time he indicated elements of the truth table with his right hand. As he described each set of conditions, the teacher gestured to the relevant row in the truth table.

The teacher's pedagogical goal for this lesson was to help students link the implemented circuit to the symbolic truth table representation. From the perspective of common ground, the teacher's addressee gestures served two goals. First, they supported the focal student's linking action by marking the row in focus at each moment. Second, they highlighted the connection between the circuit and the truth table, both for the focal student and for the other students looking on, by linking the student's actions on the circuit to the corresponding rows of the truth table. The teacher's gestures highlighted the truth table and made it more prominent for the whole group of students.

Notably, the focal student pointed to the truth table with his right hand as he indicated or touched portions of the circuit with his left hand; thus, he physically instantiated the link with his body. For example, in Unit 2, all four booths are empty; this configuration is modeled in Boolean logic as 0 0 0 0. For this instance, the student indicated the booth light in the circuit with his left hand and the corresponding value in Row 1 of the table with his right, saying "Booth is on, alarm is off." In this way, he connected the physical, grounded representation to the symbolic representation with his very body. Thus, the student demonstrates simultaneous physical linking of multiple representations through his body (Alibali et al., 2014).

Throughout this specific student utterance (i.e., Units 2–3), the teacher held his point at the end of Row 1 of the truth table. One could view the teacher's point as guiding the attention of the surrounding students (those looking on) to a specific region of the symbolic representation (the first row) and the student's points as guiding attention to an even more specific element within that symbolic representation (specific cells). Thus, the teacher's and student's points together supported targeted attention on the part of other students to specific cells within the table. Indeed, there was a certain rhythm to the coordination of their points; for each row, the teacher first moved to indicate the row as a whole, and the student then indicated specific cells within that row. In this way, the two individuals' points jointly supported a common focus on a highly specific element of the instructional context.

As the focal student shifted his attention between the circuit board and the truth table, he needed to keep track of

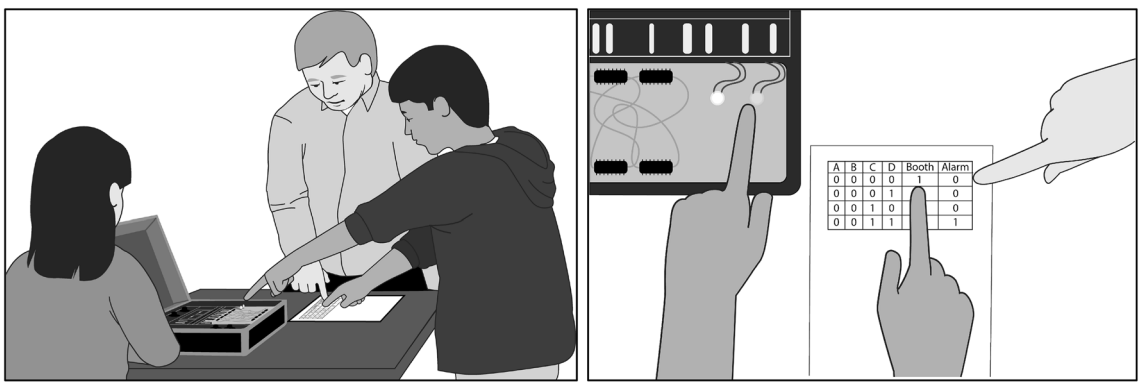

Fig. 3 **a** Students and teacher working on the voting booth problem; **b** student (hands at left and center) and teacher (hand at right) simultaneously gesturing to row 1 of the truth table (see Table 3, Unit 2)

Table 3 Transcript of Case 3

Unit	Speaker and modality	Speech and gesture transcripts
1	T speech	[K, so you're doing 0, 0, 0.
	T gesture	LH point to end of Row 1 of truth table, *holds through Unit 4*
2	S speech	So 0, 0, 0, {booth is on}
	S gesture	RH point to value of booth in Row 1 of truth table (1), LH point to booth light in circuit
	T gesture	*Held from Unit 1*
3	S speech	{Alarm is off.}
	S gesture	RH point to value of alarm in Row 1 (0), LH point to alarm light in circuit
	T gesture	*Held from Unit 1*
4	T speech	OK.]
	T gesture	*Held from Unit 1*
5	S speech	[0, 0, 1, {booth is on}
	S gesture	RH point to value of booth in Row 2 (1), LH point on rightmost switch in circuit (switches it on)
	T gesture	LH point to end of Row 2, *holds through Unit 6*
6	S speech	{Alarm is off.}]
	S gesture	RH point to value of alarm in Row 2 (0), LH point on rightmost switch
	T gesture	*Held from Unit 5*
7	S speech	[Uh, {0, 0, 1, 0, booth, alarm}
	S gesture	RH point to left portion of Row 3 (0 0 1 0), LH on circuit (finger obscured)
	T gesture	LH point to end of Row 3, *holds through Unit 8*
8	S speech	{Same thing.}]
	S gesture	RH point to value of booth in Row 3 (1), LH on circuit (finger obscured)
	T gesture	*Held from Unit 7*
9	S speech	[This {too, so the green one should come on here}
	S gesture	RH point to value of alarm in Row 3 (1), LH on circuit (finger obscured)
	T gesture	LH point to end of Row 4, *holds through Unit 11*
10	S speech	And {it does}
	S gesture	RH point to value of booth in Row 3 (0), LH on circuit (finger obscured)
	T gesture	*Held from Unit 9*
11	S speech	And the red one doesn't matter.]
	S gesture	No gesture
	T gesture	*Held from Unit 9*
12	T speech	[Yeah.]
	T gesture	LH point to end of Row 4

Within each unit, the speech transcript is in the top row and the gesture transcript is in the bottom row(s). The words that co-occur with the *teacher's* gestures are indicated in square brackets; the words that co-occur with the *student's* gestures are indicated in curly brackets. Gestural holds are indicated in italics

S student, *T* teacher, *LH* left hand, *RH* right hand

his "place" in the table, as well as to change the configuration of switches to simulate the relevant conditions. At the same time, the student also needed to assess the accuracy of his circuit design—a task overlaid on the task of connecting representations, and presumably a challenging task that demanded working memory resources at a moment when they were already taxed. The teacher supported the student's keeping track by holding the position of his own point on the relevant row until the student moved on to the next row, and he then moved his gesture in sync with the student's shifting focus.

6 Discussion

This research sought to characterize ways in which people use their *own* gestures to support *others'* turns at talk. We considered three cases in which teachers used their own gestures to support students' contributions to the classroom discourse. We have argued that gestures of this sort kind help promote shared focus and understanding. Of course, we did not directly assess teachers' intentions, so we cannot state with certainty that teachers *intended* their gestures to foster common ground. Indeed, teachers may have produced

gestures with other explicit intentions, such as to amplify or center a particular student's contribution to the discourse or to build rapport with a particular student. Nevertheless, our analysis suggests that, regardless of intentionality, such gestures may function to maintain common ground in a broad sense—not only for the teacher and the student who is speaking, but for other students who are present and looking on. In brief, we argue that teachers produce gestures in service of their pedagogical goals, broadly construed, and that these gestures function to promote common ground in the classroom as a whole.

How do such gestures contribute to establishing and maintaining common ground? In the cases discussed herein, teachers used their own gestures to highlight and disambiguate the referents of students' utterances. They did so both when those referents were distal to the student speaking (Cases 1 and 2) and when those referents were proximal but highly complex (Case 3). By identifying specific referents, teachers' gestures connect students' speech to the context, making that speech refer precisely and accurately. Such gestures may serve two functions: they demonstrate that the teacher understands the student's speech, and they identify referents unambiguously for other students in the class. Thus, we claim that teachers use gestures both to ensure they share common ground with the student who is speaking and to foster common ground for the class as a whole.

6.1 Why do teachers use gestures to support students' contributions?

Why do teachers use their own gestures to support students' turns at talk? We argue that there are spatial, sociocultural, and semiotic reasons for doing so.

One set of reasons is *spatial*. Certain classroom layouts may promote teachers' use of gestures to support students' contributions. In many US classrooms (as in Cases 1 and 2), the teacher stands at the front of the room and presents information, often at a board, to the class. Students sit at desks arranged in rows or small groups, distant from the board. When students refer to inscriptions on the board during whole-class discussions, they often do so from their desks, so their gestures are potentially ambiguous. For example, if a student in the third row points to the board and says, "I didn't get that part," the referent is likely unclear. To clarify ambiguous referents, teachers may produce gestures that indicate referents that are out of students' reach. These gestures may make the communicative acts more successful, not only for the student who is speaking, but also for other students following along. Thus, the physical layout of the classroom contributes to the "need" for addressee gestures to clarify reference. We predict that the frequency of addressee gestures in classroom discourse may depend on classroom layout.

Another set of reasons is *sociocultural*. Across cultures, there are variations in how teachers use the board (Stevenson & Stigler, 1992), and more generally, in practices of making representations visible during instruction (Richland, 2015). Teachers often use gestures to direct attention to external representations (Alibali et al., 2014; Hare & Sinclair, 2015), so it is not surprising that there are associated cross-cultural variations in teachers' use of gestures (e.g., Alibali et al., 2011; Richland, 2015). No research to date has focused on variations in teachers' use of gestures to support students' contributions; however, it seems likely that certain cultural practices, such as extensive use of the board, may promote teachers' use of gestures to clarify the referents of students' utterances.

Along similar lines, teachers' gestures may vary depending on social norms and participation structures that are typical in classrooms. In some cultures, students are often called to the board to present their work (e.g., Stigler & Hiebert, 1999). When students are near the inscriptions they are speaking about, they can produce proximal referring gestures themselves, so their teachers may be less likely to use gestures to support students' contributions. Thus, cultural practices that affect the use of inscriptions and the spatial positioning of students and teachers relative to inscriptions may influence teachers' use of gestures to support students' contributions.

Social dimensions of classrooms also influence teachers' use of gestures. Enyedy and colleagues (2008) have argued that teachers use revoicing in an effort to position students with respect to the mathematical task at hand or with respect to social and sociomathematical norms within their classrooms. Teachers may wish to amplify certain voices or to highlight certain types of mathematical contributions, and they may strategically use gestures in doing so.

There are also *semiotic* reasons for teachers using their own gestures to support students' contributions. As discussed above, students and teachers sometimes engage in "semiotic games" (Arzarello & Paola, 2007; Arzarello et al., 2008) that refine and extend students' everyday language for mathematical objects and ideas. In the semiotic game, a teacher's repetition of a student's gesture reinstates the very idea referenced by the student, thereby validating the student's contribution and fostering common ground. At the same time, the teacher introduces new mathematical terms and ideas into the discourse. As in the semiotic game, in classroom interactions like those considered here, teachers may strategically use their own gestures to knit together students' informal knowledge and the more formal mathematical knowledge that is the pedagogical focus of the lessons.

Teachers sometimes repeat or imitate students' gestures directly (Arzarello et al., 2008), and they sometimes modify students' gestures to serve their pedagogical goals (Flood, 2018). In Cases 1 and 2, the teacher gesturally revoiced the

students' gestures, modifying them to refer more precisely. In each case, the modifications seemed natural, given the spatial positioning of teacher and students. In Case 3, the teacher layered his gestures onto the student's verbal and gestural turns. Each of the teacher's gestures indexed a general referent (i.e., a row of the table) that encompassed the more specific referents (i.e., individual cells) of the student's gestures.

When teachers mimic or modify students' gestures, they may produce gestural *catchments*, defined as a set of gestures that share some recurring formal features, such as handshape or trajectory (McNeill et al., 2001; McNeill, 2005). When a teacher mimics a student's gestures, or modifies a student's gestures while maintaining some elements of their form, they are, in effect, producing a gestural catchment *across individuals* (see Yoon, Thomas, & Dreyfus, 2014). Catchments link the verbal utterances that occur with each of the catchment gestures—tying gestures and speech into a semiotic bundle, in Arzarello and colleagues' (2008) terms. According to McNeill (2005), such gestural catchments manifest cohesion in discourse. As such, teachers' use of gestural catchments may help students to "follow the thread" of the discourse, and this may be one way in which gestures help maintain common ground.

A few words of clarification on the relations among gestural revoicing, multimodal revoicing, addressee gestures, and gestural catchments are in order (see Table 4). As used by O'Connor and Michaels (1993), the term *revoicing* involves repeating another person's speech or restating it in more precise terms. The gestural counterpart—repeating another person's gestures or modifying them to have more precise referents—can be conceptualized as *gestural revoicing*. In some cases, as in Case 1, the individual producing the gestural revoicing also repeats or restates the prior speaker's speech—what we term *multimodal revoicing*. In other cases, the individual producing the gestural revoicing does not speak, but aligns his or her gestures with the other person's speech, using *addressee gestures*. In some cases, addressee gestures involve repeating or modifying another speaker's *gestures*; however, in other cases, addressee gestures involve "translating" a speaker's *speech* (produced without gesture) into gestures. We refer to both types of cases as *gestural revoicing*, because they are produced in gestures. Thus, some addressee gestures involve gestural revoicing of others' gestures, while other addressee gestures involve gestural revoicing of others' speech.

Whenever an interaction involves multiple gestures—produced either by the same speaker or by different speakers—a gestural *catchment* may occur if the gestures share common formal features. Gestural or multimodal revoicings of others' gestures often maintain some common features of the initial speaker's gestures, giving rise to gestural catchments across speakers.

6.2 Questions for future research

These findings raise several key questions for future work. Here, we consider six questions; there are certainly many others.

First, how do teachers decide when to use their own gestures to support students' turns at talk? Teachers must have some sense of when common ground is at risk, as well as some idea about what needs to be clarified or highlighted. Teachers presumably make such judgments based on an evaluation of the spatial, sociocultural, and semiotic circumstances discussed above. They also presumably draw on their pedagogical content knowledge, their ideas about what their students are likely to know, and their pedagogical goals, including goals about students' mathematical content knowledge and their developing academic identities.

With respect to addressee gestures specifically, teachers must engage in some sort of "mind reading" in order to predict what the student speaker is likely to say next, and how an addressee gesture might be beneficial to the communicative exchange. Teachers may sometimes incorrectly predict what a student is going to say, so they may produce gestures that do not perfectly align with what the student actually says. Such cases highlight that producing addressee

Table 4 Different ways in which teachers may support students' contributions

	Teacher gestures *while* student speaks	Teacher speaks and gestures *after* student speaks
Student speaks and gestures	Addressee gesture Gestural revoicing of student's gesture and/or speech Possible catchment	Multimodal revoicing Possible catchment
Student speaks but does not gesture	Addressee gesture Gestural revoicing of student's speech	Multimodal revoicing

In some cases, a teacher produces addressee gestures that align with a student's turn; these cases represent gestural revoicing of the student's contribution. In some cases, a teacher speaks and gestures *after* a student's turn; these cases represent multimodal revoicing. When a teacher produces a gestural or multimodal revoicing of a student's turn that includes gesture, the teacher's and student's gestures form a gestural catchment if they share formal features

gestures is highly complex, both cognitively and socially. Indeed, teachers may be differentially likely to use addressee gestures, depending on their teaching experience or on their views about gestures.

Second, to what extent do teachers' gestures involve mimicry of students' gestures? This broad question encompasses many more specific ones. For example, if the student who is speaking produces gestures, albeit ones that are distant from their referents (and therefore, ambiguous to others), is the teacher more likely to produce gestures than if the student did not produce gestures? And when teachers do produce addressee gestures that revoice students' gestures, are teachers likely to faithfully mimic formal aspects of the students' gestures—for example, handshape or motion—or do they often modify or transform the students' gestures? Teachers' gestural revoicings may transform students' gestures in ways that can be viewed as clarifications (i.e., of referents) or elaborations—just as verbal revoicings often involve clarifying or elaborating students' speech.

Third, how do the physical layout of the classroom and social norms about movement within the space affect teachers' use of gestures to support students' turns at talk? We suggest that people may use gesture to support others' contributions to the discourse whenever they are close to the referents of the speaker's speech and the speaker is physically distant from them. Classrooms in which students are expected to "stay seated" may be fertile ground for such gestures. This hypothesis implies that it may be possible to elicit gestures in an experimental setting—a promising avenue for future work.

Fourth, does the timing of addressee gestures matter? In Case 2, the teacher's gestures followed the relevant speech by small margin—presumably because the teacher needed to process the student's utterance in order to generate her own gestures. If the teacher were more certain of what the student was about to say, her addressee gestures might have been more closely aligned with the student's speech. How do teachers manage this delay when they produce addressee gestures? Relatedly, does the timing of those gestures matter for students' comprehension? In general, people seem to tolerate a fairly loose synchronization of speech and gesture; however, little is known about how people process gestures and speech that are tightly and loosely synchronized. More generally, little is known about the cognitive processes involved in comprehending addressee gestures, particularly those produced by speakers who are spatially distant from the speaker and those that are produced with a temporal lag.

Fifth, do teachers' addressee gestures differ in systematic, formal ways from other gestures they produce during instruction or when interacting with individual students? We have suggested that teachers sometimes use gestures to elevate an individual student's contribution as an object of focus for the class as a whole. When they do so, do they make those gestures prominent for the group, for example, by producing large gestures or by producing them high in space?

Finally, do teachers' addressee gestures matter for students' learning? Based on the large body of research on teachers' gestures, we suspect that they do. However, it might also be challenging for students to integrate gesture and speech across speakers (e.g., when a student speaks and the teacher gestures)—and this may make gleaning information from those gestures more challenging. Thus, it remains an empirical question whether addressee gestures are actually beneficial for students' learning.

7 Conclusion

In this research, we have documented previously unstudied ways in which teachers use gestures to manage common ground in classrooms. By analyzing instructional interactions in which teachers' gestures play a key role, we hope to promote further interest in micro-analyses of classroom discourse that incorporate a focus on gestures, including those produced by speakers and those produced by addressees. Our research suggests that teachers use their own gestures, not only to support individual students' contributions to the classroom discourse, but also to make those contributions prominent for other students. Thus, teachers' gestures serve both to ensure that they share common ground with individual students and to foster common ground among the class as a whole.

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