Chue et al., *Cogent Education* (2015), 2: 1021554
http://dx.doi.org/10.1080/2331186X.2015.1021554

cogent education

TEACHER EDUCATION & DEVELOPMENT | RESEARCH ARTICLE

Iconic gestures as undervalued representations during science teaching

Shien Chue[1]*, Yew-Jin Lee[2] and Kim Chwee Daniel Tan[2]

Received: 31 October 2014
Accepted: 16 February 2015
Published: 16 March 2015

*Corresponding author: Shien Chue, Learning Sciences & Technologies Group, National Institute of Education, Nanyang Technological University, 1, Nanyang Walk, Singapore 637616, Singapore
E-mail: shien.chue@nie.edu.sg

Reviewing editor:
Mark Boylan, Sheffield Hallam University, UK

Additional information is available at the end of the article

Abstract: Iconic gestures that are ubiquitous in speech are integral to human meaning-making. However, few studies have attempted to map out the role of these gestures in science teaching. This paper provides a review of existing literature in everyday communication and education to articulate potential contributions of iconic gestures for science teaching. We then analyze the iconic gestures produced by one university professor during a semester-long organic chemistry module to exemplify the functions of iconic gestures in sharing abstract scientific concepts. These gestures were found to show vital information about size, relative position, and movement of particles. Implications for designing teaching environments are discussed in light of our claims and we propose that iconic gestures can illuminate aspects of abstract scientific meaning to present a more complete version of meaning than what speech can accomplish on its own.

Subjects: Communication Studies; Education; Educational Research; Higher Education; Instructional Communication; Secondary Education; Teaching & Learning

Keywords: gestures; iconic; organic chemistry; lectures; teaching

ABOUT THE AUTHORS

Shien Chue is a research fellow at Learning Sciences & Technologies Group, National Institute of Education (NIE). Her research interests include instructional gestures and science curriculum innovations. She has published in areas of science teaching and curriculum implementation.

Yew-Jin Lee is an associate professor at Natural Sciences and Sciences Education Academic Group, National Institute of Education (NIE). A former high school biology teacher and Fulbright Exchange scholar, he has published extensively in areas of sociocultural learning, adult learning, curriculum research, and the Learning Sciences.

Kim Chwee Daniel Tan is an associate professor at the NIE; he conducts research into students' alternative science conceptions, impact and translation of research on practice, and the use of ICT in science learning.

Combining the authors' research interests and expertise in the subject area of chemistry, this work is part of their continuous effort to develop a deeper understanding of instructional pedagogy for teacher knowledge and skills.

PUBLIC INTEREST STATEMENT

This article describes and illustrates the functions of iconic gestures for the learning of science. While instructors frequently gesture when giving explanations, these gestures seem ubiquitous or fleeting, and usually pass without notice from learners. Through close analysis of the iconic gestures produced during an undergraduate organic chemistry course, these gestures manifested many aspects of scientific knowledge that were neither visible from the inscriptions nor audible from the speech of the lecturer. The findings that gestures communicate vital aspects of size, direction, and movement during science teaching can potentially offer fresh insights into the traditionally heavily oral nature of lecturing.

1. Introduction

Gestures are pervasive in human meaning-making and an increasing amount of attention has been paid to examining their role in education over the last two decades. Essentially, gestures are representational modes that can convey spatial, relational, and embodied concepts (Alibali, Nathan, & Fujimori, 2011), and are unconsciously produced when speakers talk (Goldin-Meadow & Alibali, 2013). A seminal work by McNeill (2005) has classified gestures according to several non-exclusive basic dimensions: deitic gestures, which point to existing or virtual objects; metaphoric gestures referencing an abstract thought; beat gestures used for emphasis, and finally iconic gestures where the displayed form is directly related to the semantic content of speech. During explanations of complex processes, it has been reported that the gestures of teachers may help students relate their understanding of one event to their understanding of others (Hostetter, Bieda, Alibali, Nathan, & Knuth, 2006). Teacher gestures can also scaffold student comprehension by grounding abstract ideas in body-based forms (Alibali & Nathan, 2007). While there exists a body of literature that draws attention to the importance of gestures during communication of mathematical ideas such as geometry (Chen & Herbst, 2013; Roth & Gardener, 2012; Shein, 2012) and conservation of quantity (Ping & Goldin-Meadow, 2008) among others (Radford, Edwards, & Arzarello, 2009), this cannot be said for science education where teachers face the everyday and challenging task of explaining abstract scientific concepts.

On the whole, the field of science education has not developed any systematic documentation of science teachers' gestures produced during teaching. Existing studies reinforce the function of gestures as a means to ground ideas in instructional context (Pozzer-Ardenghi & Roth, 2007) and during scientific explanations (Roth, 2002). Gestures are posited as an important tool for both learners and experts to communicate about spatially complex structures and processes in geosciences (Herrera & Riggs, 2013; Kastens, Agrawal, & Liben, 2008). Similarly, gestures are also known to be produced as precursors to arrows during explanations of scientific diagrams (Roth, 2000). However, little research exists about the functions of gestures in the subject of chemistry, which is acknowledged to be characterized by highly abstract ideas.

Iconic gestures capture our interest in this paper as they appear to exhibit meaning relevant to the semantic content of speech in two ways (McNeill, 1985). For example, iconic gestures have been reported to help students clarify space and shape aspects of abstract knowledge (Elia, Gagatsis, & van den Heuvel-Panhuizen, 2014). Science teachers have also been reported to spontaneously use gestures and body movements to convey spatial-temporal concepts often present in scientific concepts (Padalkar & Ramadas, 2011). Hence, we want to build on this growing evidence about gestures produced during teaching to characterize how science teachers produce gestures in naturalistic instructional settings and the possible meanings that these gestures can add to teaching above speech and other visual modalities.

In this regard, lectures offer fertile ground for deeper investigations on the function of iconic gestures in science education. Lecturing practices are often misunderstood as passive teaching modes (Barak, Lipson, & Lerman, 2006), yet as the most common pedagogical format for efficiently transmitting vast amounts of information, they oblige lecturers to use their voices and bodies to express themselves (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Laurillard, 2002). Essentially, lecturers, as meaning-making individuals, are immersed in a dynamic environment where they communicate specific intentions (i.e. knowledge) to their students (Knewstubb, 2014) though this desire is actually implicit (Hattie & Yates, 2014). Our research question therefore asks "What type of scientific information do iconic gestures communicate during science lectures?" We suggest that the conditions for improving teaching are strengthened when gestures are regarded as part of the dynamic, joint process of directing attention, emphasizing, and shaping concepts for students rather than viewing instruction solely as an attempt to help students shed naïve conceptions in favor of scientific ones (Duit & Treagust, 2003). We also claim that if instructional methods are designed to enhance student learning, we need to recognize iconic gestures as part of the vast repertoire of meaning-making resources for teaching and that teachers are not merely "waving" their hands when "transmitting" ideas about math and science (Crowder & Newman, 1993).

http://dx.doi.org/10.1080/2331186X.2015.1021554

2. Literature review

Iconic gestures are pervasive in human talk (Goldin-Meadow & McNeill, 1999). The problem, however, is that iconic gestures may be common when people speak, but they are by no means universal. We wish to focus on iconic gestures for a number of interesting reasons. First, iconic gestures in everyday conversation are found to be intimately connected with speech itself and they appear to exhibit a meaning relevant to the semantic content of the speech (McNeill, 1985). Even congenitally blind individuals, who have never seen anyone gesture, spontaneously tilted a C-shaped hand in the air as though pouring liquid from a glass when indicating a liquid had been transferred to a different container (Iverson & Goldin-Meadow, 1998) highlighting the ubiquity of gesturing in communication. Second, iconic gestures are communicative. Examples include participants who heard verbal accounts of stories and saw the accompanying gestures were significantly better at answering questions probing the semantic features of the original stories than those who only heard the verbal account (Beattie & Shovelton, 1999). Specifically, participants demonstrated that when they hear a clausal unit of speech and see the accompanying iconic gestures, there is a significant increase in the amount of information that they obtain (Beattie & Shovelton, 2001). Third, iconic gestures depicting semantic categories of relative position, size, and movement are argued to possess high communicative powers. These gestures found in routine talk in everyday communication relates information for participants as these gestures can directly show the position of something in relation to the body of the speaker (Beattie & Shovelton, 2002).

In the context of instruction, researchers have been investigating what gestures of teachers look like and how these affect students learning (Goldin-Meadow, Kim, & Singer, 1999; Singer & Goldin-Meadow, 2005). Not only is there evidence that teachers can detect information that children express in gestures (Alibali, Flevares, & Goldin-Meadow, 1997), the former are found to be able to alter their instructional input to children as a result of those actions (Goldin-Meadow & Singer, 2003). In the construction of algebraic equations of a pan balance model, evidence from an early algebra lesson suggests teachers use iconic gestures especially during utterances indexing the weighing pan to help scaffold understanding (Alibali & Nathan, 2007). Iconic gestures can also simulate action on mathematical objects, such as toothed gears and demonstrate for students how they may orientate movement of gears for solving problems related to any number of toothed gears (Bartolini Bussi, Boni, Ferri, & Garuti, 1999). Additionally, iconic gestures can be used to explore meaning of geometric features. For example, teacher–student interactions showed that students would use gestures in communicating and defining the characteristics of height, so teachers would subsequently build on these to negotiate and strengthen the concept of height (Shein, 2012). Importantly, iconic gestures of teachers often embody ideas that may not be adequately conveyed in words and thus increase understanding of mathematical concepts (Radford, 2003).

What is still lacking within this burgeoning body of research on teacher gestures is the role of gestures in teaching science, which is a highly abstract subject (Roth, 2002). Studies have shown that science lessons with gestures promote deeper learning better than lessons without gestures (Valenzeno, Alibali, & Klatzky, 2003) as science teachers spontaneously engage gestures and body movements to convey spatial–temporal concepts. It is becoming increasing clear that the gestures teachers produce during their lessons matter greatly for students learning (Goldin-Meadow, 2014). In fact, speech and gestures represent a more complete version of meaning than what either can accomplish on its own. For example, when attributing the circulation of blood in the blood vessels to ventricular contraction, a lecturer folded his elbow inwards, hands slightly apart, and moved this iconic gesture apart and back at the same time maintaining the shape of holding up a large bowl (Pozzer-Ardenghi & Roth, 2010). This gesture invoked an image of the contraction of the cardiac muscle, while his speech referred to the function of ventricles as “big pumps.” Taken as a logical unit of meaning, the concept of contraction is therefore distributed between the movement of the ventricles as symbolized by the iconic gesture of movement and the ventricles responsible for blood flow as articulated in speech (Pozzer-Ardenghi & Roth, 2010). Our review of the literature, however, suggests that few studies have been done that examine how iconic gestures as a semiotic resource play a part in the communication of chemistry concepts. Notably in an analysis of a chemistry teacher explaining reactions of metals, abstract concepts were made salient by means of inscriptions, speech volume, gestures, rhythm and pace of voice, and their interlacing (Hwang & Roth, 2013). The scientific conceptions of the chemistry teacher are thus within a set of irreducible resources for guiding students through abstract chemical concepts. Just as students produce more iconic gestures when explaining abstract concepts (Herrera & Riggs, 2013), we need to examine when teachers invoke more iconic gestures and what pedagogic effects do they achieve by so doing. Central to communication as a vital aspect of knowing (Lampert & Cobb, 2003), we know that iconic gestures of lecturers produced during science lectures have the potential as a resource for assisting student learning. Building on growing evidence that gestures are consequential for student learning, recent studies have sought to characterize how teachers use gestures in naturalistic instructional settings (Alibali & Nathan, 2012; Richland, Zur, & Holyoak, 2007), and our research joins others in examining the types and function of iconic gestures produced in chemistry instructional talk.

3. Method

The data came from a corpus of video-recorded lessons drawn from a larger ethnographic study that examined how university chemistry lecturers taught organic chemistry to first-year undergraduates who were taking organic chemistry modules for the first time. Professor Barry (pseudonym used) has a PhD in organic chemistry and had at least five years of lecturing experience prior joining the university as a faculty member. Professor Barry was assigned to teach an introductory organic chemistry module to a class with a mix of students who had completed their GCE A-levels (Grade 12 equivalent) as well as polytechnic diploma graduates. The lectures took place in a traditional classroom setting where students were seated in rows in front of the professor. Professor Barry often placed himself in front of the projector screen and his twice weekly lectures were intact (Greeno, 1998) as they involved no special design or negotiation of lesson plans between professor and researcher, and represented customary lecturing practices (Shallcross & Harrison, 2007). Organic chemistry lectures of Professor Barry were video recorded during the fall semester after his voluntary agreement.

The resulting video data were analyzed in three phases. Firstly, to organize the 18 h of video data collected, content logs were written after each session of video recording to provide a quick overview of the data. Using these content logs together with the lecture outlines provided by Professor Barry, the digital data were chunked into segments where gross shifts in posture, position, communicative modes, and content were read as start and end markers of analytical units. In the process of identifying units, we drew upon our personal, cultural, and academic knowledge to identify the transition from one activity to another. In the first phase of analysis, we arranged the video clips into teaching episodes of broad main organic chemistry topics such as naming structures of organic compounds, bonding, alkanes, alkenes, alkyl halide, stereochemistry, reactions of benzene, and carboxylic acids. For the second phase of analysis, we listed the subtopics taught within each main topic and the time taken to teach them. This also involved detailing how these subtopics were communicated through speech, visual inscriptions, projections on screens, gestures, and use of ball-and-stick models. By noting the subject matter taught using each individual resource, it was possible to identify concepts that were taught mainly through teacher talk or through various combinations of talk, gestures, or writing on the whiteboard. This phase of analysis not only provided us with an in-depth view of the events in the lectures, it also enabled us to select segments of video clips where iconic gestures were produced.

We watched the videotapes together in the third phase of our video-based analysis following the principles of interaction analysis (Jordan & Henderson, 1995) and discussed emergent meanings about the functions of iconic gestures in the video clips. We focused on the iconic gestures as we were motivated to understand how iconic gestures of Professor Barry carried semantic meaning with benefit for learners. With such a focus, we viewed the video recordings multiple times with image only, with sound only, and with both sound and image in order to build up a transcript that could index functional dimensions of the iconic gestures for Professor Barry. During the intensive group viewing of the data, we asked questions such as: What is the trajectory of learning when doing that inscription/gesture/action? How did it get into and out of the scene? Why does Professor Barry shape his hand like a molecule? Such questions were useful in focusing our attention on the gestures of lecturers during repeated viewings. Ultimately, using Beattie and Shovelton's (2002) semantic categories of iconic gestures, we were able to identify how Professor Barry's iconic gestures contributed to the teaching of particular concepts. We then chose representative examples of these instances in this article to present Professor Barry's use of iconic gestures.

4. Results

This section identifies three functions of iconic gestures used in the teaching of organic chemistry. Through an in-depth analysis of the video data, we illustrate below how Professor Barry produced iconic gestures alongside the abstract information conveyed in speech. We conclude by discussing how knowledge of these iconic gestures can constitute a key resource for teachers faced with the task of making difficult to understand organic chemistry concepts accessible for students. Though gesture is typically treated as a transparent, seamless package, unpacking the work of Professor Barry can help educators see gesture as a meaningful display characteristically involving not just orientation to someone's moving hand, but rather an ongoing synthesis of scientific knowledge emerging through time and space.

4.1. Iconic gesture communicates size of particles

The chemical concept of carbocation stability requires one to understand the nature of carbocation as an unstable positively charged particle. However, by attaching electron donating groups such as alkyl groups to the carbocation, the positive charge of the carbocation can be delocalized and this can help stabilize the carbocation. Barry first identified the tertiary carbocation as being the most stable [1]. To help students understand why it was so, Barry mentioned the concept of hyperconjugation [2] as having an inductive effect [3] to stabilize the carbocation (positively charged carbon particle). This implies when the electron releasing alkyl groups are attached to the carbocation, electrons are released to decrease the positive charge of the carbon and the net effect is a more stable carbocation.

To further elaborate on the new terms introduced, Barry turned his body towards his student audience and asked them to imagine that he has a "positive charge" in front of him. Raising his hands in front of him, Barry shaped both hands to maintain a circular space to present the positive charge [4]. This iconic gesture represented the aspect of finite volume of the carbocation (Figure 1, figure drawing).

[1] Tertiary carbocation is the most stable.

[2] Another phenomenon is that alkyl groups can participate in hyperconjugation.

[3] When we say alkyl groups are electron donating group, this is an inductive effect

[4] Ok, (turns his body to face this students) see this. Let us say [we have a positive charge].
(*hands raised, enclosing a circular space in front of himself*)

Students were next quizzed with regard to what happens to the carbocation when electrons "are coming in" [5] (Figure 2). Relating the movement of electrons which is an inductive effect to having an effect on size of carbocation, Barry asked students if the positive center will become smaller. While the carbocation center does not physically exist, with reference to the iconic gesture of Barry [4], we have a glimpse of how an abstraction of a carbocation center is concretized within a gesture shaped like a round object. At the same time, his hands previously enclosing a circular space to represent the positive charge, moved inwards [6] in the direction of arrow 1 in front of his body to represent a smaller carbocation size. Requesting his students to imagine the effect of electron releasing alkyl groups in reducing the size of the carbocation, Barry used everyday language such as "coming in" to help students imagine the movement of negative electron cloud towards the center of the positively charged carbon particle. In this situation, while there was no inscriptional representation as an additional resource to help students understand the effect of alkyl groups in stabilizing the carbocation, the iconic gestures as well as the motion support the idea that stability of the carbocation involves shifting of the electron cloud toward the positively charged carbocation center.

Figure 1. Professor Barry explaining the stability of carbocations.

Figure 2. Professor Barry questioning students about effects of electrons on the carbocation.

[5] So what happens to the carbocation when electrons are coming in?

[6] Does the positive center [become smaller]

(*hands move inwards in direction of arrow 1*)

[7] [or bigger]?

(*hands move outwards in direction of arrow 2*)

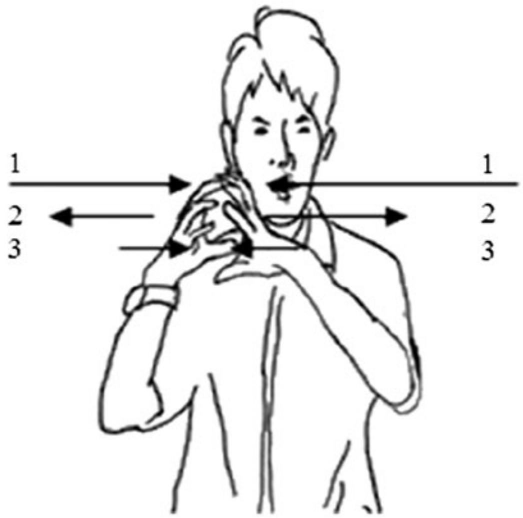


Figure 3. Professor Barry demonstrating a particle approaching neutrality.

Students responded that the positive center would become smaller. Barry quickly repeated their answer verbally and with hands that moved inwards to enclose a small space (Figure 3)—an iconic gesture was produced to illustrate the smaller sized ion [8]. This idea of a smaller carbocation was repeated again with hands moving away from each other [9] (arrow 2) and coming back together [10], and with finger tips almost touching one another to represent the phenomenon of neutrality [10]. Holding his hands stationary, shaped like a round ball, Barry retained for students a visual image of the stabilized carbocation [11] albeit smaller in size as compared to the original positively charged carbocation that was not attached to any electron donating groups [4].

[8] It becomes [smaller right]?
(*hands move towards each other as shown by arrow 1*)

[9] So [when it]
(*hands move apart as shown by arrow 2*)

[10] [becomes smaller],
(*hands move back in direction of arrow 3*)

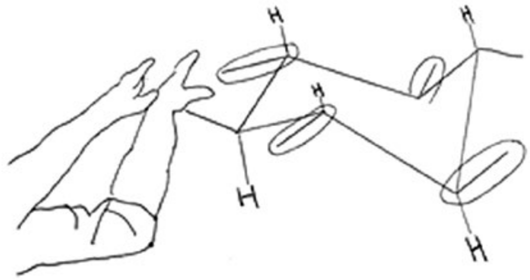
[11] [does it not approach neutrality]
(*finger tips of left hand touching finger tips of right hand*)

Barry used iconic gestures to help students visualize the effect of electron donating groups on the stability of carbocation and nested this concept on the main idea that a less "charged" particle was more stable. The concept of stability as related to inductive effect came to exist in the presentation of the effect of electron donating groups on the size of the carbocation. Relying on any single meaning-making resources by itself is insufficient. While verbal discourse was relevant to convey the relationship between the inductive effect of alkyl group and stability of carbocation, iconic gestures relayed the visual component of how electron donating alkyl groups reduces the positive charge of the carbon center. Relying on the verbal discourse alone, students would only hear a linear description of explanation. Attending to the iconic gestures, we can have a clearer view of the inductive effect of alkyl groups affecting the stability of the carbocation as Barry shapes his hands to illustrate the changing size of the positive center.

4.2. Iconic gestures reveal relative positions of particles

Barry also used iconic gestures to relate different spatial positionings of carbon–hydrogen bonds when sketching stick diagrams of cyclohexane—a cyclic ring molecule that can exist in various conformers. Often, undergraduate students in chemistry have difficulty in representing cyclohexane

Figure 4. Professor Barry's method of checking a drawing of cyclohexane.



according to the chair conformer due to the sequences in which the lines forming the chair and carbon–hydrogen bonds are drawn (Shaw, 1988). Barry used iconic gestures as a means to show parallel relationship of C–H bonds to help students relate inscribed chemical molecules to three-dimensional models. Prior to the production of the drawing on the whiteboard (Figure 4), Barry had built a ball-and-stick model of the cyclohexane model. Using the physical model, Barry explained the presence of equatorial and axial C–H bonds to his students. After which Barry taught his students how to draw the chair structure of a cyclohexane. While we expect the drawn diagram to signal the end of the drawing, Barry went a step further to circle out the equatorial bonds [12] and he verbally informed students that he would "always check." The method of checking was next elaborated as Barry paused in his speech, moved his body in front of the inscribed diagram. To identify which pair of bonds was parallel, Barry used iconic gestures to emphasize the relative positional relationship between the equatorial bonds [13]. He placed his hands parallel to a pair of C–H bond that were initially circled out. Juxtaposing his iconic gestures with the highlighted bond pair, Barry demonstrated for students the method of checking after inscription. By placing his hands parallel to the circled out bonds [13], his iconic gestures served as a meaning-making resource to help students see the parallel relationship between each pair of equatorial bonds. Relying on spoken words, we may not be able to identify which bonds he was referring to. Similarly, looking only at the diagram, we may think Barry was referring also to the axial bonds which were parallel. However, what is important to note here is that Barry was referring to the equatorial bonds as his iconic gestures were placed parallel (slanted) rather than pointed directly upwards which would have implied he was referring to the axial bonds. This was significant information that may enable students to know how much to tilt the equatorial bonds when drawing.

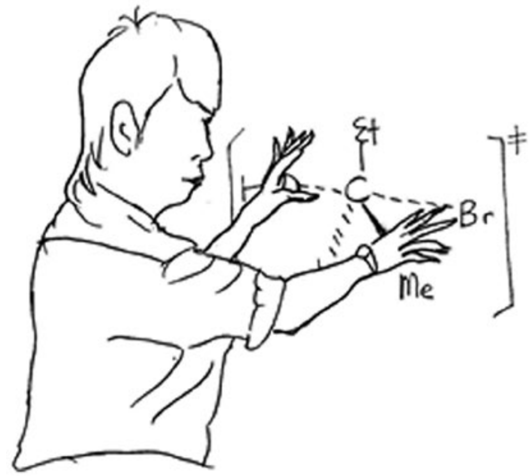
[12] Another thing, I always check. (circles out 4 bonds)

[13] This two bond must be parallel and this two bonds must always be parallel.
(raises hands parallel to C–H bonds at the equatorial position)

4.3. Iconic gestures reveal movement of particles

Barry also used iconic gestures to illustrate the movement of particles. During the lecture on the topic of nucleophilic substitution reaction, Barry had introduced the basic concept of a S_N2 nucleophilic reaction to his students by stating the reaction as bimolecular involving the substitution of one substituent group with another. He continued to explain the mechanism of the reaction as one where the halide group leaves the organic compound, while a nucleophilic particle forms a bond with the central carbon of the molecule. He next explained the mechanism of reaction by focusing on the types of bond breaking and forming during the transition stage of the reaction. With his right hand cupped over the leaving group (Br) and left hand cupped over the attacking group (OH) on the left [Figure 5], these iconic gestures represented the particles that were involved in the bond breaking- and bond-forming process. With iconic gestures that moved in tandem with speech, Barry illustrated the simultaneous breaking [14] and forming [15] of bonds with movements of iconic gestures along a straight trajectory over the inscribed transition state diagram. These complex movements corresponded to the dynamic path of particles during the transition state of the reaction. Importantly, this movement provided students a glimpse of the backside attack by the nucleophile, a critical concept of a S_N2 reaction which otherwise was a mere static illustration on the whiteboard.

Figure 5. Professor Barry demonstrating the mechanism of electrophilic substitution.



[14] They occur at the same time, [C–Br break]

(*right hand cups the inscribed Br and moves in straight line towards the right and drops to side of body*)

[15] [OH bond form] at the same time

(*left hand cups over inscribed OH and moves towards the right*)

5. Discussion and conclusion

The results of our analysis identify and underscore how iconic gestures unpack complex chemistry content during lectures. We found that iconic gestures communicated critical information about the size, relative positions, and movement of particles that complemented speech and inscriptions. This reinforces McNeill's (1992) position that imagistic gestures do carry information that cannot be readily inferred from speech. Using iconic gestures to represent the changing size of carbocation, Barry attempted to guide students along his pathway of scientific reasoning to understand the effects of electron releasing groups on the stability of carbocation. To overcome the difficulty of drawing chair conformers, Barry used iconic gestures to spatially map out the positions of carbon–hydrogen bonds against an inscribed version of cyclohexane. In doing so, his iconic gestures represented the concept/orientation of the carbon–hydrogen bonds, which is a productive way of viewing a three-dimensional drawing spatially. Similarly, with the use of iconic gestures to make the bond breaking and bond forming process physically visible, Barry traced for students the movement of particles, offering an additional layer of information over the static representation of a dynamic transitional state during the nucleophilic substitution process. It is clear that iconic gestures help us better understand how chemistry teachers can engage gestures to explain abstract concepts by making aspects of abstract concepts perceptually available. Our findings therefore contribute to research emphasizing the complex, multimodal nature of scientific explanations (Braaten & Windschitl, 2011; Givry & Roth, 2006; Márquez, Izquierdo & Espinet, 2006; Prain & Tytler, 2012).

Given that this study focused on iconic gestures, important questions remain, such as "How do these iconic gestures influence the student audience?" Current research tells us about the superior functions of iconic gestures in capturing audience attention (Shein, 2012); however, we do not know if the effect is due to the topic of speech or the form of gesture. Research on gestures in mathematics teaching has already demonstrated the positive effects of gestures on comprehension of concepts by making them "visible" (Alibali et al., 2014), which resonates with our argument here. This study focuses on introductory organic chemistry topics which contains spatially rich content that lends itself to the use of gestures during lectures. There is perhaps a need to broaden the scope to include more advanced (and visual) organic chemistry topics such as retrosynthesis and spectroscopy. With a similar research design implemented over a longitudinal study to include a wider spectrum of topics, we can envision a more comprehensive profile of iconic gestures and their effects on teaching and learning. Future studies can also include naturalistic interventions such as comparing groups of teachers who gesture and those who do not. This may be an important next step towards evidence-based claims on what and how gestures tells us about our learners and chemistry teachers as teaching and learning bodies.

In conclusion, gestures are an embodied way of communicating what is important in lecturing practices. In the teaching of organic chemistry, the act of interpreting chemical representations forms a large part of instructional discourse as this is the basis for understanding abstract properties and reactivity of chemical compounds (Graulich, 2015). Alongside verbal descriptions and two-dimensional chemical representations, gestures are potential affordances for students to extract information for successful representational translation tasks in organic chemistry (Cook, 2006; Olimpo, Kumi, Wroblewski, & Dixon, 2015). Our current categorization of iconic gestures produced during chemistry instruction thus complements current ways of understanding the functions of gestures for effective instructional communication (Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014; Singer & Goldin-Meadow, 2005). We also think that such knowledge can be useful for future technological developments such as gesture-recognition technology used to create immersive teaching environments to help students focus on important content in massively open online courses (Fan & Pong, 2013). Gestures as bodily actions normally consigned as superfluous or mere rhetorical moves have an ad hoc and episodic characteristic; they often appear unplanned and thus ungovernable. Yet, it surely would be a grave mistake to think that their lack of formality in educational theory and practice render them useless or unimportant as a complementary meaning-making resource that drive home a point (McLaren, 1999).

Funding
The work reported in this paper was supported by a research grant (RI 10/06 TKC) from the National Institute of Education, Singapore.

Author details
Shien Chue[1]
E-mail: shien.chue@nie.edu.sg
ORCID ID: http://orcid.org/0000-0001-9679-8309
Yew-Jin Lee[2]
E-mail: yewjin.lee@nie.edu.sg
Kim Chwee Daniel Tan[2]
E-mail: daniel.tan@nie.edu.sg
[1] Learning Sciences & Technologies Group, National Institute of Education, Nanyang Technological University, 1, Nanyang Walk, Singapore 637616, Singapore.
[2] Natural Sciences and Sciences Education Academic Group, National Institute of Education, Nanyang Technological University, 1, Nanyang Walk, Singapore 637616, Singapore.

Citation information
Cite this article as: Iconic gestures as undervalued representations during science teaching, Shien Chue, Yew-Jin Lee & Kim Chwee Daniel Tan, *Cogent Education* (2015), 2: 1021554.

References

Alibali, M. W., Flevares, L. M., & Goldin-Meadow, S. (1997). Assessing knowledge conveyed in gesture: Do teachers have the upper hand? *Journal of Educational Psychology, 89*, 183–193. http://dx.doi.org/10.1037/0022-0663.89.1.183

Alibali, M. W., & Nathan, M. J. (2007). Teachers' gestures as a means of scaffolding students' understanding: Evidence from an early algebra lesson. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 349–366). Mahwah, NJ: Erlbaum.

Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the Learning Sciences, 21*, 247–286. http://dx.doi.org/10.1080/10508406.2011.611446

Alibali, M. W., Nathan, M. J., & Fujimori, Y. (2011). Gestures in the mathematics classroom: What's the point. In N. Stein & S. Raudenbush (Eds.), *Developmental cognitive science goes to school* (pp. 219–234). New York, NY: Routledge.

Alibali, M. W., Nathan, M. J., Wolfgram, M. S., Church, R. B., Jacobs, S. A., Johnson Martinez, C., & Knuth, E. J. (2014). How teachers link ideas in mathematics instruction using speech and gesture: A corpus analysis. *Cognition and Instruction, 32*, 65–100. http://dx.doi.org/10.1080/07370008.2013.858161

Barak, M., Lipson, A., & Lerman, S. (2006). Wireless laptops as means for promoting active learning in large lecture halls. *Journal of Research on Technology in Education, 38*, 245–263. http://dx.doi.org/10.1080/15391523.2006.10782459

Bartolini Bussi, M. G. B., Boni, M., Ferri, F., & Garuti, R. (1999). Early approach to theoretical thinking: Gears in primary school. *Educational Studies in Mathematics, 39*, 67–87. http://dx.doi.org/10.1023/A:1003707727896

Beattie, G., & Shovelton, H. (1999). Mapping the range of information contained in the iconic hand gestures that accompany spontaneous speech. *Journal of Language and Social Psychology, 18*, 438–462. http://dx.doi.org/10.1177/0261927X99018004005

Beattie, G., & Shovelton, H. (2001). An experimental investigation of the role of different types of iconic gesture in communication: A semantic feature approach. *Gesture, 1*, 129–149.

Beattie, G., & Shovelton, H. (2002). An experimental investigation of some properties of individual iconic gestures that mediate their communicative power. *British Journal of Psychology, 93*, 179–192. http://dx.doi.org/10.1348/000712602162526

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education, 95*, 639–669. http://dx.doi.org/10.1002/sce.20449

Chen, C. L., & Herbst, P. (2013). The interplay among gestures, discourse, and diagrams in students' geometrical reasoning. *Educational Studies in Mathematics, 83*, 285–307. http://dx.doi.org/10.1007/s10649-012-9454-2
Cook, M. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education, 90*, 1073–1091. http://dx.doi.org/10.1002/(ISSN)1098-237X
Crowder, E. M., & Newman, D. (1993). Telling what they know: The role of gesture and language in children's science explanations. *Pragmatics & Cognition, 1*, 341–376.
Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*, 671–688. http://dx.doi.org/10.1080/09500690305016
Elia, I., Gagatsis, A., & van den Heuvel-Panhuizen, M. (2014). The role of gestures in making connections between space and shape aspects and their verbal representations in the early years: Findings from a case study. *Mathematics Education Research Journal, 26*, 735–761.
Fan, P. M., & Pong, T. C. (2013). Constructing knowledge representation from lecture videos through multimodal analysis. *International Journal of Information & Education Technology, 3*, 304–309.
Givry, D., & Roth, W. M. (2006). Toward a new conception of conceptions: Interplay of talk, gestures, and structures in the setting. *Journal of Research in Science Teaching, 43*, 1086–1109. http://dx.doi.org/10.1002/(ISSN)1098-2736
Goldin-Meadow, S. (2014). How gesture works to change our minds. *Trends in Neuroscience and Education, 3*, 4–6. http://dx.doi.org/10.1016/j.tine.2014.01.002
Goldin-Meadow, S., & Alibali, M. W. (2013). Gesture's role in speaking, learning, and creating language. *Annual Review of Psychology, 64*, 257–283. http://dx.doi.org/10.1146/annurev-psych-113011-143802
Goldin-Meadow, S., Kim, S., & Singer, M. (1999). What the teacher's hands tell the student's mind about math. *Journal of Educational Psychology, 91*, 720–730. http://dx.doi.org/10.1037/0022-0663.91.4.720
Goldin-Meadow, S., & McNeill, D. (1999). *The role of gesture and mimetic representation in making language the province of speech*. New York, NY: Oxford University Press.
Goldin-Meadow, S., & Singer, M. A. (2003). From children's hands to adults' ears: Gesture's role in the learning process. *Developmental Psychology, 39*, 509–520. http://dx.doi.org/10.1037/0012-1649.39.3.509
Graulich, N. (2015). The tip of the iceberg in organic chemistry classes: How do students deal with the invisible? *Chemistry Education Research and Practice, 16*, 9–21.
Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53*, 5–26. http://dx.doi.org/10.1037/0003-066X.53.1.5
Hattie, J., & Yates, G. (2014). *Visible learning and the science of how we learn*. London: Routledge.
Herrera, J. S., & Riggs, E. M. (2013). Relating gestures and speech: An analysis of students' conceptions about geological sedimentary processes. *International Journal of Science Education, 35*, 1979–2003. http://dx.doi.org/10.1080/09500693.2013.775609
Hostetter, A. B., Bieda, K., Alibali, M. W., Nathan, M. J., & Knuth, E. J. (2006). Don't just tell them, show them! Teachers can intentionally alter their instructional gestures. In *Proceedings of the 28th Annual Conference of the Cognitive Science Society* (pp. 1523–1528). Mahwah, NJ: Erlbaum.
Hwang, S., & Roth, W. M. (2013). The work of lecturing in high school chemistry. *Cultural Studies of Science Education, 8*, 683–708. http://dx.doi.org/10.1007/s11422-013-9502-y
Iverson, J. M., & Goldin-Meadow, S. (1998). Why people gesture when they speak. *Nature, 396*, 228–228. http://dx.doi.org/10.1038/24300
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*, 39–103. http://dx.doi.org/10.1207/s15327809jls0401_2
Kastens, K. A., Agrawal, S., & Liben, L. S. (2008). Research methodologies in science education: The role of gestures in geoscience teaching and learning. *Journal of Geoscience Education, 56*, 362–368.
Knewstubb, B. (2014). The learning–teaching nexus: Modelling the learning–teaching relationship in higher education. *Studies in Higher Education*, 1–16. http://dx.doi.org/10.1080/03075079.2014.934802
Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: Rhetorics of the science classroom*. London: Continuum.
Lampert, M., & Cobb, P. (2003). Communication and language. In J. Kilpatrick, W. G. Martin, & D. Shifter, (Eds.), *A research companion to principles and standards for school mathematics* (pp. 237–249). Reston, VA: National Council of Teachers of Mathematics.
Laurillard, D. M. (2002). *Rethinking university teaching* (2nd ed.). London: Routledge. http://dx.doi.org/10.4324/9780203304846
Márquez, C., Izquierdo, M., & Espinet, M. (2006). Multimodal science teachers' discourse in modeling the water cycle. *Science Education, 90*, 202–226. http://dx.doi.org/10.1002/(ISSN)1098-237X
McLaren, P. (1999). *Schooling as a ritual performance: Toward a political economy of educational symbols and gestures*. Maryland: Rowman & Littlefield.
McNeill, D. (1985). So you think gestures are nonverbal? *Psychological Review, 92*, 350–371. http://dx.doi.org/10.1037/0033-295X.92.3.350
McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago, IL: University of Chicago Press.
McNeill, D. (2005). *Gesture and thought*. Chicago, IL: University of Chicago Press. http://dx.doi.org/10.7208/chicago/9780226514642.001.0001
Novack, M. A., Congdon, E. L., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From action to abstraction using the hands to learn math. *Psychological Science, 25*, 903–910. http://dx.doi.org/10.1177/0956797613518351
Olimpo, J. T., Kumi, B. C., Wroblewski, R., & Dixon, B. L. (2015). Examining the relationship between 2D diagrammatic conventions and students' success on representational translation tasks in organic chemistry. *Chemistry Education Research and Practice, 16*, 143–153.
Padalkar, S., & Ramadas, J. (2011). Designed and spontaneous gestures in elementary astronomy education. *International Journal of Science Education, 33*, 1703–1739. http://dx.doi.org/10.1080/09500693.2010.520348
Ping, R. M., & Goldin-Meadow, S. (2008). Hands in the air: Using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology, 44*, 1277–1287. http://dx.doi.org/10.1037/0012-1649.44.5.1277
Pozzer-Ardenghi, L., & Roth, W. M. (2007). On performing concepts during science lectures. *Science Education, 91*, 96–114. http://dx.doi.org/10.1002/(ISSN)1098-237X
Pozzer-Ardenghi, L., & Roth, W. M. (2010). Toward a social practice perspective on the work of reading inscriptions in science texts. *Reading Psychology, 31*, 228–253. http://dx.doi.org/10.1080/02702710903256361
Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education, 34*, 2751–2773. http://dx.doi.org/10.1080/09500693.2011.626462
Radford, L. (2003). Gestures, speech, and the sprouting of signs: A semiotic-cultural approach to students' types of generalization. *Mathematical Thinking*

and Learning, 5, 37–70. http://dx.doi.org/10.1207/S15327833MTL0501_02

Radford, L., Edwards, L., & Arzarello, F. (2009). Introduction: Beyond words. *Educational Studies in Mathematics, 70*, 91–95. http://dx.doi.org/10.1007/s10649-008-9172-y

Richland, L. E., Zur, O., & Holyoak, K. J. (2007). Mathematics: Cognitive supports for analogies in the mathematics classroom. *Science, 316*, 1128–1129. http://dx.doi.org/10.1126/science.1142103

Roth, W.-M. (2000). From gesture to scientific language. *Journal of Pragmatics, 32*, 1683–1714. http://dx.doi.org/10.1016/S0378-2166(99)00115-0

Roth, W.-M. (2002). Gestures: Their role in teaching and learning. *Review of Educational Research, 71*, 365–392.

Roth, W. M., & Gardener, R. (2012). "They're gonna explain to us what makes a cube a cube?" Geometrical properties as contingent achievement of sequentially ordered child-centered mathematics lessons. *Mathematics Education Research Journal, 24*, 323–346. http://dx.doi.org/10.1007/s13394-012-0044-5

Shallcross, D. E., & Harrison, T. G. (2007). Lectures: Electronic presentations versus chalk and talk—A chemist's view. *Chemistry Education Research and Practice, 8*, 73–79. http://dx.doi.org/10.1039/B6RP90021F

Shaw, D. G. (1988). Drawing the chair conformers of cyclohexane. *Journal of Chemical Education, 65*, 587 p. http://dx.doi.org/10.1021/ed065p587

Shein, P. P. (2012). Seeing with two eyes: A teacher's use of gestures in questioning and revoicing to engage English language learners in the repair of mathematical errors. *Journal for Research in Mathematics Education, 43*, 182–222.

Singer, M. A., & Goldin-Meadow, S. (2005). Children learn when their teacher's gestures and speech differ. *Psychological Science, 16*, 85–89. http://dx.doi.org/10.1111/psci.2005.16.issue-2

Valenzeno, L., Alibali, M. W., & Klatzky, R. (2003). Teachers' gestures facilitate students' learning: A lesson in symmetry. *Contemporary Educational Psychology, 28*, 187–204. http://dx.doi.org/10.1016/S0361-476X(02)00007-3