# Coordinating and sharing gesture spaces in collaborative reasoning

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In collaborative reasoning about what causes the seasons, phases of the moon, and tides, participants (three to four per group) introduce ideas by gesturing depictively in personal space. Other group members copy and vary these gestures, imbuing their gesture spaces with similar conceptual properties. This leads at times to gestures being produced in shared space as members elaborate and contest a developing group model. Gestures in the shared space mostly coincide with conversational turns; more rarely, participants gesture collaboratively as they enact a joint conception. An emergent shared space is sustained by the joint focus and actions of participants and may be repositioned, reoriented, or reshaped to meet changing representational demands as the discourse develops. Shared space is used alongside personal spaces, and further research could shed light on how gesture placement and other markers (such as eye gaze) contribute to the meaning or function of gestures in group activity.

**Keywords:** gesture space, depiction, group reasoning, shared space, collaborative gesture

## Introduction

The common locus for gesture[1] is the space in front of a speaker's upper body. This finding is well supported by studies of conversations in natural settings (Kendon, 2004, and many others) and by experimental studies in which participants retell events from a cartoon, film, or fairy tale (McNeill, 1992, and subsequent work in this paradigm). In conversations and experiments like these, speakers talk often about things that are not visible to their addressees, and their hand movements evoke aspects of what they are describing in the air in front of them. In studies that focus on situated activity, by contrast, speakers often talk about objects that are part of the task they are engaged in, and their hand movements couple with these objects to generate task-relevant meanings (Goodwin, 2007); indeed, work and school settings are populated by artifacts intended to support specific activities. Of course, people do gesture in the air while conversing in a task setting, and people do gesture over objects in everyday interaction, yet how people use different spaces for gesture remains a relatively underexplored area of research.

The present study lies between these two types of scenarios, as participants engage in joint activity without material supports for the task at hand. Small groups of college students reason about spatial relations, relative motion, and force dynamics of multiple

celestial bodies as they seek to explain what causes the seasons, the phases of the moon, or the tides. In their interactions, they offer a mix of spontaneous ideas based on direct experience ("Is it hotter in summer because the earth is closer to the sun?") and remembered bits of knowledge from past education ("I think it has something to do with the earth's tilt on its axis"). Without tools for modeling or drawing, the participants use their hands to represent, explore, and contest portions of celestial models that may explain the phenomena they are considering. As participants gesture in front of their own bodies, they often copy and vary the gestures they see in others, and they also, at times, begin to gesture in the space between participants, giving rise to a shared locus for gestural turn-taking or collaborative gesturing.

In what follows, I briefly review how gesture space has been described in the field of gesture studies, introduce the study of gesture space in collaborative reasoning, and present and discuss findings, focusing on the coordination and sharing of gesture spaces.

## Descriptions of gesture space

### *Personal gesture space*

In his groundbreaking experimental studies, psychologist David McNeill (1992) describes co-speech gestures as occurring in a space that "can be visualized as a shallow disk in front of the speaker, the bottom half flattened when the speaker is seated," in which "the fore-aft dimension is shorted" (p. 86). Though he describes gesture space as a disk, McNeill depicts gesture space as boxlike (Figure 1a), with nested squares and labeled regions used to code the location of speakers' gestures. From studies in which a participant views a cartoon and then describes the portrayed events to a listener, McNeill and his team find that iconic gestures representing objects or actions shown in the cartoon fill the center space in front of the speaker's chest, while metaphoric gestures that serve metanarrative or discourse functions, such as establishing the context or offering an explanation, occur somewhat lower, closer to the speaker's lap (p. 88). Deictic (pointing) gestures extend away from the center into the periphery. For research on deixis in gesture, Ellen Fricke (2005, in prep.) added a third dimension to McNeill's coding scheme: an axis extending from the speaker's chest, used to code distance from the speaker's body (Figure 1b), resulting in a three-dimensional, though still box-like, representation of gesture space.

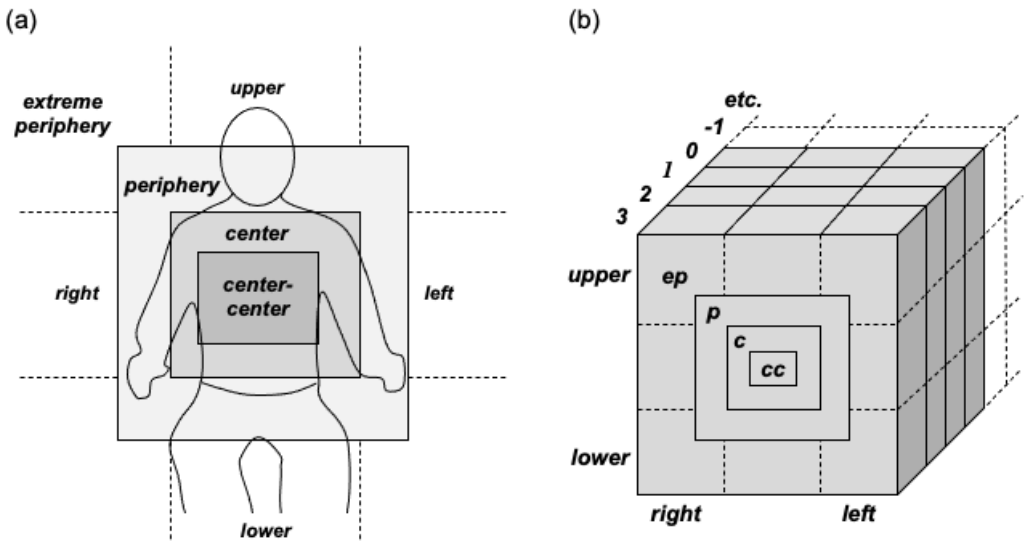


**Figure 1.** (a): McNeill's coding scheme for the gesture space of a seated adult speaker (see McNeill, 1992, p. 89). (b): Fricke's expansion of McNeill's space to three dimensions, adding an axis to code distance from the speaker's body (Fricke, 2005, in prep.).

In ethnographic studies of conversational gesture in natural settings in Italy and Britain, gesture studies pioneer Adam Kendon also describes gesture space as in front of the speaker's upper body, with gestures being "spatially inflected" in the direction of objects or locations to which they refer (2004, pp. 200 & 311-312). The object may be present, may be referenced through a surrogate object, or may be evoked as a virtual object by the gestural actions. Kendon finds that locations in space may also be treated as tokens for people or ideas being considered in the discourse, with verbal reference coinciding with gesture toward these locations (pp. 200, 311-312). While Kendon does not use a scheme to code gesture placement and movement as McNeill does, his findings from naturalistic studies are similar to McNeill's experimental conclusions that the space in front of the upper body is the conventional locus for gesture.

More recently, researchers have begun to use motion-capture technology to examine the use of space in gesture. In a pilot study, Priesters and Mittelberg (2013) analyzed data from four seated German speakers talking about life and career decisions. They found that the speakers differed strongly in their rates and spatial distribution of gestures and also varied in their relative use of the dominant versus non-dominant hand. For infrequent gesturers, one gestured near the lap (where the hands were resting) and another in a dispersed pattern in front of the upper body with some left-hand holds near the lap. For frequent gesturers, one gestured in front of the chest and the other alternately in front of the chest or near the lap. Viewed from above, lower gestures were closer to the knees and higher gestures midway between the chest and knees, reflecting the bending of the arm at the elbow; one active gesturer also extended the dominant hand farther forward, In this limited sample, Priesters and Mittelberg find that while speakers are

idiosyncratic in how they use gesture and how they distribute gestures with different functions across space, the majority of gestures are performed in front of the speaker's upper body, with less extension in depth than in other dimensions, consistent with the views above. Priesters and Mittelberg argue for a view of gesture space as "adaptive, dynamically constructed and sphere-shaped" (p. 4), and they state their intention to refine the motion-capture techniques to study "the shape and structures of shared gesture spaces," although to date, no further data has been published.

The view that has coalesced from these and other studies is of a personal gesture space in front of the speaker's body, where the hands move freely below eye level yet within the speaker's peripheral vision. The space has breadth, owing to the separation of the arms, and also roundness from the way the arms move. Movements extend beyond this space when they are directed toward objects or locations, whether real or virtual. Individuals differ in how much they gesture and how they distribute gestures in personal space when conversing.

*Viewpoint, scale, and status*

While speakers commonly gesture in front of the upper body, the use of space is affected in part by the viewpoint from which gestures are produced. McNeill (1992) distinguishes *observer viewpoint* (O-VPT), in which the gesturer depicts objects or actions in front of the body as if viewing them from the outside, from *character viewpoint* (C-VPT), in which the gesturer enacts a person's or character's actions, thereby inhabiting the gesture space and incorporating more of the arms, head, or upper body into the gestures (pp. 118-125). Others refer to this distinction as *third-person* or *external perspective* versus *first-person* or *internal perspective* (see Parrill, 2009, p. 274, for a table of terms and distinctions). Streeck (2009) distinguishes *mimetic viewpoint* (first-person) from *analytic viewpoint* (third-person), claiming that conceptual distance is displayed by the speaker producing mimetic gestures frequently "in the plane of the body, i.e., laterally" and analytic gestures "at arm's length from the observer." Speakers alternate between viewpoints to "re-enact and re-experience their own intense emotional involvement in situations" and "give an empathetic display of their … actions" (mimetic viewpoint) or to "analyze these same actions within an objectively construed context" (analytic viewpoint) (p. 207). Studies of young children's gestures find a high preponderance of character-viewpoint gestures (McNeill, 1992, pp. 301-302; Andrén, 2010; Zlatev, 2014), so the proportion of observer-viewpoint gestures must increase during development; this is an area in need of further research. Finally, it's worth noting that gesturers can exhibit both viewpoints at once, using separate articulators to produce "dual viewpoint gestures" (McNeill, 1992, pp. 98, 122-125, 318-319; Parrill, 2009), but most commonly gestures are produced from a single viewpoint or perspective at a time.

Gesture spaces also vary in scale and size. The hands can depict anything from molecules (Becvar, Hollan, & Hutchins, 2005) to planets (this study); scaling what is being represented into the space in front of the speaker makes it possible to "think with eyes and hands" (Latour, 1986). An analytical depiction may be expanded to make it more visible to

an audience, as when a lecturer produces oversized diagrams in the air (Núñez, 2007; Mittelberg, 2010). For mimetic depiction, inhabiting the space and portraying from the perspective of someone or something within that space renders events at what Fauconnier and Turner (2002) call "human scale," that is, the scale at which humans perceive and act. A speaker rapidly selects a viewpoint and scale for gesture to serve her communicative purpose in the given context.

As the discussion of viewpoint suggests, when gestures are produced, they imbue the space in which they are performed with a temporary conceptual status. When a person telling a story makes a pointing gesture, the "pointing conjures up a space oriented and populated by conceptual entities" (Haviland, 2000, pp. 18-19), and this narrative space is often distinct in time, location, and composition from the local space in which the interlocutors interact. Surrogate objects in the setting or the gesturing hands themselves may stand for objects in the narration, grounding the narrative space (Liddell, 1998; Haviland, 2000; Parrill & Sweetser, 2004). In a study of math teachers engaged in joint problem-solving during a professional development session, Yoon, Thomas, and Dreyfus (2011) note that a teacher gesturing the gradient of a function in the air endows the space with mathematical properties, and this meaning is maintained by the original speaker and by her interlocutor (pp. 382-383). Speakers may establish and switch rapidly among spaces with different conceptual statuses, and they may even laminate one space onto another to create conceptual correspondences (Haviland, 2000, pp. 32-38) or conceptual blends anchored by material structure (Williams 2008a, 2008b).

*Interpersonal space and alignment of gesture spaces*

When people interact, multiple gesture spaces come into play. Sweetser and Sizemore (2008) distinguish three types of space: personal gesture space, interpersonal space, and extrapersonal space (Figure 2). Personal gesture space is the space described earlier in which speakers produce gestures in front of their bodies, although Sweetser and Sizemore characterize it as semi-spherical (defined by the range of hand motion) rather than disk-like or box-like. Interpersonal space is "the space in between two personal gesture spaces, along the line between the interlocutors" (pp. 25-26), while extrapersonal space is "the 'unclaimed' surrounding space" (p. 26) that can be annexed by speakers during communication. With this distinction it becomes significant when gesturers reach into interpersonal space or gesture toward extrapersonal space. In the conversation they analyze in detail (two young women seated at a table while they discuss terrible roommates), Sweetser and Sizemore find that participants reach into interpersonal space with a palm-down or pointing hand to claim or hold the floor ("Listen, …") or to mark solidarity by affirming similar goals or feelings. They assert that "when [speakers] reach outside of their personal space into the interpersonal space, this is a sure sign that (1) they are engaged in regulating the speech interaction, and (2) that the regulation is highlighted rather than backgrounded" (p. 27). We will see in the present study that speakers also reach into interpersonal space under certain conditions to depict content, and we will examine how that arises.

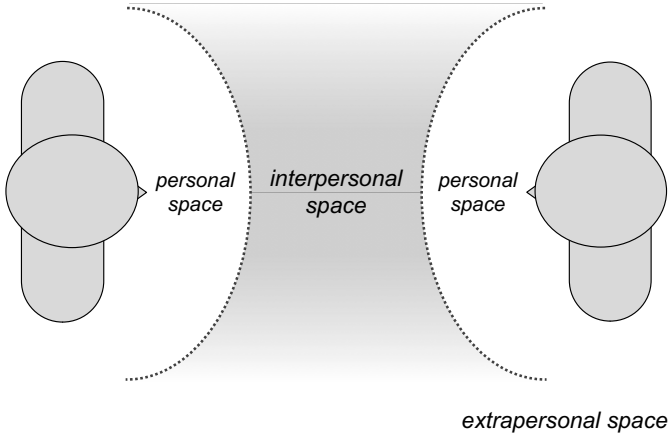


**Figure 2.** Gesture spaces described by Sweetser and Sizemore (2008). The interlocutors' personal spaces are semi-spherical, in contrast to McNeill and Fricke (Figure 1). Between the personal spaces lies interpersonal space, while the surroundings constitute extrapersonal space. A gesture's significance is affected by the space in which it is produced or toward which it is directed.

Without making this tripartite distinction, Özyürek (2000) finds that the positioning of interlocutors affects the alignment and use of gesture spaces, even to the point that depictions may not conform precisely to the events being described. Özyürek has speakers narrate cartoon events as in McNeill (1992). When a listener is positioned slightly to the side, the speaker's gesture on the word "across" crosses the region of the speaker's gesture space that faces the listener rather than the space directly in front of the speaker's body (Figure 3a). When two listeners are present, forming a triangular configuration, the speaker enacts throwing something over her shoulder (into what Sweetser and Sizemore call "extrapersonal space") as she says "threw him [Sylvester the cat] out the window" (Figure 3b), even though in the cartoon the cat was thrown forward. Were the speaker to depict the throwing as it was done in the cartoon, she would appear to throw the cat toward her interlocutors or into the space between them, which could lend the gesture a different significance. In these examples, an imaginary axis between the speaker and listener affects the orientation of personal gesture spaces, and multiple such axes circumscribe the area that is interpersonal versus extrapersonal space, with concomitant effects on the placement and direction of gestural movements.

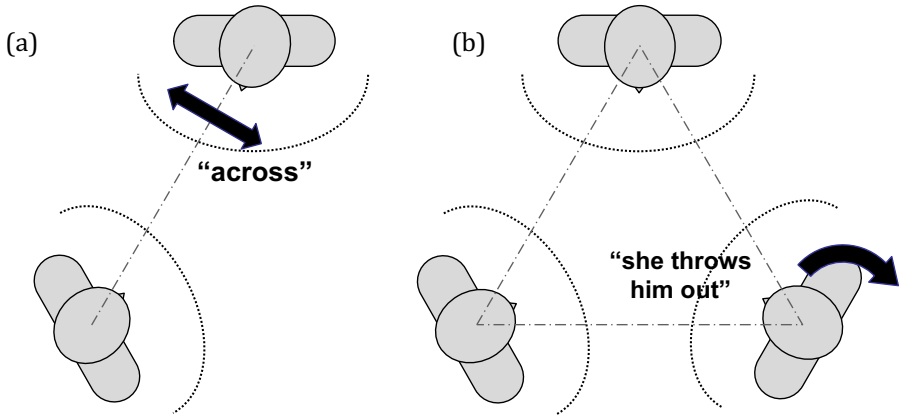


**Figure 3.** The arrangement of interlocutors affects the alignment and use of spaces for depictive gestures (Özyürek, 2000).

*Mutual orientation and environmentally coupled gestures*

The foregoing discussion of gesture spaces focuses on conversational interactions or experimental situations where people talk about characters, objects, and events that are not present at the moment of discourse. In much interaction—especially in workplace or educational settings—people talk about objects that are both present and the focus of shared attention (Figure 4). In these situations, interlocutors orient variously toward each other, toward focal objects in the local space (such as diagrams, displays, or environmental features), or toward distant objects, even when these are beyond view (as when giving directions). When mutually orienting toward an object (such as a map), participants may gesture on or over the object to direct attention to its features and to elaborate task-relevant meanings. Because these "environmentally coupled gestures" (Goodwin, 2007) depend on the focal object for their interpretation, the space on and over the object can become a site for gestural turn-taking as meanings are depicted or contested in the discourse. A focal object thus comes to anchor a shared space for gesture that is distinct from participants' personal spaces, which also persist as possible loci for gestures in the air in front of speakers' bodies.

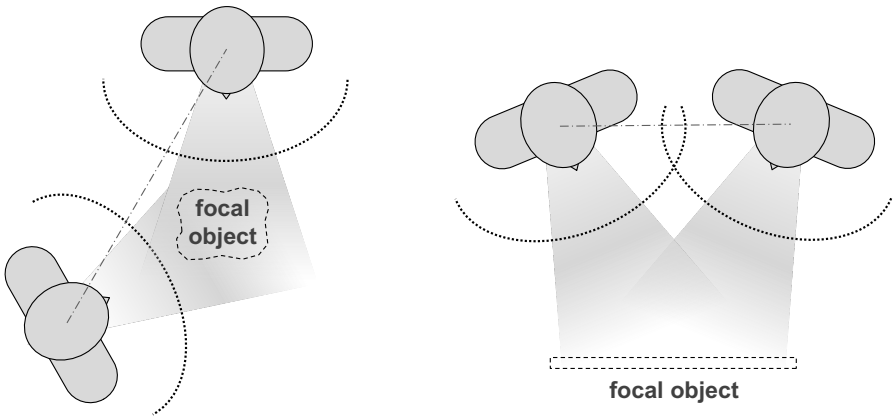


**Figure 4.** Interlocutors' orientation toward an object of shared attention, which may become the locus for environmentally coupled gestures (Goodwin, 2007).

When people orient toward multiple objects (such as a map and the surroundings), they often shift their gestures between these object-anchored spaces so that meanings elucidated in one space can be linked with meanings in another, creating correspondences. Goodwin (2003) describes the example of an archaeology professor and graduate student gesturing over features in the soil and over a diagram the student is constructing as they seek agreement on what the features represent and how they are to be recorded (pp. 221-225). Alač and Hutchins (2004) describe a similar interaction between an experienced fMRI researcher and a novice in which the researcher gestures over a chart she has drawn and then, with the same handshape, over the image of a brain scan on the computer monitor as she teaches the novice how to interpret the display (pp. 645-650). Interactions like these can include several spaces: Williams and Harrison (2012) analyze an impromptu teaching situation in which a lifeguard on a beach gestures in four different spaces—over diagrams in the sand, on top of a digital wristwatch he is wearing, toward the surrounding geography, and (least often) in the air in front of his body—as he seeks to teach a novice how to find cardinal directions using an analog wristwatch and the sun. These examples show how cognitively complex activities are perpetuated in part by the creation and linking of meanings in multiple gesture spaces, including personal gesture space and spaces anchored by artifacts that support particular kinds of tasks.

*Summary*

As this brief discussion shows, our understanding of gesture space is becoming multifaceted, raising questions about how spaces are established and employed in interaction and how this gives rise to different effects. Each speaker has a personal space that is a home for gestures in the air when they are not inflected toward objects or locations or coupled with focal objects in the setting. Gestures may couple with actual objects referenced in the discourse or with surrogates for these objects (as when a speaker points to her own body to identify the location of someone else's injury) or even with virtual objects evoked by the gestural movements themselves (Kendon, 2004, pp. 311-312). Gestures may also reference locations in space that have been established as tokens

for particular people, objects, or ideas in the preceding discourse (p. 312). The positions of discourse participants and their orientations toward one another affect the alignment and use of personal gesture spaces, while they also create an intervening, interpersonal space that may play a role in regulating the discourse. While speakers typically gesture in their own personal space, they may reach into another's space when gesturing over a focal object in front of that person (Goodwin, 2007; Streeck, 2009) or when indexing a virtual object or surrogate established by the other person's gesture (Kendon 2004). Reaching into another's space may be facilitated when interlocutors are aligned shoulder-to-shoulder and viewing a real or virtual object from a similar vantage point (Furuyama, 2000; Yoon, Thomas, & Dreyfus, 2011). Reaching into another's space may also have emotional overtones depending on the nature of the relationship between the interlocutors and on the situational context; the affective dimensions of gesture space, while intriguing, are beyond the scope of this discussion.

## Study of collaborative reasoning

The present study examines the use of gesture spaces in collaborative reasoning about everyday scientific questions. Dillenbourg (1999) considers a situation to be collaborative "if peers are more or less at the same level, perform the same actions, have a common goal, and work together" (p. 7). The study uses situations that match these characteristics, with small groups of peers attempting to formulate explanations for familiar phenomena without the aid of reference materials. Dillenbourg further notes that interaction is collaborative when it is interactive, synchronous, and negotiable, with space for misunderstandings (pp. 8-9). In the present study, members are co-present and engaged in synchronous communication, and no roles are assigned or directives given as to how members should interact, only that they should discuss until they agree on an explanation, thus leaving space for disagreement and negotiation of understanding. The directive to seek agreement is meant to encourage continued engagement in the task and to distinguish phases of discourse for later gesture analysis, namely, reasoning toward joint understanding (building a model) versus explaining an agreed-upon solution (presenting a model). The examples presented in this article focus on the first phase: reasoning toward joint understanding.

In the study, groups of three to four undergraduates at a small midwestern American university are asked questions about what causes the seasons, the phases of the moon, and the tides, and instructed to discuss until they agree and then to explain their answer. The causes of the seasons, phases of the moon, and tides were chosen as topics because they involve changing spatial relationships among multiple objects and are prone to common misconceptions: that the earth is closer to the sun in summer (seasons), that the earth casts its shadow on the moon (lunar phases), and that the moon's gravity alone pulls on the oceans (tides). Students have typically learned at some point in the past that seasons have to do with the tilt of the earth on its axis and the angle of sunlight, that the phases of the moon have to do with the directions of viewing from the earth and

illumination from the sun, and that the tides are affected by the gravitational pulls of both the moon and the sun, with the moon's proximity making its influence greater. When students reason about these questions, they often begin with a mixture of common misconceptions and remembered bits of previously heard explanations. They must work together to fit these pieces into a coherent model, to resolve discrepancies among them, and to arrive at an explanation that everyone is willing to acknowledge as preferred over the other possibilities. In this process of interactive reasoning, students frequently use gesture to represent celestial bodies and their relations and effects on one another as they seek to arrive at a shared understanding.

There were two rounds of data collection. The first round involved four groups of four students each. Each group was seated at a semi-circular table on which there were three face-down cards with the questions "What causes the tides?", "What causes the phases of the moon?", and "What causes the seasons?" A group member selected a card at random and read the question to the group. The group discussed until they agreed upon an answer (or came as close to agreement as they felt possible), and then one group member, self-selected or chosen by the others, explained the group's solution. The group then continued in the same way with the remaining two questions. Discussions in the first round ranged from 4:28 to 14:46 (minutes:seconds), depending on how long it took groups to reach agreement. The second round involved eight groups of three students each. Each group was seated in three swivel chairs in a semi-circle, this time with no table present, and each answered the questions "Why is it hot in the summer and cold in the winter?" and "Why is the tide highest at the full moon"? As before, groups were instructed to discuss until they agreed upon an answer and were then asked to explain their solution. Discussions in the second round ranged from 2:04 to 8:02. Both rounds used the same topics, directions, and phases of discourse. The number of participants, presence or absence of a table, and wording of questions (asking about causes versus relationships) were varied across the two rounds to create diverse conditions for group reasoning and explanation, so that common patterns would be attributable to the nature of the discourse rather than the particulars of the set-up. The present paper considers only the reasoning phase, where groups sought to construct and agree upon an answer to the posed question.

The group discussions were recorded with digital video to provide records of interaction that could be examined to compare the production and timing of gestures during the reasoning and explaining phases (a separate study) and to examine the use of space for individual or joint depiction through gesture (the study reported here). For the use of space, the study proceeded micro-ethnographically (as in Alač & Hutchins, 2004; Goodwin, 2003; Streeck, 2009; Williams, 2006; and others), explicating patterns in the data rather than applying a predetermined coding scheme. Key phenomena with illustrative examples are presented below.

## Findings

### *Collaborative model building*

Whether the topic was seasons, phases of the moon, or tides, the group interactions followed a similar progression: introducing facets (initial ideas or remembered bits of information) with speech and gesture, exploring or elaborating facets to accept or reject them as potential building blocks, fitting facets together and thereby often detecting problems, and testing emergent models to see if they could produce the known effects. Groups varied in the number of facets they explored before arriving at an agreed-upon model. One group attempting to explain what causes the seasons considered all of the following: the rotation of the earth; the angle of the earth's axis; the effects of the moon and sun and gravitational fields of "all the planetary bodies" on the earth's axis; magnetic fields; hours of sunlight; the orbit of the earth around the sun, including its distance at different times of the year; and earthquakes and other geological phenomena that affect the earth's axis. Most groups explored fewer facets before agreeing on a model or, if not a complete model, a small set of factors likely to play a role. The form and timing of gestures produced while reasoning toward an agreed-upon model is the focus of separate work; what concerns us here is the use of space for depictive gesture during the group activity.

### *Appropriating and elaborating others' gestures in personal space*

Group members who introduced a facet commonly did so with a representative gesture in their personal space; others who considered the facet often produced a similar gesture in their own personal space as they expressed acknowledgement of the facet, and they varied the gesture as they explored its possibilities, elaborated it with further speech, or combined it with other elements (as in Yasui, 2013). Samples of this appropriation, elaboration, and combination of gesture are shown in Figure 5, where bolded text indicates speech with gesture, bracketed text in italics describes the gesture, and an asterisk in the text locates the moment depicted in the image.

(a) Mirroring, 0:10-0:20 (*= image 0:18)


S1: the **axis**… *[R vert. hand, swaying]*
S2: the axis of the earth
S1: yeah, the, the-
S2: the **angle**- *[L hand tips out]*
S1: the **an*gle-of-the** ┌ **axis** *[R hand mimics]*
S2: └ yeah-
S1: -yeah
S2: yeah

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(b) Copying, 0:15-0:32 (*= image 0:29)

S1: anyway, **the earth** *[R palm up, index traces small horz. circle]* rotates on its **axis** *[R palm up, thumb & index twist],* right? / S2: yeah
S1: **anyway…** *[repeats thumb & index twist]* / S2: *[raises R vert. hand and tips inward]*
S1: the, oh-, yeah *[2 hands palm in, rocking]*


S3: well that's night and day, we're rotating-
S1: but then like- *[R held in air]*
S3: -revolving is when it's **closer** *[R palm down, index finger traces horz. circle]*, like
S2: oh, so it's like **this-** *[R palm up like S1]*
S1: ┌ *[repeat R palm up, *hold]*
S3: ├ like **a re*volution** *[retraces horz. circle]*
S2: └ **mov*ing** *[moves S1 handshape around horz. circle with S3]*
S1: uh-huh / S3: during the year / S1: right

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(c) Copying, 2:24-2:36 (*= image 2:29)


S2: *[R vertical hand swaying, gaze forward]*
S1: *[R hand sways like S2]* when in winter it'd be **cooler** *[R lax hand beat]* when I'm **still** *[beat]* **hot** *[beat]*, but then
┌ in summer *[2 hands cross]*
S2: └ whenever ┌ it's **tilted** *[R hand tips in]*
S3: └ **both** *[R hand tips out]*
S1: ┌ *[L hand * tips in]*
S3: └ ye*ah, *[R hand tips out more]* so if it's **rotating this way** *[rotates hand; S2 mimics]* some of the **time it's gonna** *[extends thumb & index finger]*, **this other hemisphere** *[turns hand palm down]* **isn't gonna see** *[turns hand to right],* like, the sun at all

**Figure 5.** Appropriating another's gesture as a form of cooperation in collaborative reasoning. The appropriated gesture acknowledges the contribution while it affords exploration or elaboration of what is represented.

In these excerpts, groups are attempting to explain why it is hotter in summer and colder in winter. Group members in excerpt (a) are considering the tilt of the earth's axis. Speaker 1 (S1) introduces "the axis," holding his two hands pressed together vertically and swaying them back and forth while looking at the participant to his left (the one who read the question); he then slides his left hand down to his right wrist as he continues swaying his right hand silently. Speaker 2 (S2) says "the axis of the earth," and as S1 turns to him saying "yeah, the, the-," S2 raises his left vertical hand tipped outward, with his right hand touching his wrist (mirroring S1's gesture without the sway), saying "the angle-," whereupon S1 quickly raises his right hand tipped outward (mirroring S2) as he links the two stated elements: "the angle-of-the-axis"; this is the moment shown in the image at 0:18. The speakers exchange agreement as they drop their hands back to rest positions. In this short interaction, "axis" was introduced with S1's wobbling vertical hand (first two hands together, then reduced to one), "angle" added by S2 mirroring S1's vertical hand and holding it steady (eliminating the wobble), and "angle-of-the-axis" joined together with S1's quick mirroring of S2's vertical hand. The mirroring of gestures back and forth with slight modification led to a stable form: the *tilted axis* hand, glossed as "angle of the axis." Similar *tilted axis* forms were produced in many groups.

Just before the start of excerpt (b), the middle participant (labeled S3) has offered the tentative explanation "'cause the earth is closer to the sun?" without gesturing. The participant on the left (S1) raises her right index finger and says "the earth rotates," tracing a small horizontal circle in the air, and then extends her thumb and index finger as she says "on its axis," turning her hand palm up and twisting at the wrist on the word "axis." She repeats this motion while saying "anyway…," whereupon the participant on the right (S2), who is watching her, silently raises her right hand vertically and tips it inward, appearing to form a *tilted axis* gesture. S1 reacts to this movement by changing abruptly to an open handshape similar to S2, saying "the, oh-, yeah," and then rocking both her hands, palms apart and facing inward, in a seeming variant of the 'absence of knowledge' recurrent gesture (Cooperrider, Abner, & Goldin-Meadow, 2018). S3 introduces a distinction between the earth rotating on its axis ("that's night and day") and revolving around the sun. As S3 says "revolving is when it's closer," he uses his right index finger (pointing downward) to draw an ellipse in the air. S2, who has been following the exchange without speaking, then puts the two ideas together, saying "so it's like this" while making a palm-up hand configuration (like S1's 'rotating' handshape), "and then" (while S1 copies the 'rotating' handshape in silence), "moving" (moving this handshape through the path of a horizontal ellipse as S3 says "like a revolution" and repeats his elliptical drawing motion in the air); this is the moment shown in the image at 0:29. By combining the handshape and orientation of S1 with the elliptical movement of S3, S2 links the ideas they put forth in gesture: the earth rotates as it revolves around the sun.

In excerpt (c), which occurs in the same discussion two minutes later, the group merges the facets of tilt and revolution and begins to consider the effects on different hemispheres: northern and southern. At the start, S2 is swaying the *tilted axis* hand while gazing forward, and S1 mimics the swaying hand while saying "when in winter"; after a few

beat gestures and further description, she continues with "but then in summer" and raises her left hand, tilted inward, and crosses the two tilted hands to form an X pattern, momentarily superimposing the tilts of the axis at different times of the year. S2 and S3 react in overlap, with S2 saying "whenever it's tilted" while making a *tilted axis* hand tipped inward and S3 saying "both" while making a *tilted axis* hand tipped outward; as she sees this, S1 forms a *tilted axis* inward with her left hand (the opposite hand from her initial swaying-axis gesture); this moment is shown in the image at 2:29. Here we see the idea of the tilted axis being displayed variably by different hands (right/left) and different directions of tipping (inward/outward), showing that it is only the conceptually relevant *components* of the gesture—the vertical handshape representing the earth's axis, and the tipping of the hand representing tilt—that are precisely duplicated and not necessarily the full or precise form of the manual action. In subsequent dialogue, S3 tips his hand outward more and says "so if it's rotating this way" as he rotates his tipped hand clockwise (S2, who is watching, mimics this rotation), "some of the time it's gonna" (changing handshape to extended thumb and index finger), "this other hemisphere" (turning hand palm downward), "isn't gonna see" (rotates hand again), "like, the sun at all." Here S3 begins to note the different angles of sunlight on the northern and southern hemispheres as he seeks a way to represent the emerging idea with his hand. The next portion of discourse (not included here) shows some continuing confusion about rotation and revolution and how all the facets fit together into a coherent explanation.

In all three excerpts, when group members copy another's gesture, they are not engaged in simple mimicry. The gestures are duplicated variously by the same hand (b), opposite hand (a), or different hands by different group members (c) and even different hands by the same group member (S1 in b and c), with variation in the direction of tilt (inward or outward). Evidence that the reproduced gesture coincides with consideration of the facet it represents can be seen in how it is elaborated in the discourse. In (a), the second speaker repeats the word "axis" and then replaces it with "angle" as he tips the vertical-hand gesture outward; the first speaker appropriates this by saying "angle-of-the-axis" as he duplicates the outward tipping. In (b), three elements are introduced in rapid succession: S1 introduces a palm-up-gesture to signify the earth, twisting the thumb and index finger for rotation; S2 produces a vertical hand to represent the earth's axis and tips it inward to indicate tilt; and S3 uses a downward-pointing index finger to trace a horizontal ellipse signifying the earth's revolution around the sun. In the next moment three things happen in parallel: S1 repeats and holds the palm-up earth-ball, S3 retraces the horizontal ellipse (glossing it as "a revolution"), and S2 combines these facets by duplicating S1's handshape and moving it around an ellipse in parallel with S3's motion. Excerpt (c) shows a similar elaboration of elements: using a vertical hand to signify the earth's axis while tipping the hand to show its tilt (all group members), swaying the hand to consider its tilt at different times of the year (S2 and S1), crossing two tilted hands to compare winter and summer (S1), and rotating the tilted hand to add rotation of the tilted axis (S3, copied by S2). While gestural forms converge in the moments leading to expressed agreement ("yeah," "uh huh," right"), the gestures remain in personal space and

produced from the speaker's perspective in observer viewpoint as the group members coordinate their understandings. Part of this coordination is the alignment of gesture spaces as loci for depicting cosmic objects, relations, and dynamics, and this alignment is achieved through the copying, varying, and combining of others' gestural forms (or key components of those forms) as ideas are shared and elaborated. Though the participants coordinate their spaces and gestures, they stop short of combining them in a shared space (as we will see in "moving from personal to shared space" below).

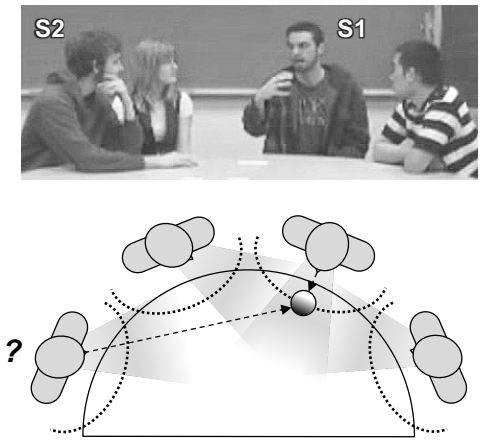
*Re-aligning gesture space to share perspective*

A challenge in producing and interpreting depictive gestures is that the speaker and listener view the depictions from different directions. The listener must commit to either the speaker's perspective or their own perspective to interpret the intended meaning. For portrayals of spatial relations where the direction of viewing matters, confusion can ensue. Speakers who encounter this problem may try to reverse the direction of their gestures to privilege the listener's viewpoint, but this can be awkward for the speaker and confusing for the listener. Another tactic is for the speaker to reposition or rotate their body to afford the listener a view of their gestures that is more similar to their own. This approach preserves natural gesture production by the speaker while it facilitates perception by the listener. Perhaps the most obvious example of this is how people turn shoulder-to-shoulder when giving and receiving directions.

In the example shown in Figure 6, Speaker 1 (S1) is describing how the direction of sunlight and the direction of viewing make the moon appear partly lit and partly shaded to an observer on earth. He first portrays this in his own gesture space (Figure 6a), saying that when the sun shines on the moon, part of the moon is lit up and part is not lit up. Here he uses his right hand to model the half of the moon that is lit up as it would be seen from his own perspective (Figure 6a image). The listener (S2) asks, "So why is it only lighting, like, half of it?" apparently not grasping the point. After a brief interlude, S1 makes a second attempt (Figure 6b) by forming a ball shape with two hands ("if you take a ball") and then *turning slightly to the left*, so that the listener can view his gestures in a way more similar to his own perspective. From this position he produces a series of depictive gestures in which he models a ball with his left hand ("it's lighting up"), locates the sun in center space with his right hand ("the sun is here"), points in the direction of the left-hand ball as he identifies it as the moon ("the moon is here"), moves his point from the center sun-location to the held moon-ball to indicate the direction of sunlight ("it's lighting up"), and traces around the front side of the moon-ball to indicate the portion that is lit ("this area of the ball") and then around the back side to indicate the portion that is not ("but the back half of the ball isn't"). S2 provides signs of understanding ("right, right"), whereupon S1 continues his explanation to describe how this depicted situation is viewed from the earth ("and we on the earth"). On the word "earth" he makes his right hand into a fist, and then he *turns his body more to the left* ("are, like,"), further aligning his and the listener's views, and pulses the right earth-fist in front of his body ("right here"), establishing an origo from which the depicted scene is to be viewed. S1 then points from this location to

the moon-ball ("and we're looking at," Figure 6b image), traces the viewed side of the ball ("this"), traces the dividing line between light and dark ("and we can see the line where"), traces around the lit side ("from this half it's being lit up"), and finally around the unlit side ("and from this half it's not being lit up"). This series of depictions occurs within a personal gesture space that has been rotated to align the listener's view with the speaker's. While the perspective on the space is shared, the speaker preserves control over the space and the depictions that occur there, having moved the space away from the listener and out of his reach. This contrasts with the next example, in which a space for gesturing emerges within reach of all group members and becomes a locus for gestural turn-taking as participants work collaboratively to build a model they can agree on.

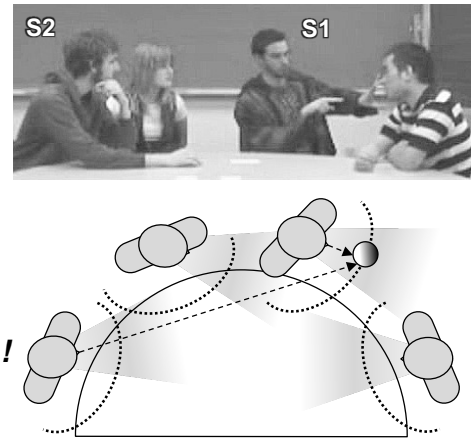
(a) RotatingSpace, 0:00-0:13 (*= image 0:05)




S1: is it because… like **the sun is lighting up** *[moves R hand from center table to space in front of eyes]*, uh **one * half** [*makes half-ball shape & holds]* **of the moon** and we can only **see** *[makes 2 open hands in same loc.]*, we see **part of the half** *[pulses L hand]* that's not lit up and **part of the half** *[pulses R hand]* that is currently lit up?

S2: so why is it only lighting, like, half of it?

(b) RotatingSpace, 0:34-1:00 (*= image 0:53)




S1: because the moon is not-, er the sun is lighting the… like, if you **take a ball** *[makes 2-hand ball shape & turns left]*, it's **lighting up** *[holds L hand as "ball," opens R]*, the sun is **here** *[places R hand in center space]*, the moon is **here** *[points toward ball]*, it's **lighting up** *[moves point to ball]* **this area of the ball** *[traces around front side of ball]* but the **back half of the ball** *[traces around back side]* isn't, isn't lit

S2: right, right

S1: and we on the **earth** *[R hand makes fist]* are, like *[turns farther left]*, right **here** *[pulses fist in front of body],* and *** we're looking at** *[moves point to ball]* **this** *[traces viewed side of ball]* and we can see **the line** *[traces line top-down]*… where… **from this half** *[traces lit side]* it's being lit up and **from this half** *[traces dark side]* it's not being lit up

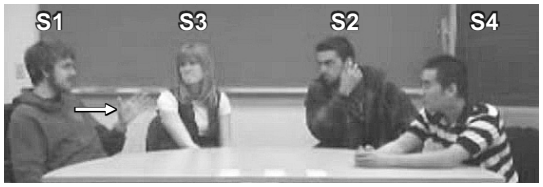
**Figure 6.** (a): The speaker (S1) gestures in personal space to depict the lit half of the moon as he would see it, and the listener (S2) does not understand. (b): The speaker (S1) rotates his gesture space away from the listener (S2) so that he and the listener can view his depiction from the same direction, which leads to shared understanding.

*Moving from personal to shared space*

In the examples above, participants in collaborative reasoning have gestured in their own spaces to introduce ideas or remembered bits of knowledge, copied or mirrored gestures of

others to acknowledge these facets and to explore or elaborate them, and, in the previous example, changed the orientation of their gesture space so a listener could see the gestures from a similar perspective. The next example describes how a shared space for gesture arises as participants proffer, consider, and contest various facets being fitted into the emerging model. Significant moments in the emergence of the space are shown in italics.

In this episode, displayed in Figure 7, participants are attempting to explain why the magnitude of the tides varies with the phases of the moon. At the start of the transcribed portion, a speaker (S1) gestures with an open left hand into the air in front of him, still clearly in personal space, as he remarks on how we see the moon when it's fully exposed to the sun (time stamp 0:10). A second speaker (S2) responds with what becomes the first step toward a shared space: a notable *shift from gesturing in the air to gesturing on the tabletop* (0:15). He traces a circle counter-clockwise on the table in front of himself as he introduces the notion that the moon's orbit isn't perfectly circular and varies somewhat, so that when the tide is higher, the moon is closer to the earth. This prompts S1 to *slide his hands into the middle of the table* (0:27) as he picks up this idea ("oh yeah, it's like an elliptical orbit"). S2 places his right hand on the table again as he prepares to initiate a new turn ("-so-," 0:35) and *keeps his hand on the table* as S1 continues by speaking and touching the tabletop at points on either side of his left hand ("here," "instead of here") to indicate two locations of the moon as it orbits the earth. S1 then *also keeps his hands in the middle of the table* as S2 picks up the form of S1's gestures (left finger for stationary earth, right finger for moving moon) and traces the moon's full orbit around the earth (0:38) plus a line from the left finger (earth) to the traced circle (orbit) to indicate the nearest distance from earth to moon ("closer to this point," 0:40); for this depiction S2 has *shifted his body slightly closer to the center of the table* than the previous depiction at 0:15. In this first part of the excerpt, participants have gestured in separate spaces, even as they changed from depicting in the air to diagramming on the tabletop. The pronounced forward lean by S1 shifted the locus of his gestures closer to the center of the table and into the interpersonal space between the participants, whereupon S2 moved his own gestures toward the center, nearer but still distinct from the space used by S1.




SharingSpace, *= image (for each segment)

[0:10]

S1: er, like, where *[brings L hand to chest]* we s-, we see, **we see it** * *[extends hand outward as shown]* when it's fully exposed to the sun

[0:15]

S2: my instinct is that the moon's orbit around the earth isn't perfect**ly * … um** *[traces circle as shown]*, circular, **or oval** *[retraces last half]*, so it varies, um, somewhat

[0:27]

S2: so… when th-, the **tide is higher** *[retraces tiny circle]*, my guess is that *[retracts hand]* the moon's closer to the earth

S1: *[moving hands into center of table]* * oh yeah, it's like an elliptical orbit-

[0:35]

S2: -so- *[placing hand back on table]*

S1: -when it's like, when it's like * **here** *[touches table where shown]*, you mean,… instead of **here** *[touches table at x]*


[0:38]

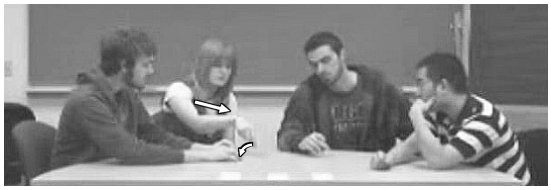
S2: **so…** if the * earth is here

[0:40]

S2: sometimes the moon will be orbiting **around… * like this** *[traces circle shown, pausing halfway to reach over left arm, then continuing]*, and when it's closer **to this point** *[traces line from center to edge x]* the tide will be higher

[…] [1:16]

S1: say **the sun's * here** *[pointing in center as shown]*, if it's **here** *[shifting point slightly to side]*, like, we'd be seeing the dark side, but if it's here *[tracing point along arc to x]* …, um… *[continues pointing and tracing in this space]*



[…] [1:38]

S3: but it's also **close** * *[R held as shown]* to, like, **here** *[R index touches table next to S1's hand]*, and it's not necessarily-


[1:41]

S3: *** with your fingers where they were** *[2 hands, index fingers extended, rotate back and forth like steering through an S curve]*, it's like

[1:43]

S3: **this is * where** *[taps R finger, holding L in place]*, it's **close to here** *[repeats]*, but it's not really the sun
S1: yeah
S3: so then *[lifts hands, rubs table with heel of R hand]*

[…] [2:03]

S2: **well when it's the same** *[moving L hand to table where shown]*, when it's the same phase of the moon, **the * moon** *[moves R hand to table where shown]*… is…

[2:09]

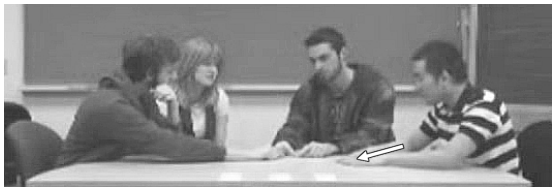
S2: say the **sun's here** *[taps L index]*, the **moon's here** *[taps R index]*, the **earth's here** *[taps R thumb]*, um, it's the same phase, that means that the earth and the moon are **similarly lined up *** *[L index traces from R index to prior location]*


[…] [2:40]

S2: **the…** *[L index retraces from R to prior location]* moon was back here, then it'd be not lit up
S1: *[reaching in]* cause the earth is **there *** (S2: or…) *[pointing]*, shadowing it?
S2: yeah, **I think you** *[points at S1 with R index]* might be right about the shadowing

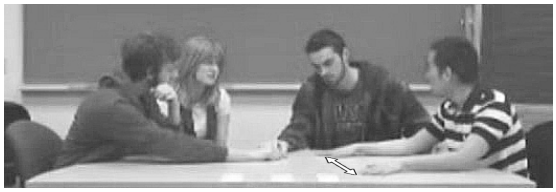
[…] [2:55]

S2: but if the moon was- **sun's here** *[L index tap]*, **moon's here** *[L index tap near R]*, **earth's here** *[R thumb tap]*, then the… *** sun hitting** *[L traces line shown]* **the moon** *[L traces lit portion]*, we aren't gonna **see** *[L index taps]* any part of the sun ┌ hitting the moon-



[3:05]

S4: └ just, **you have to understand** *[reaching in as shown]* it's ***** not



[3:06]

S4: **in a plane *** *[sliding hands apart as shown]*
S2: ┌ yeah
S4: └ like that


[3:08]
S1: well it's like there's um, the sun's **much bigger** * *[2 hands expand outward as shown]* than the moon

[3:10]
S1: so, like, the moon could be-
S4: ┌-right-
S1: └-**hit by the sun** * *[returning R hand to center]* but it wouldn't be like ┌ a box

[3:12]
S4: └ it could be like, **just like that** * *[2 hands make configuration shown]*, you know, the **earth is here** *[taps R thumb twice]*, the **moon is here** *[jiggles R index; L hand held as sun]*

[continues to 5:18]

**Figure 7.** The emergence of a shared gesture space on the tabletop (0:15-2:55) and the expansion of the shared space into a volume (3:05-3:12). Participants are reasoning about how the magnitude of the tides is related to the phases of the moon.

The next change occurs at 1:16, when S1 begins describing the location of the sun relative to the earth and moon. Here he *reaches farther into the center of the table* ("say the sun's here," 1:16; compare image with 0:35). His explanation prompts a response from a third speaker (S3), who *reaches into the same space* (1:38) to elaborate his model ("but it's also close to, like, here") and touches the table next to his hand (on the word "here"). She then brings her other hand into the now-shared space, causing S1 to retract his fingers slightly, and *moves her extended index fingers back and forth above the table (like steering through an S-curve)* while saying "with your fingers where they were" (1:41), thus *calling attention to the difference in orientation* between her access to the space and his. She subsequently places her fingers on the table and contests part of the model he has depicted (1:43). At this point, the central space on the table has emerged as a place for turn-taking in gesturally depicting aspects of the model the group is building.

Following this exchange, S2 initiates a new turn ("when it's the same phase of the moon," 2:03), gesturing on the table *now closer to the center and adjacent to S1's hand* (compare "are similarly lined up" at 2:09 to 0:40 and 0:15). S1 then *reaches into the space of S2's gestures* to indicate a location in S2's depiction ("cause the earth is there, shadowing it?" 2:40). S1 and S2 *keep their right fingers jointly touching the earth's position*, their bodies leaning in, as S2 elaborates further with his left hand, locating the sun and moon by touching two points on the tabletop, locating the earth with a quick tap of his right thumb, and tracing the path of sunlight from sun to moon with his left index finger ("the sun hitting the moon," 2:55). The central space is now fully established as a shared space for model-

building, with the hands of more than one speaker occupying and holding positions in this space while the speakers take turns elaborating the model they are jointly constructing.

Finally, the fourth speaker (S4), who has been watching this model emerge from the collaboration of S2 and S1, interrupts by *placing his hands palm-down near the middle of the table* ("you have to understand," 3:05)—prompting S2 to retract his left hand—and then *sliding his hands apart* ("it's not in a plane," 3:06) to indicate the tabletop plane on which they have been diagramming their two-dimensional models. This prompts S1 to *lift his hands from the table and gesture high in his personal space* (retreating from the shared space), where he molds a two-handed ball as he comments on the greater size of the sun ("the sun's much bigger," 3:08), and then to *slide his right hand back into the shared space* as he offers a comment ("the moon could be hit by the sun, but it wouldn't be like a box," 3:10), finally retracting both hands to a rest position in front of his body. S4 builds on his previous comment that "it's not in a plane" by *moving his right hand into the shared model-building space*, placing his *thumb on the table* (at the previously indicated earth-location) and *index finger up in the air* (for the moon, now raised slightly above the table), while he also *raises his left hand, cupped as if holding a ball, up to shoulder-height* (to show the placement of the sun, higher than the earth and moon), saying "it could be just like that" (3:12); in this way he demonstrates a possible three-dimensional configuration of the earth, moon, and sun. S4 highlights the components of this 3-D model with two taps of his right thumb on the table ("the earth is here"), a jiggle of his right index finger above the table ("the moon is here"), and a sustained hold of his left hand in the air (for the position of the sun). This enactment *changes the shared space for collaborative model-building from a flat diagrammatic space*, where points are tapped and circles and lines are drawn on the tabletop, *to a volumetric model space*, where objects are modeled by hand shapes resting on the table surface or suspended in the air above it.

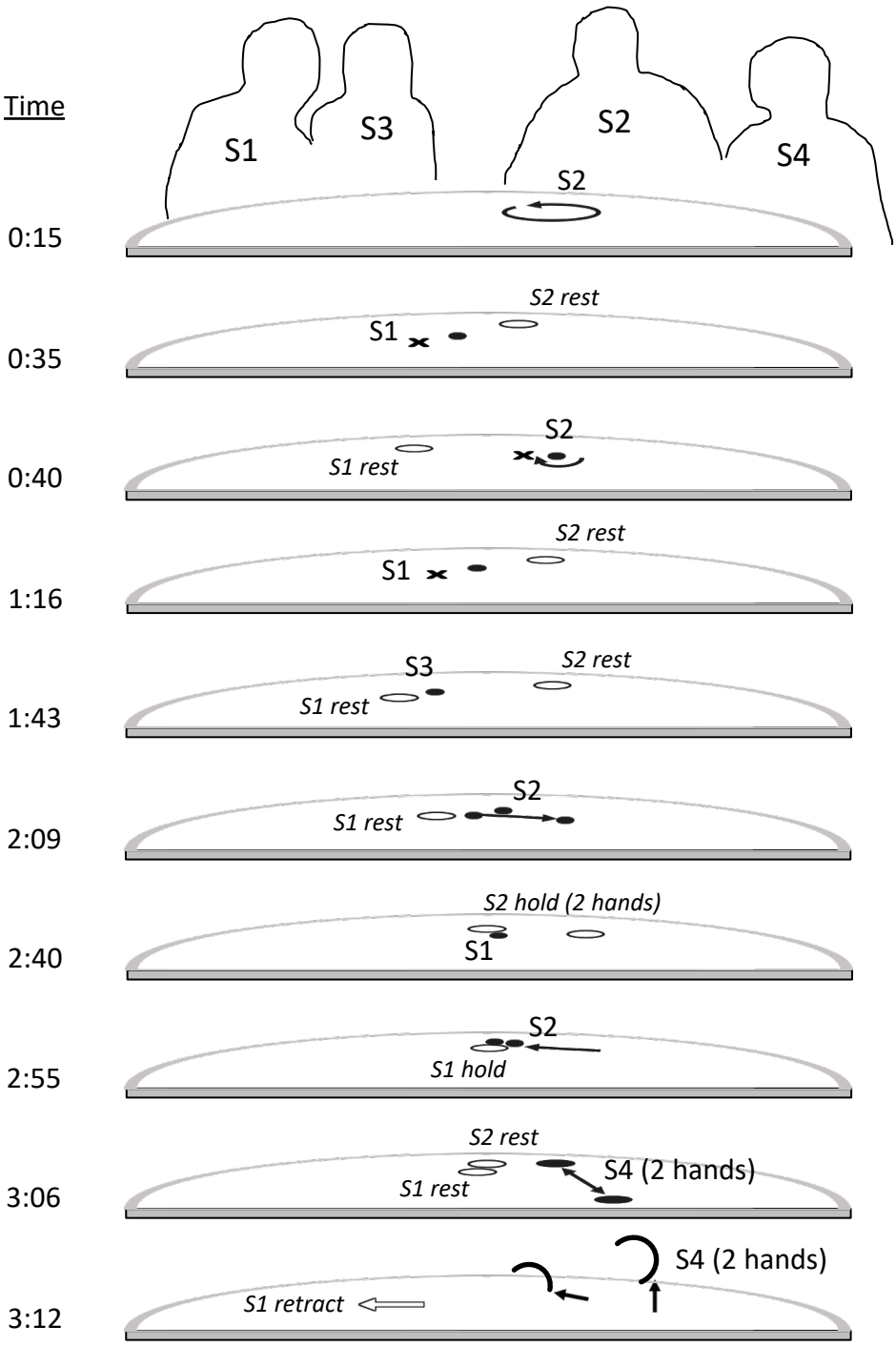



**Figure 8.** Key moments in the emergence of a shared gesture space on the tabletop (0:15-2:55) and the expansion of that space to a volume (3:06-3:12). Timestamps correspond to Figure 7.

Figure 8 shows where gestures were placed as the shared space emerged, beginning with the first gesture on the tabletop at 0:15 and ending with the first gesture in the expanded shared space (with added height) at 3:12. It is S1's pronounced leaning in that places his gestures at 0:35 proximal to S2's in the central area of the table. When S3 enters at 1:43, she indicates points on the table that were part of S1's depiction; now the group members' gestures are overtly in the same location. By 2:09, S2 is also gesturing in this central space, and he and S1 keep their hands in this space as they alternate gesturing and holding while the other gestures. S4's two-handed entry into the near portion of the space and his spreading of his hands at 3:06 halts this alternation, as it indicates the plane of the table (referenced in speech) and seemingly sweeps away the two-dimensional representations created there. S4's raising of his gestures above the table at 3:12 demonstrates how a three-dimensional configuration might appear in an expanded, volumetric model space. From this point forward, for the next two minutes, three of the participants (S4, S1, and S2) alternately depict and elaborate various spatial configurations, movements, and gravitational effects of the moon, earth, and sun, all through gestural actions in the central space bounded underneath by the tabletop and rising up to about shoulder height. They lean in and stretch their arms as needed to reach fully into what has become a collaborative space for building the group model. As the exploration dies down, they retract their hands to rest positions, and S2, who is the last to speak, asks "what was the question again?"

The diagram in Figure 9 shows where the collaborative model-building space arises, in the interpersonal space at the center of the group, just beyond the usual confines of the members' personal gesture spaces. This collaboration space is reachable by all and is roughly equidistant to all participants, and the production of gestures in the space by multiple participants demonstrates the space's shared ownership. Participants move increasingly into the space as they engage more collaboratively in model-building, leaving a hand at the edge of the space to mark ongoing engagement, and they retract from the space to reconsider or observe while others take action or to express a separate idea in personal space before returning to the shared space to continue the collaboration. The collaborative space continues as a locus for group members' gestures only for the portion of discourse where the joint model is being constructed; once the topic ends, the space dissipates.

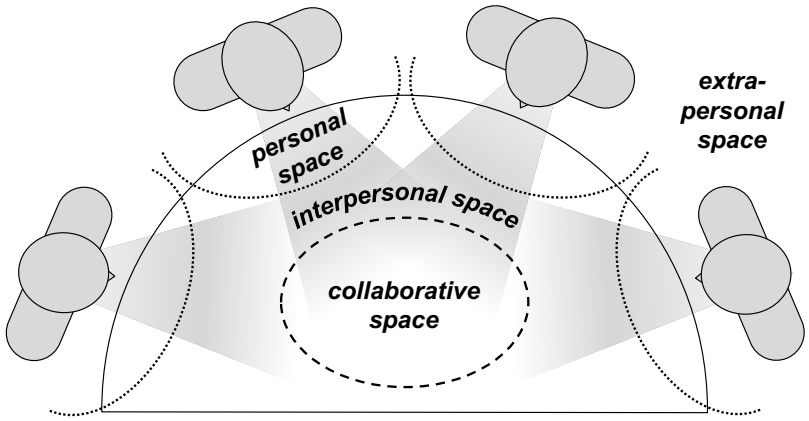



**Figure 9.** Emergence of a collaborative space within the interpersonal space bounded by personal gesture spaces. The collaborative space is central and reachable by all and is the locus for co-constructing a virtual representation of the relative positions and movements of celestial bodies at model scale.

*Collaborative gesturing*

The previous section detailed the emergence of a shared space as participants began to elaborate each other's ideas and jointly construct a model; this section will show collaborative gesturing within a shared space as participants demonstrate a common understanding. Addressing questions about what causes the seasons, the phases of the moon, and the tides involves reasoning about the relative positions and movements of multiple celestial bodies (sun, earth, and moon), which is difficult to depict with two hands. The challenge is increased if the person doing the depicting also wants to index parts of the model while describing its characteristics. The surfacing of this difficulty can prompt other group members to participate in the depiction or annotation, especially if the depiction is in an accessible space not too close to the speaker's body.

An example of annotating another's depiction is shown in Figure 10. S4 has just established the relative positions of three celestial bodies in the shared space described in the previous section: a downward point above the center of the table to locate the earth, a traced horizontal circle around this point to show the orbit of the moon, and a raised cupped left hand (similar to 3:12 in Figure 7) to locate the sun. In the portion shown in Figure 10, he thrusts his right hand inward with his index finger pointed toward the sun-location as he describes the sun pulling on the moon, bringing it closer to the earth. He produces this inward thrust three times in rapid succession, and during the second inward thrust, S1 raises his left hand, palm-lateral, into the shared space toward S4's gesture while turning his gaze to the participant that S4 is addressing, making what appears to be a display of affirmation; this moment is shown in the top image at 4:36. S4 continues his line of reasoning with "so it's [the moon is] closer to the earth," indicating a small distance with his thumb and index finger with his hand positioned near table center. S4 holds this pose

while S1 turns his left hand palm-down and taps locations on the table indicating the moon's position on different sides of the earth, saying "that causes a low tide here" (touching the table on the side closer to him) "and a high tide here" (touching the table on the far side); the latter moment is shown in the bottom image at 4:41 (note that S1's identification of low tide and high tide is mistakenly reversed, which S4 attempts to correct in the next moment not shown here). While we see S4 and S1's hands at play in the same space as they build and describe this model, we also see turn-taking in the performance of depictive gestures, with a hold by the non-speaker during the other's turn. The only moment of simultaneous gesture is when S1 displays affirmation by gesturing palm-lateral toward S4's depiction in progress.

SharingSpace, 4:30-4:41 (* = image 4:36, ** = image 4:41)


S4: **let's say** the moon is *[R points downward just beyond center of table (= earth)]*…
**further away** *[arcs hand outward, still pointing down]*
it **ha-** *[pulls hand inward, returns]*… um… *[turns hand so point is toward his body]*
it **gets pulled** *[pulls hand inward in direction of point, returns]*
S1: [ * **toward** *[repeats]* **the sun** *[repeats]*, right?
[ * *[raises L hand palm-lateral in direction of S4]*

S4: so it's **closer to the earth** *[holding index finger and thumb apart near center of table]*
S1: that causes **a low tide here** *[touching table on near side of center]*
and **a high tide here** ** *[touching table on far side of center]*

**Figure 10.** Multiple participants gesturing in a shared space.

The next example shows the spontaneous appearance of collaborative gesture in a shared space. In Figure 11 the group is considering why it is hotter in summer and colder in winter, and the participant on the right (S1) is offering the mistaken notion that the earth is closer to the sun in the summer and farther away in the winter. He claims that the earth's orbit is elliptical and that the earth slingshots away from the sun, and he enacts this by holding a left-hand grappolo (finger bunch) in the air in front of him, as if grasping a miniature sun, and using his right index finger to trace the path of the earth as it passes close to the sun (moving his finger between the grappolo and his body) and is subsequently

flung outward away from the sun (moving his finger past the grappolo and, with a thrust, out into the central space). The young woman sitting to his right (S2) responds to this depiction by rolling the wadded tissue she is holding into a ball, tearing off a portion, and rolling that between her fingers to form a smaller ball. She holds the larger ball with her left hand in the space in front of her and S1, using a similar grappolo handshape to hold the surrogate object like S1 held the virtual sun. She announces that this is the sun and hands him the smaller ball of tissue with the implication that he use it to represent the earth. S1 takes this small ball of tissue in his right hand and uses it to retrace the path of the earth's movement around the sun, again slingshotting outward into central space as he did before. When the earth-wad reaches its farthest point in the orbit, S2 raises her right index finger and waves it back and forth between the depicted sun and earth, highlighting the distance between them, as she says "winter" (the moment shown in the Figure 11 image at 1:05). In this three-handed display, S2 holds the sun-wad with her left hand while S1 moves the earth-wad through its elliptical orbit with his right hand and S2 highlights and annotates the point in the orbit where the earth is farthest from the sun. S1 continues moving the earth-wad along the depicted orbit, and as it passes between the sun-wad and his body, S2 says "summer" without gesturing. It's unclear whether the lack of gesture for "summer" is due to the short distance between the sun- and earth-wads, the need for S2 to cross her arms to perform a similar gesture at this point in the orbit, the potential awkwardness of S2 gesturing so close to S1's body, or simply the perception that the supporting gesture is no longer required to indicate the salient aspect of the configuration at that moment.

Collaborating, 0:58-1:11 (* = image 1:05)


S1: **here it's closer to it** *[S1 moves small wad just inside large wad held by S2]*
and then it **slingshots it out** *[S1 moves small wad quickly past large wad outward]*
and it **slows down** *[slows down and reaches end of trajectory as shown]*
S2: ***winter** *[S2 wags R finger between large wad and small wad held by S1]*
S1: and the **whole process repeats again** *[S1 moves wad slowly back]*, and then it,
and then **when it gets back here it's** *[S1 brings small wad inside large wad held by S2]*
S2: summer *[high tone, no gesture]*
S1: **fffoo** *[S1 moves small wad quickly out again]*
S2: winter *[low tone, no gesture]*

**Figure 11.** Gesturing collaboratively to enact and annotate a shared conception.

In this example, two speakers use three hands in coordination to simultaneously depict and annotate their jointly-understood model. S2's entry into collaborative gesturing is facilitated by S1 producing his depictive gestures relatively low and away from his body in a space that is reachable by S2. This allows S2 to enter into joint depiction without needing to reach near S1's body, and her collaborative gestures affirm the shared space as a group "celestial model space" for this portion of the discourse.

**Discussion**

The episodes detailed here have implications for how we define and treat gesture space. In studies of situated activity, Goodwin (2000; 2003; 2007) describes how speakers point, trace, and depict on, over, and around objects to direct attention and construct meaning, and he argues that these gestures can be understood only in conjunction with the objects with which they are coupled. The coupling of gestures with objects creates spaces for meaningful action that are distinct from the conventional gesture spaces in the air in front of speakers' bodies. Goodwin (2000) emphasizes this by saying that McNeill (1992) "defines gesture space only with reference to the body of the party producing the gesture," while the common situation of interlocutors interacting in a setting with objects "allows us to expand his notion of gesture space and go beyond the body of the party making the gesture to focus on a multi-party interactively sustained space that provides a framework for common orientation and the production of meaning" (p. 88). The shared spaces for collaborative reasoning in the present study fit this description of being "multi-party" and "interactively sustained"; what distinguishes them from Goodwin's examples is that they emerge in the empty space between participants, whether on the bare tabletop or in the air, rather than in relation to a physical object that is the focus of discourse. The virtual objects evoked by the gestures are themselves the focal objects for joint orientation and action, and even as these are modified or replaced by subsequent depictions, the shared space, once it has attained status as the model-building space, continues as the locus for creating and enacting virtual group models. Whether a shared space emerges is a consequence of how participants engage in the activity they are mutually pursuing. Consistently producing gestures from a third-person perspective, as was the case here, may facilitate the sharing of space or emergence of collaborative gesture. Like the spaces anchored by objects that Goodwin describes, these shared spaces, once they appear, are used by multiple parties, are jointly oriented to and sustained through the way the parties interact, and are the locus for building and, at times, contesting the group's common understanding, as distinct from the individual understandings represented in personal spaces.

Because emergent shared spaces are not anchored by physical objects, they can be flexibly constituted. They have no pre-determined orientation and can be variously oriented toward different speakers or fixed by the structure of the virtual model being depicted. They can also be rescaled or repositioned to meet the changing demands of the communicative situation and how group members engage. In Figure 11 we see that the

shared space has emerged in front of two group members who are jointly enacting the current model, while it remains slightly farther from a third member who watches with his arms crossed; were he to enter into the collaboration, the space could be shifted in his direction to make it more accessible. In Figure 7 the first and second speakers are seated apart with a group member between them; here the shared space for gesture arises centrally, and the member seated between the first two readily accesses this space while she calls attention to how it is oriented. The last speaker, seated opposite the first, must lean forward to reach into the space, and he reshapes it with the added dimension of height. The shared space is dynamically modified to support the ongoing collaboration while it remains central and accessible to all. While the shared space persists, personal spaces continue as loci for personal expression (as in Figure 7, 3:06), providing options for the placement of gestures for different purposes.

Wherever gestures are performed, the hand actions define the space and how it is to be understood. Manual depictions imbue a region of space with a shape, size, scale, and orientation. Pointing, tapping, and tracing on the table surface—actions associated with diagramming—make a region of the tabletop into a representational space that is horizontal and that can remain proximal to the speaker or be shifted toward other group members. When a participant calls attention to the flatness of the space and raises a cupped hand modeling the "sun" to shoulder height, he expands the representational space into a volume. These actions support Priesters & Mittelberg's (2013) claim that gesture spaces are dynamically constructed and adapted. While they evoke a space with a particular size, shape, and orientation, depictive gestures also assign the space a conceptual value or status, as the space for exploring the gradient of a mathematical function (in Yoon, Thomas, & Dreyfus, 2011) or for constructing a cosmic model (as shown here). Multiple parties gesturing in the same space, whether sequentially or simultaneously, maintain that conceptual status and demonstrate shared ownership of the space as a place for contributions to the group project. While the conceptual status of the space is defined by what the gestures represent, the ownership of the space is defined by who gestures within it. This depends in part on how accessible the space is: whether it is within reach and how proximal it is to interlocutors' bodies.

The data show mimicking or mirroring of others' gestural forms, and this may play an important role in the emergence of shared space. When one participant copies the gestural form of another, they assign their personal space a similar conceptual status, which then affords the merger of spaces or the onset of collaborative gesture. In Yoon, Thomas, and Dreyfus (2011), where participants were seated beside one another at a table reading a problem on a single sheet of paper, after the second speaker copied the first's depictive gestures in an adjacent space, imbuing it with the same mathematical properties, she then reached into the accessible space established by the first speaker to elaborate the virtual model depicted there. In the data presented in Figure 7, the initial two speakers' gestures created a conceptual alignment between their personal spaces, and as they continued their engagement, they shifted their gesture spaces toward the center of the table. The third speaker's contesting speaker one's depiction in the same space where he

performed it marked the merger into a single group space, which was used from that point forward. The fourth speaker maintained the conceptual status of this shared space as he expanded it into a volume.

Once a shared space acquires status as the 'model-building space' in a group task, it becomes a communal locus for meaningful action akin to that experienced in familiar activities like playing a board game, assembling a puzzle, or building together with blocks. In these group activities, multiple participants reach into a common space anchored by a focal object, whether a representational artifact like a game board or an emerging physical structure like a puzzle or block tower. Reaching into the common space may be regulated by ordered turn-taking, as in a board game, or may proceed in freer form, with false starts, stops, and potential overlaps as participants make contributions while avoiding collisions with other participants' actions. In the case of group reasoning, the flow of gesture accompanies spoken discourse and so is subject to the tacit rules of conversational turn-taking (Sacks, Schegloff, & Jefferson, 1974). The gestures produced in the emergent shared space in Figure 7 show this turn-taking, with participants leaving a hand at the edge of the central space to display ongoing engagement or potential re-entry after another's turn. When two group members begin gesturing collaboratively in Figure 11, their joint action regulates their speech so that S2 must interleave her gestural/verbal annotations into S1's gestural demonstration at precise moments in the ongoing action. How the emergence of shared gesture spaces and of collaborative gesture affect the timing of gesture and speech, both within and across participants, is an area for further study.

The emergence of a shared space for depictive gestures in the data presented here counters the claim by Sweetser and Sizemore (2008) that reaching into interpersonal space is a "sure sign" that a gesture is for interactional regulation (p. 27). The gestures in interpersonal space during collaborative reasoning are primarily for depicting or highlighting content, and what brings them into interpersonal space is their proffered contribution to a shared group conception, as distinct from a purely personal expression. This placement of gestures becomes more consistent once central space has become established as the group model-building space, and it diminishes or disappears once that status is lost, reflecting the dynamic way that speakers use space for conceptual purposes. One way that the data are consistent with Sweetser and Sizemore is that entry into the shared space for depiction is also an act of floor-claiming, and we do see participants placing or leaving a hand at the edge of the shared space to potentially claim the next turn.

Among the areas for further study, the connection between eye gaze and gesture placement may be important to marking a gesture's purpose, e.g., whether a depiction is an individual consideration (looking at one's own hands gesturing in personal space), a tentative offering (looking at others while gesturing in personal space), or a proffered contribution to the group construction (jointly looking at the hands gesturing in shared space). The group task used in this study—reasoning about the causes of the seasons, phases of the moons, and tides—could be used for further research in this area and also potentially combined with motion-capture technology to record precise data on gesture

placement as shared spaces emerge and as participants gesture for different purposes, realizing the promise of the early motion-capture work by Priesters and Mittelberg (2013).

## Conclusion

In this study, group members engaged in collaborative reasoning without any provided materials or tools for representation. As they introduced possibilities and sought confirmation from others, they produced gestures in the air in front of their own bodies—the conventional locus for gesture—and, at times, in a more central space between the interlocutors that became a locus for collaborative model-building. The emergence of a shared space is facilitated by appropriating others' gesture forms so that personal spaces come to share conceptual properties, making them combinable. Once a shared space becomes a locus for virtual model-building, participants may take turns entering the space for depictive or deictic gesture as they verbally elaborate or contest the developing group model. More rarely, they may engage in collaborative gesturing in the space as they jointly enact and annotate a shared conception. A shared space that emerges through gesture alone (without anchoring by a physical object) may be dynamically repositioned, reoriented, or reshaped to support the representational demands of the unfolding discourse, before vanishing when the discourse shifts to another topic. Overall, the findings of this study support a dynamic view of gesture spaces as defined by the gestures themselves in the course of interaction. Further research could explore how multiple spaces are used simultaneously in interaction and how eye gaze might coordinate with gesture placement to mark the function of gestures in discourse.

## Notes

[1]The term "gesture" is used in this article to refer to gesticulation: the hand movements that accompany speech in ordinary interaction.

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