Chemistry Education Research and Practice

RSC Publishing

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Speaking across levels – generating and addressing levels confusion in discourse

Cite this: DOI: 10.1039/c3rp20158a

Mike Stieff,*[a] Minjung Ryu[b] and Jason C. Yip[b]

Reasoning across descriptive levels is a fundamental component of scientific reasoning, particularly in chemistry. Repeatedly, students are seen to confuse features applicable to one level across multiple levels despite instruction. Although many instances of such 'levels confusion' have been documented, little is known about the generation or reconciliation of levels confusion in the science classroom. The present study examines the nature of teacher–student discourse practices that generate, maintain, and reconcile levels confusion in chemistry. We present two case studies of whole class discussions of chemical and physical changes to illustrate how teachers and students enter the chemistry classroom biased to reason about chemistry phenomena from very different descriptive levels. Microanalysis of teacher–student discourse practices show how teachers implicitly refer to multiple descriptive levels during instruction and employ technical definitions and heuristics that tacitly appeal to multiple levels simultaneously. Our analysis suggests that levels confusion in chemistry arises from multiples sources that include the epistemological assumptions of chemistry, representational practices of the domain, and epistemological moves made by teachers in classroom discourse.

Received 27th November 2012,
Accepted 31st March 2013

DOI: 10.1039/c3rp20158a

www.rsc.org/cerp

Levels confusion in chemistry

Coordinating information across multiple levels in a complex system is required to achieve deep conceptual understanding in many science disciplines (Wilensky and Resnick, 1999; Stieff and Wilensky, 2003; Chi, 2005; Duncan and Reiser, 2007; Hmelo-Silver *et al.*, 2007). Students face a significant challenge in the chemistry classroom where they are explicitly asked to coordinate multiple symbolic representations of chemical phenomena to relate submicroscopic phenomena to macroscopic observations (Johnstone, 1982, 1993). As students attempt to coordinate information across levels, they often experience 'levels confusion' or 'levels slippage' (Wilensky and Resnick, 1999); that is, students mistakenly infer that characteristics applicable to one level apply to another level. Levels confusion represents a profound challenge to learning chemistry and impedes conceptual change in the discipline. Indeed, students routinely demonstrate levels confusion in chemistry classrooms despite years of science instruction (*e.g.*, Eylon *et al.*, 1986; Ben-Zvi *et al.*, 1989; de Vos, 1990; Albanese and Vicentini, 1997; Van Driel, 1998; Dori and Hameiri, 2003; Chittleborough and Treagust, 2007).

The challenge associated with reasoning across levels in chemistry has been a fundamental concern to chemistry education researchers for decades. In 1982, Johnstone proposed that the challenge results from chemists' use of three *descriptive levels* to represent the central ideas of their discipline. Chemists describe matter on both macroscopic and submicroscopic levels, and students must learn the relationship between these levels. On the ''tangible, edible, and visible'' macroscopic level, matter is described phenomenologically; on the submicroscopic level matter is described according to ''molecular, atomic, and kinetic'' features (Johnstone, 1993, p. 702). Johnstone also asserted that chemical formulae and other symbols comprise a discrete third level: because students do not perceive the connection between symbolic representations and the represented world, they instead treat representations as objects that can be manipulated and transformed in their own right. Coordinating across these three levels is not trivial and presents an inherent challenge to novice students in the discipline.

Levels confusion is further complicated by the fact that many concepts to be learned in chemistry are examples of emergent phenomena that result from the interactions between many components in a complex system (Rappoport and Ashkenazi, 2008). That is, many macroscopic properties are not the sum of the properties of submicroscopic particles:

[a] *Learning Sciences Research Institute & Department of Chemistry, University of Illinois-Chicago, 845 W. Taylor Street (M/C 111), Chicago, IL 60607, USA. E-mail: mstieff@uic.edu; Tel: +1 312-996-4348*

[b] *College of Education, University of Maryland, 2311 Benjamin Building, College Park, MD 20742, USA. E-mail: mryu@umd.edu, jasonyip@umd.edu*

rather, it is the multitude of interactions between atoms or components on the submicroscopic level that produce an aggregate system with its own distinct properties and behaviors (Chi, 2005). For example, the structure and composition of each water molecule in a rain droplet explains the adhesive and cohesive properties of the droplet and the interactions between the sextillions of water molecules present result in the emergent shape and size of the droplet. The relationship between the submicroscopic level and the macroscopic level is rarely intuitive and varies in complexity across systems, which creates many challenges for learning chemistry. Events on the submicroscopic level may have direct or indirect effects on the macroscopic level, and events on the macroscopic level may or may not have effects on the submicroscopic level. Therefore, deep understanding in chemistry is not guaranteed by simply relating descriptive levels to one another; students must understand how macroscopic observations emerge from submicroscopic interactions to understand any given chemistry concept more fully.

Johnstone's (1982) triangle and a complex systems framework each offer excellent approaches for productive research in chemistry education, and each provides insight into the underlying factors that contribute to levels confusion. According to Johnstone's triangle, levels confusion results from students' inherent bias to describe matter phenomenologically according to familiar characteristics from everyday experience. Mistakenly, students *misattribute* macroscopic properties to submicroscopic entities, such as claiming that copper atoms (submicroscopic level) are malleable because copper wire (macroscopic level) is malleable. While we acknowledge that it is arguable whether the symbolic level is a theoretical entity comparable to macroscopic and submicroscopic levels, Johnstone's framework effectively models the cognitive demands that students may experience learning chemistry (see Taber (2013) for a full treatment of the relationship among Johnstone's three levels).

According to a complex systems approach, levels confusion results from students' difficulty perceiving the *relationship* between phenomena on the submicroscopic level and phenomena on the macroscopic level. From this perspective, students fail to see that malleability is an emergent property of the macroscopic copper bar that involves both copper atoms and their interactions. According to either framework, it is important to note that levels confusion is not merely attributable to the challenges associated with reasoning about phenomena and processes that occur on different scales (Wilensky and Resnick, 1999). Rather, levels confusion arises from challenges associated with coordinating information among descriptive levels that differ not only in scale, but also in the very phenomena represented at each level.

Identifying levels confusion in teacher–student discourse

Although occurrences of levels confusion are well documented, the factors that contribute to levels confusion in chemistry remain less well known. Multiple researchers have pointed to the epistemological assumptions of chemistry (Erduran, 2005), the structure of curriculum materials (Kozma *et al.*, 2000), and teacher knowledge (Thiele and Treagust, 1994) as potential factors that bias students to apply features across levels incorrectly. More recently, Johnstone (2010) has suggested that the contribution of these factors to levels confusion is exacerbated by two common pedagogical practices in the chemistry classroom. First, levels confusion is promoted when chemistry teachers focus primarily on only one (usually symbolic) level while teaching. With no instruction regarding other levels, students are left alone to decide which properties are applicable to each level and whether phenomena or processes can be attributed to multiple levels. Second, levels confusion is promoted by classroom lessons that emphasize multiple descriptive levels unsystematically. In such lessons, multiple levels are presented simultaneously without careful instruction in the relationships among levels. With no support to relate levels together, students struggle to identify which level is relevant to a concept and to develop a full understanding of a concept using evidence drawn from multiple levels.

Building on Johnstone's (2010) observation that common pedagogical practices may contribute to levels confusion, the present study provides empirical evidence that illustrates how levels confusion is triggered and maintained in teacher–student discourse practices. To achieve this goal, we present two case studies of teacher–student discussions concerning the introductory concepts of chemical change and the classification of matter. Each case involves a whole class discussion taught by a single teacher in a secondary chemistry classroom. The cases provide evidence that despite common terminology and apparent consensus, chemistry students and teachers reason and talk about chemical phenomena and processes differently. Specifically, we argue that chemistry teachers, experienced in the domain, may refer to a phenomenon from multiple levels simultaneously while chemistry students speak about the same phenomena from a macroscopic level only. The interchanges between the students and teachers demonstrate how tacit references to each descriptive level obscures significant miscommunications in the classroom. Thus, students and teachers may appear to agree on the relevant descriptive level when in fact, they are referring to different levels. Consequently, these unacknowledged disagreements generate and exacerbate levels confusion among students. Furthermore, discourse practices that involve acknowledging students' level of reasoning provide one avenue to address levels confusion when it arises, yet also fail to resolve levels confusion.

Prior analyses of teacher–student discourse practices in science classrooms that have analyzed the epistemological moves of teachers and the processes by which classroom participants reach *intersubjective agreement* provide fruitful lenses to examine how levels confusion is generated and addressed through social interactions in the chemistry classroom. Nathan *et al.* (2007) define intersubjective agreement as a state of agreement and complete understanding, a shared participatory framework, or a common reference framework among participants in classroom discussions. From a detailed analysis of group problem solving in whole class discussions, Nathan *et al.* revealed that students and teachers often enter into discussions with discrete interpretive frames of reference and employ idiosyncratic representations when making ideas public. Through extended dialogue, students and teachers attempt to converge on a problem solution by refining public representations and by selecting increasingly abstract representations that convey common meanings to all interlocutors. By fostering extensive discussions, teachers create opportunities for students to make clear their interpretive frames, foster conceptual change, and improve interpretation.

Analyzing teacher–student discourse for instances of intersubjective agreement can shed light on how levels confusion is generated and addressed in the context of chemistry classroom discussions. In this study, we define intersubjective agreement as discourse in which interlocutors (*i.e.*, the teacher and students) refer to the same descriptive level when communicating about chemical phenomena. For instance, in a chemistry classroom, a teacher may use the word ''water'' to mean a molecule composed of one oxygen atom and two hydrogen atoms, but a student may use ''water'' to mean an aggregate collection of molecules that comprise a system that flows and does not have a fixed shape. A teacher who means the former when referring to water is reasoning from the submicroscopic level, whereas one who means the latter is reasoning from the macroscopic level. Thus, even when two people use the same word and ostensibly agree on the substance of their conversation, they may in fact reason from different levels. In such a conversation, the interlocutors do not reach intersubjective agreement regardless of whether they explicitly disagree. We argue that conversations in which interlocutors to do not recognize the lack of intersubjective agreement generate levels confusion among students. Conversely, when intersubjective agreement about the relevant descriptive level is achieved, instances of levels confusion are more readily addressed.

As Nathan *et al.* (2007) demonstrated in their analysis, teachers attend closely to meaning-making attempts by students and to students' intended meanings when they create public representations. Teachers routinely encourage students to elaborate on their reasoning and make their thinking public to encourage dialogue characterized by intersubjective agreement. In an analysis of teacher–student discourse, Lidar *et al.* (2006) documented how teachers employ specific discursive practices to help students learn what knowledge is valued in a chemistry classroom and how a learner can resolve misunderstandings. As in mathematics classrooms, Lidar *et al.* illustrate how science teachers attend closely to how students reason using different perspectives and frameworks and encourage students to reason about scientific phenomena from a shared perspective using various dialogic *epistemological moves*. These epistemological moves are ''the way in which the teacher gives the students directions that expose what counts as knowledge and appropriate ways of getting knowledge in this specific social practice'' (p. 149). As such, epistemological moves should be understood as the way in which people engage one another in the process of shared meaning making.

Based on their analysis of a science teacher working with students in a laboratory experiment, Lidar *et al.* (2006) identified a variety of epistemological moves that teachers employ to give students directions ''that expose what counts as knowledge and appropriate ways of getting knowledge in this specific social practice'' (p. 149). Of particular note are the confirming and re-orienting moves that the teacher employs to support students' meaning making. *Confirming moves* communicate to students that they have recognized the correct phenomena and validate students' planned learning activities. *Re-orienting moves* call students' attention to other information or phenomena that merit consideration in the moment. Although Lidar *et al.* limited their analysis to describe how teachers support students' meaning making during laboratory activities, their analytical framework is equally useful for examining teacher's discursive practices that trigger and address levels confusion in chemistry. When learning about any given phenomena, chemistry teachers may ask students to reason about one or more descriptive levels depending on the context of a lesson. Reasoning from one level alone may be a valid way to achieve legitimate understanding in a certain context whereas the same level may be invalid in another context. Here, we analyze teacher discourse practices to identify the epistemological moves that teachers make that (1) confirm students are reasoning about the appropriate descriptive level and (2) re-orient students to reason on other levels. By analyzing teachers' epistemological moves, we are able to identify how teachers direct students to specific levels and how such moves address levels confusion in authentic classroom discourse.

Generating and addressing levels confusion in teacher–student discourse

In this paper we illustrate how levels confusion is generated, maintained, and addressed in the chemistry classroom by analyzing teacher–student discourse practices that occur during two cases of whole classroom discussions. First, we illustrate how teachers and students use particular words, such as *water* or *stuff*, to refer to discrete levels as they enter classroom discussions from different levels of perspective that are rarely made explicit. Second, we illustrate how students have great difficulty attending to teacher's epistemological moves, and how teachers employ explicit re-orienting and confirming moves in pursuit of intersubjective agreement about the relationship between levels through extended discussions of chemical phenomena.

In each classroom, the participants debate the differences between chemical and physical changes. Although an elementary topic, student difficulties differentiating chemical and physical changes are well documented as novice students routinely classify all transformations as chemical changes (Ardac and Akaygun, 2004; Calyk *et al.*, 2005; Adadan *et al.*, 2009). Students who fail to differentiate between chemical and physical changes may have increased difficulty understanding more advanced topics, such as precipitation or chemical reactivity, and fail to interpret chemical equations. Levels confusion provides a compelling mechanistic explanation for these difficulties: students mistakenly infer that the dramatic changes associated with some physical changes (*e.g.*, boiling water) visible on the macroscopic level are evidence that the chemical identity of the substance has changed. Here, we show how levels confusion about chemical and physical changes is generated and addressed by a teacher's epistemological moves.

Method

Video data from high school chemistry classrooms was analyzed through multiple phases of close examination. The video was obtained as part of data collection activities for a larger design research project focusing on developing novel computer-based chemistry curricula. During the first phase of the analysis, we reviewed videos of high school chemistry classrooms to identify episodes of classroom discussion for potential close analysis (Erickson, 2006). Specifically, we watched episodes of teaching, which occurred at the beginning of the school year, focused on the introductory concept of chemical and physical changes. We reviewed 22.5 hours of videotaped lessons taught by five teachers at three different high schools and identified two episodes of whole classroom discussion led by two different teachers for presentation here. Cases were selected based on the extent to which teachers and students were involved in active discussion that included reference to multiple descriptive levels. In the selected episodes, while the teacher largely led the whole class discussion, students frequently participated in the discussion as a form of answering the teacher's questions in a triadic dialogue or arguing for their ideas without seeking the intended answer (Lemke, 1990).

In the second phase, the selected classroom episodes were transcribed. First, we transcribed utterances of both the teachers and students. We added more details to this initial transcript by describing teachers' hand gestures and inscriptions on the blackboard or overhead projector. Gestures are a medium in which speakers convey information that is not found in speech (Kendon, 1980; McNeill, 1992; Goldin-Meadow, 1999). Gestures often take on a form of communication that is fully integrated with speech. To better investigate the meaning of the classroom dialogue, we inserted the teachers' gestures and inscriptions into the transcript to support analysis of meaning and identification of descriptive levels referred to in their utterances with joint consideration of these non-verbal expressions. Because the video camera was placed at the back of the classroom, we were not able to analyze the details of students' non-verbal behavior.

During the third phase, we segmented each class episode into stanzas, within which we analyzed the intersubjective agreement of the discourse. Following the guidelines of Lemke (1990) and Gee and Green (1998), we defined a stanza as a self-contained unit comprising sequences of utterances that are spoken by one person or more. Each stanza represents a unitary idea or topic, and the start of a new idea indicates the end of one stanza and beginning of another stanza. Within each stanza, we identified the descriptive level (*e.g.*, symbolic, submicroscopic, macroscopic) referenced by each interlocutor by examining utterances, gestures, and inscriptions. Importantly, evidence for a speaker's referenced descriptive level cannot always be identified from a single utterance as in some cases the speaker's reasoning only became clear after extended talk or interchanges with others. Adapting the approach of Nathan *et al.* (2007), we evaluated intersubjective agreement within each stanza by seeking evidence that both the teacher and students referred to a shared descriptive level (IS+) or they reasoned and spoke from distinct descriptive levels (IS−). The final phase of the analysis aimed to identify the epistemological moves made by the teachers as described by Lidar *et al.* (2006). From the analysis of the stanzas, we identified confirming moves and re-orienting moves made by teachers. Confirming moves included the specific utterances, gestures, and inscriptions that teachers made to confirm that students were reasoning from the appropriate descriptive level. Re-orienting moves included a discrete set of utterances, gestures, and inscriptions that teachers made to guide students to reason about phenomena using a different descriptive level.

Each case was independently coded for referenced descriptive level and epistemological moves by two of the authors. Inter-rater reliability on all codes was calculated to be 80% (Cohen, 1960). Disagreements were resolved through discussion and a final code was assigned in these cases by mutual agreement. All names used in these two cases are pseudonyms.

Speaking from different levels: Mrs Brown and state changes

Our first case examines a discussion of physical and chemical changes in Mrs Brown's chemistry classroom. At the time of the study, Mrs Brown held a BS in chemistry and had five years of experience of teaching at Lakeview High School. Mrs Brown's students were primarily second-year students and had taken one general physical science course prior to enrolling in chemistry. Mrs Brown described teaching chemistry as an attempt to get students excited and more engaged in science. She advocated strongly for connecting chemistry to everyday examples and emphasized group work in all of her lesson plans.

The discussion we present here was taken from two separate 55-minute lessons. Each lesson occurred on Days 1 and 2 of a four-day unit on the particulate nature of matter taught during the first month of the school year. The objective of the unit was for students to understand that matter can be classified as a substance (element or compound) and mixture according to its submicroscopic composition, and that matter can undergo chemical and physical changes. Following the unit, the students completed a unit test. As seen elsewhere (*e.g.*, Ardac and Akaygun, 2004; Adadan *et al.*, 2009), Mrs Brown's students remained confused about the relationship between physical and chemical changes after the unit was completed as their performance on the unit test indicated the majority incorrectly answered questions regarding chemical changes, physical changes, and the particulate nature of matter. Here, we overview the dialogic interchanges from Mrs Brown's lessons that illustrate the distinct descriptive levels used by teachers and students and how Mrs Brown employed both confirming and re-orienting epistemological moves that generated and maintained levels confusion among the students.

Stanza 1 – Teacher's descriptive level indeterminate: apparent intersubjective agreement. Prior to Day 1 of the unit, Mrs Brown's students had completed a reading assignment that included discrete definitions of matter, states, as well as chemical and physical changes. On the first day of the unit, Mrs Brown began her lesson by revisiting these definitions from a prepared set of notes. She repeatedly and explicitly reminded students that chemists are foremost concerned with the composition and behavior of the particles that comprise matter. To emphasize the relationships between each level, she instructed her students to consider how a drop of water would appear on the macroscopic, microscopic, and submicroscopic levels with illustrations drawn on a transparency.

Approximately 20 minutes into the lesson, a whole class discussion revealed that the students tended to privilege macroscopic descriptions of phenomena as individual students provided everyday macroscopic examples of physical change when asked by the teacher.

†Mrs Brown:	What does that mean^ to you: 'physical changes'?
S1:	(?)
Mrs Brown:	((She appears to acknowledge and repeat S1's response.)) Something physically^ changes, right? ((She turns to S4.))
S4:	(?)
Mrs Brown:	((Responding directly to S4.)) Changes in appearance, perhaps? Ok. What are some examples in chemistry when we are talking about physical changes? Jan?
Jan:	The color and texture of something.
Mrs Brown:	Typically, color isn't changed much unless it undergoes a chemical change. That's something to be careful with. Be careful with color. But texture might change. You might cause something like/ can you imagine a sugar cube *versus* powdered sugar *versus* granulated sugar? Those have completely different texture, yet they are all the same. So that would work. Ok, what else?
S3:	A dent in a bumper?
Mrs Brown:	Dent in the bumper? So looks different? ((She nods.)) Megan?
Megan:	(?) burning (?)
Mrs Brown:	Burning is going to cause a chemical change.
Megan:	What about water (?). Is water (?)
S4:	(inaudible) is size?
Mrs Brown:	If size is changed in size into small sizes, like breaking apart. Ok.

Throughout these interchanges, Mrs Brown made multiple confirming moves by validating students' examples of physical changes with an appeal to the macroscopic level. For instance, Mrs Brown responded to students' answers by saying "texture might change" and "So looks different" without acknowledging how the interactions between submicroscopic particles remain identical before and after each physical change. In these responses, Mrs Brown agreed with her students that the macroscopic features (*e.g.*, color, appearance) could be used to distinguish between physical and chemical changes and confirmed the macroscopic descriptive level that students used was valid.

However, Mrs Brown also made epistemological moves that did not clearly indicate to which descriptive levels she referred. For example, when Mrs Brown stated that powdered sugar and granulated sugar "are all the same," it is not clear if she meant that the particles that make up granulated sugar remain the same or whether she meant that the granules remain the same as the cube only smaller. Alternatively, Mrs Brown might have meant that other macroscopic features such as color and sweetness are "the same." Given that Mrs Brown confirmed that color is a valid criterion to discern physical and chemical change, her students might have understood her explanation of "the same" to indicate that the color of the sugar is white regardless of its shape. As such, while Mrs Brown confirmed her students' use of macroscopic level as a valid descriptive level for distinguishing physical or chemical changes, the descriptive level to which she refers is indeterminate in this interchange. With no clear indication that Mrs Brown was reasoning from a specific level, it is ambiguous whether intersubjective agreement among interlocutors is attained. Nevertheless, at this initial moment in the discussion, the teacher and students seemingly agreed that the relevant descriptive level is macroscopic (IS+).

Stanza 2 – Employing two levels concurrently: intersubjective disagreement is revealed. As the discussion proceeded, it becomes apparent that intersubjective agreement was not reached (IS−) in the initial interchange when one student, Megan, pressed Mrs Brown to explain why freezing water is a physical change.

Megan:	Is water to ice a physical change or chemical change?
Mrs Brown:	It is a physical change.
Megan:	Huh, why though?
Mrs Brown:	[Water to ice is a physical change/
Students:	[((Several students express disbelief with outbursts that echo Megan's question.))
Mrs Brown:	[and this is how you tell/ ((Mrs Brown raises her voice to shout over the class, which has begun to argue loudly.)) THIS IS HOW YOU TELL. Perfect/ we got tons of time. This is how you tell!] Is it the SAME stuff?

†Transcription notations: / interruption or self-interruption, [ ] overlapping speech, (.) one second pause, (( )) nonverbal actions, (?) unintelligible, ^ rising pitch, > falling pitch, CAPS emphasis on word. Identified speakers are indicated with a pseudonym and unidentified speakers are indicated with a participant number.

Megan:	Yeah>
Mrs Brown:	Is ice still the same thing, but it's solid? Is it the same stuff?
Megan:	But, it's solid. But water evaporating, is that still a physical change?^
Mrs Brown:	Yes, it is.
Megan:	See, I don't really understand that.
Mrs Brown:	Phase changes are the same! Steam, water (?) evaporated/ is still water/ is still H_2O. They are just moving around faster and they are farther apart. ((She raises both of her hands and quickly moves her index fingers randomly in the air before her face.)) So the water vapor (?) in the air right now, especially right here while I talked, the water vapor's coming from my mouth now. Right? ((Mrs Brown breathes into her hands, and then rubs them together)). You feel it? It's wet? Water vapor, that's still water even though it's a phase change.
Megan:	So what's the chemical change of water (?)?
Mrs Brown:	Chemical change is when you are going to have a rearrangement of the atoms, so that there are (sic) some new arrangement. So when you burn something, there is a new arrangement of atoms/ you have something different in the end. So if you are going to undergo a chemical change with water, you wouldn't have water in the end. You would have something else, something other than water. OK?

In this interchange, Megan has expressed confusion over why the change from water to ice is a physical change. Although Megan seemed to agree with Mrs Brown that ice is "the same stuff" as water, she remained incredulous because "it's (ice) solid" and water evaporates to something that is not water. Drawing on the macroscopic differences between ice, water, and water vapor, Megan asserted that water state changes should be a chemical change. On the contrary, Mrs Brown argued that the compound H_2O does not change upon state change despite macroscopic differences in appearance. The outbursts from several students in support of Megan's question and concern of the chemical change of water suggest that she was not alone in her confusion and that the students mostly reasoned at the macroscopic level. The lack of intersubjective agreement (IS−) indicates that the class did not reach consensus on the nature of the processes under discussion.

Mrs Brown attempted to help clarify the confusion with an implicit re-orienting move to direct the students to consider the submicroscopic composition ("is still water/is still H_2O") and behavior of the particles of water ("they are just moving around faster and they are farther apart") that have undergone a state change. In this way, she appears to encourage here students to consider how the interactions between the particles result in the different emergent properties of ice and steam. However, her re-orienting moves were implicit; she referred to molecules ambiguously with nouns (*e.g.*, water, stuff) and pronouns (*e.g.*, they) that can have multiple meanings. For instance, in the above excerpt Mrs Brown's use of water indicated she was referring to a submicroscopic compound in some utterances (*e.g.*, "a chemical change with water, you wouldn't have water in the end") and a macroscopic substance in others (*e.g.*, Line 26, "water to ice is a physical change"). In addition, while not explicitly articulated, the pronoun "they" appears to mean water molecules since her utterance accompanies gestures indicative of the movement of particles. Moreover, when Mrs Brown re-oriented students to consider the submicroscopic descriptive level with her hand gestures, she concurrently referenced the macroscopic level by demonstrating the visible condensation of water on her hand when she exhaled. Teachers produce gestures when they speak, however, those gestures do not always convey the same information in the speech. Students can interpret information from both speech and gesture and often give preference for the gestural channel (Goldin-Meadow *et al.*, 1999). Thus, the explicit mismatch between Mrs Brown's utterances and gestures may have gone unnoticed as students attended to one modality or the other.

In Stanza 2, the intersubjective disagreement on the relevant descriptive level becomes salient in the interchange. Importantly, the salience of the disagreement was not sufficient to resolve the apparent levels confusion among the students given the students' vocalized confusion. Notably, Mrs Brown made an explicit re-orienting move to describe the result of a chemical change in terms of atoms on the submicroscopic level (*i.e.*, "a new arrangement of atoms"), but she made no clear connection to macroscopic properties described by her students. As such, the exchange does not provide evidence as to whether the students noticed the relevance of the re-orienting move. At this point in the discussion the bell rang and the class was dismissed. Thus, it is not clear whether simply re-orienting the students to reason from her descriptive level is sufficient to resolve levels confusion and promote intersubjective agreement.

Stanza 3 – Teacher's implicit reference to submicroscopic level: intersubjective disagreement maintained. On Day 2, Mrs Brown revisited the previous day's discussion to address any lingering confusion. She began by stating, "Students... tend to typically think that phase changes are chemical changes. ... When it's still the same STUFF, it's all a physical change." Then, she asked students to provide examples of chemical changes:

Mrs Brown:	So what would be an example of a chemical change?
Sarah:	Rusting nail.
Mrs Brown:	Right, so making iron oxide out of an iron nail: An oxidation reaction with the oxygen in the air.
Lisa:	Your body?
Mrs Brown:	What do you mean by that?
Lisa:	Like growing.
Mrs Brown:	Like growing?
David:	That's a physical change 'cause you're still the same stuff.

Joe: You're not producing any new substances.
Mrs Brown: Let's take that a little further. Be specific.
Lisa: Uh (.) I don't know. Like, I don't know about...

Similar to the epistemological moves used on the previous day, Mrs Brown employed several implicit re-orienting moves to direct the students' attention to the submicroscopic level. For instance, Sarah stated that a "rusting nail" is a chemical change with no further justification. In response to Sarah's answer, Mrs Brown responded to Sarah's macroscopic observation ("rusting nail") with a direct appeal to the process of a nail rusting ("oxidation reaction") and the resulting compound ("iron oxide"). We interpret that Mrs Brown reframed Sarah's observation with an appeal to the submicroscopic level in that she referred to the chemical identity of a substance and situated it within a chemical reaction process, a description applicable to the submicroscopic level. However, she did not communicate her descriptive level with explicit terms; thus, her re-orienting move is clearly implicit.

Following this re-orienting move, David and Joe employed the teacher's heuristic from Day 1 (*i.e.*, physical changes produce "the same stuff") with direct reference to the macroscopic level. They argued that a "growing" body is a physical change because an individual person is still "the same stuff" and no new substances are produced at the macroscopic level. Although the students in the class may have taken biology, we do not have any evidence to suggest that they are thinking on the submicroscopic level (*e.g.*, maintaining DNA is "the same stuff" as humans grow). The students do not mention cells, replication, or genetics during this dialogue, which suggests they are likely referring to the person as "the same stuff". Mrs Brown implicitly indicated that growing is not a physical change by asking the students to, "take that a little further." In response, Lisa, David, and another student, Marc, struggled to determine whether growing was a chemical or physical change. Mrs Brown interrupted to clarify that growing involves digestion, a chemical change, with an extensive discussion of metabolism on the submicroscopic level:

Mrs Brown: You eat all this, you got your stomach acids in there and their beginning to break that stuff down and their beginning to break it apart and then certain chemicals are there and they absorb the chemicals from the food into your bloodstream and they go to your cells in your body and they can extract some of that and use that to generate energy.

In this utterance, similar to the previous example of the rusting nail, Mrs Brown's explanation of digestion references the submicroscopic descriptive level with mention of "chemicals" and "energy" while explaining biochemical reaction mechanisms. Interestingly, her discursive expressions of chemical changes (*e.g.*, "break that stuff down", "break it apart") are consistent with the examples of physical changes from the previous day regarding changes of size on the macroscopic level (*e.g.*, "If size is changed in size into small sizes, like breaking apart"). These expressions can be used to describe physical changes on the macroscopic level as well, and none of them make it clear that digestion involves both the rearrangement of molecular bonds and physical breakup of foodstuffs. In her comment, Mrs Brown appears to refer to the rearrangement of molecular bonds, yet it is not clear how her students interpreted these expressions. Indeed, after her explanation, David voiced his confusion.

David: I still don't know what the definition of a chemical change is.
Mrs Brown: Definition of a chemical change? Ok. So, someone give me a definition of a chemical change? ((She looks at Kara.))
Kara: ((reading from the textbook.)) When two substances react to form a different substance?
Mrs Brown: Yes, when atoms rearrange to form a different substance. So, you no longer have the same stuff. That's an example of a chemical change.

As evidenced in this excerpt, some students still remained confused with the concept of physical and chemical changes. To resolve the confusion, Mrs Brown asked for a definition from Kara, who read the definition from the reading. The definition, however, does not appeal to the submicroscopic descriptive level, nor did Kara refer to Mrs Brown's earlier appeal to submicroscopic level. Although Mrs Brown tried to re-direct students to the submicroscopic level by saying, "when atoms rearrange to form a different substance" and "no longer have the same stuff," Mrs Brown and students did not seem to reach intersubjective agreement (IS−).

These interchanges between Mrs Brown and her students illustrate how teachers and students enter into discussions speaking from different descriptive levels and how implicit re-orienting moves are insufficient to re-direct students' attention to submicroscopic phenomena (Stanza 1). The case illustrates how simple terms used in the chemistry class may serve as referents to multiple levels by teachers and students. Although Mrs Brown's students used words and phrases (*e.g.*, "physical change," "water," "rusting nail") to refer to observable macroscopic objects and events, she instead used those same terms to refer to submicroscopic chemical processes and particles (Moment 2). What is more, Mrs Brown recognized the lack of agreement and produced explicit epistemological moves that also failed to re-direct all students to a state of intersubjective agreement (Stanza 3).

In effect, the descriptive level referred to by particular terms renders lessons such as this especially confusing for some students. For instance, the students may hear terms like 'water' and believe they understand the teacher's meaning (IS+) never to realize they have a different understanding (IS−) unless a clear example is offered that highlights the descriptive level intended by the teacher. What is more notable in the case of Mrs Brown's lessons is that she repeatedly directed students to reason from the submicroscopic level. Yet, her students responded quickly with macroscopic observations and terms, which she then validated. When pressed for more extensive descriptions of the submicroscopic level, the students could offer no additional explanations beyond the macroscopic references and maintain levels confusion. In the next case, we illustrate how a teacher who attends to the descriptive levels of students addresses levels confusion as it arises.

Addressing levels confusion: Mr Darius and chemical change

In this second case, we present an analysis of a whole class discussion regarding chemical and physical changes in Mr Darius' chemistry classroom at Fieldstone High School, a suburban arts magnet school. At the time of the classroom observation, Mr Darius had attained a chemistry BS and a MEd and had six years experience as a secondary chemistry teacher. The students in his course were primarily second-year students enrolled in their first chemistry course after taking an integrated science course on matter and energy. Mr Darius described his own teaching practice as an attempt to motivate his students to think more deeply about their everyday observations of matter, and he wished to create a learning environment that allowed his students to feel comfortable to ask questions and think about mechanistic explanations for their daily observations. To that end, he worked to integrate as many everyday examples as he could (as well as infuse a little humor) to help students relate to the abstract principles of chemistry.

The interchanges presented here occurred on the first day of a three-day unit on the particulate nature of matter and chemical and physical changes. On Day 1, Mr Darius conducted a whole class discussion primarily on physical and chemical changes and demonstrated several chemical changes to the students. On Days 2 and 3, the students completed inquiry explorations of computer simulations related to the content of the unit and a laboratory activity to explore the differences between chemical and physical changes. After completing the unit, the students were assessed *via* a written exam, which indicated that the distinction between chemical and physical changes remained blurred for the students as they were for Mrs Brown's students.

Stanza 1 – Use of heuristics appealing to macroscopic level: intersubjective agreement attained. On the first day of instruction, Mr Darius began a whole class discussion by introducing the need to differentiate chemical and physical changes. At the outset of the discussion, Mr Darius offered the students a simple heuristic to determine whether a chemical or physical change has occurred in nature. Specifically, he stated, "the idea is that with chemical changes it's hard, very, very difficult to change it back... with physical changes we can often reverse them back." This heuristic is not unusual and can be found in chemistry textbooks (*e.g.*, Wilbraham *et al.*, 2000); however, this heuristic is not an adequate criterion for classification since some physical changes are irreversible and some chemical changes are reversible. For example, when rice is cooked, water molecules penetrate the walls of the rice kernels. The change is physical, yet each rice kernel cannot be restored to its original state after cooking. Similarly, many chemical reactions are completely reversible given the right thermodynamic system. However, reasoning exclusively from the macroscopic level, the students offered various interpretations that were not consistent with Mr Darius' use of the same heuristic and began to question the use of the heuristic. Following presentation of the heuristic, Mr Darius demonstrated its utility of by folding and unfolding a piece of paper in front of the students.

Mr Darius:	But the idea right here is with physical changes we can often reverse them back.^ So lets say if I crumple this paper right here/ if the paper gets crumpled up/ like this/ ((He crumples a piece of paper in his hands)) all you gotta do to change it back is to do WHAT?^	
Students:	((several shouting)) (?)	[Unfold it.
Mr Darius:		[Unfold it. THAT'S IT.
S1:		[It still won't be the same. (?)
S2:		[It won't be smooth.
Students:		[((several shouting)) (?)]
Mr Darius:	It's not going to be as smooth. But, you can probably end up making it smooth. Eventually, over time you could smoothen it out. Try to make it smooth later on, but it's a little difficult. But, the idea is that you DO get it back right HERE. ((He waves the uncrumpled paper in the air.)) But, the idea is that if I burn this paper, can I GET IT BACK?^	
S3:	[Yes!	
S4:	[No!	
Students:	[((several shouting)) (?)]	
Mr Darius:	NO! You can't get the ORIGINAL paper back.	
Brian:	Maybe!	
Mr Darius:	It's hard, very difficult. If you can figure out a way, let me know.>	
Brian:	You can put it in the soil and grow a tree off it.>	

In the above excerpt, Mr Darius began the discussion using a demonstration to elaborate on the heuristic by crumpling a piece of paper and unfolding it again before asserting that crumpling a paper is a physical change. Mr Darius used the demonstration to draw students' attention to the macroscopic features of the paper sheet. While several students agreed with Mr Darius that "crumpling a paper" is reversible ("Unfold it") and thus a physical change, others students remained unsure ("It still won't be the same"). In this moment, both Mr Darius and his students referred to the macroscopic level to determine physical or chemical change through the use of the heuristic. Mr Darius makes clear that even if every feature of an object is not restored, a change can be reversible if some critical feature remains the same. Problematically, Mr Darius did not specify what the critical feature was that he used to make a determination. As with the case of Mrs Brown, Mr Darius make no reference to the relationship between submicroscopic interactions and the emergent properties of the paper sheet.

Nevertheless, Mr Darius and his students agree that the relevant descriptive level in the discussion is macroscopic (IS+).

Interestingly, although his students also referred to the macroscopic level, they appear to have alternative interpretations of the heuristic. For S1 and S2, ''reversible'' means that every observable feature must be restored. That is, the unfolded paper would have creases that the original paper did not have, and, thus, crumpling a paper is not reversible and not a physical change. To Brian and some other students, reversibility could also mean getting an object back in a cyclical sense. For instance, because ash can be used as a nutritional resource for growing a tree, which can be processed into a piece of paper, even burning a piece of paper can be reversible. Importantly, these alternative interpretations of ''reversible'' indicate fundamental differences in students' conceptual understanding of reversibility. Regardless, even these students justified their claims about reversibility with appeals to the macroscopic level.

In this moment, both Mr Darius and his students primarily referred to the macroscopic level (IS+). Yet, because the students interpreted the reversibility heuristic differently, they cannot agree on whether the crumpled paper has undergone a chemical or physical change. These students did not seem to advocate for their alternative interpretations of the heuristic strongly. Rather, the students' sporadic utterances lacked extended justification and the light tone of their voice suggest that they jokingly offer these alternative interpretations. In the following stanza, however, it became clear that the students were indeed insistent that the heuristic exclusively referred to the macroscopic level as Mr Darius begins to re-orient the students to the submicroscopic level.

Stanza 2 – Introduction to new criteria ''taste'' and ''identity'': intersubjective disagreement revealed. Despite the disagreement among the students about the use of the heuristic, Mr Darius continued the lesson. He presented the class with a list of 15 different phenomena and asked the students to classify if each phenomenon is a chemical or physical change. As the class proceeded through the list, Mr Darius and his students continued to apply the reversibility heuristic introduced in Stanza 1. The students' rapid and correct responses indicate that the students thought that the task was relatively trivial on the whole and that they agreed with Mr Darius about the nature of chemical and physical changes. However, Stanza 2 revealed a failure to reach intersubjective agreement (IS−). It became clear that the students were justifying their claims by appealing to the macroscopic level while Mr Darius reached the same conclusion appealing to the submicroscopic level. The lack of intersubjective agreement was fully realized as the class compared squeezing oranges and exploding fireworks:

Mr Darius:	SQUEEZING oranges to make orange juice? That would obviously be (..)
Students:	((several shouting)) Physical.
Mr Darius:	PHYSICAL, tastes the same. Fireworks EXPLODING?
Students:	((several shouting)) Chemical!
Mr Darius:	CHEMICAL. Why?^
S5:	[Because there's a difference in the (?)
S6:	[They're exploding!
S7:	[EXPLODING!
Marla:	[It's exactly the same as squeezing oranges.>
Brian:	(?)
Mr Darius:	((Mr Darius directs the class to listen to Brian.)) OH-that's a very good question! So the idea right here is this. He asked a very/ very good question. I can't take the orange juice and make an orange again. (..) You're probably right. You can't reform the orange back to what it was. But when you taste the orange and when you taste the juice does it taste the same?^
Brian:	Yup.
Mr Darius:	It does taste the same right?^ So it is really/ really/ the difficulty is correct. So he is correct/ It is very, very difficult to get the orange back. When you squeeze it/Oh^, how do I get the juice back into the orange!?^ But the thing is that you're basically tearing it apart. (.) You're not really changing the identity of it. It's still an ORANGE. By the way, fireworks exploding what's an indication that it's a chemical change?^
S9:	'Cause there's an explosion.
Mr Darius:	There's an explosion. So I see fire. Can I get the chem/ can we get the bomb back? Once it explodes, that's pretty much it.

In this interchange, Marla and Brian argued that because an orange cannot be reformed into an orange once juiced, squeezing an orange cannot be a physical change. Using this reasoning, they conjectured that juicing the orange is the same as exploding a firework, which also cannot be returned to its original state. In response, Mr Darius employed a confirming move to acknowledge that Brian's reasoning about the macroscopic level was correct (''You can't reform the orange back to what it was.''). It is at this point that Mr Darius introduced two additional warrants to help the students distinguish physical and chemical changes: taste and identity. Notably, Mr Darius does not explicitly specify the descriptive level on which taste and identity should refer; however, by making a contrast between the destruction of macroscopic shape of an orange and the unchanged identity (*i.e.*, ''You're basically tearing it apart. You're not really changing the identity of it.''), it would seem that identity refers specifically to the submicroscopic level. Similarly, Mr Darius seems to suggest that because taste is invariant regardless of the macroscopic shape of an orange, no change in submicroscopic composition has occurred without explaining the relationship between taste and chemical composition. Thus, Mr Darius appears here to implicitly re-orient the students to apply the heuristic to the submicroscopic level.

Although his re-orienting move was implicit, Mr Darius later provided strong evidence that he was always referring to the submicroscopic level ("Can I get the chem/can we get the bomb back?") with a self-interrupted reference to chemicals. However, it is not clear at this point whether his students agreed that the submicroscopic level was relevant. While the students' confusion between physical and chemical changes appeared to be resolved after Mr Darius' explanation, the following stanza illustrates that the students failed to transition to the submicroscopic level following the reorienting move.

Stanza 3 – Explicit re-orientation to submicroscopic level: intersubjective agreement not attained. Despite the apparent resolution regarding the criteria for identifying a physical change and a chemical change in the previous exchange, as the conversation proceeds, Mr Darius and his students again disagreed over the reversibility heuristic and the taste and identity warrants:

Mr Darius: How about frying an egg? It's still an egg isn't it?
Students: ((several shouting)) Physical!
Mr Darius: That's a chemical change. >
Students: ((shouting erupts across the room))
Terrell: [Huh?
Rhonda: [What?
Brian: [Wait a minute! WAIT A MINUTE!
Mr Darius: [That's the] / (Mr Darius cannot be heard over the students' shouting. (?))
Brian: WAIT a minute / If orange/ if orange make/ making orange juice is physical, then that should be physical.
Mr Darius: Ok, here is a QUESTION right here/ (?) with an orange/ (?) that's very [good/
Terrell: [Because it still tastes/
Mr Darius: [FOOD is great (?)/
Brian: [It tastes the same!]
Terrell: ((to Brian)) Exactly!
Mr Darius: I say it DOESN'T taste the same.

In this exchange, students utilized Mr Darius' previous warrant that squeezing an orange is a physical change ("it tastes the same") to determine whether frying an egg is a physical or chemical change. Brian and several other students argued that frying an egg must be a physical change because fried eggs taste the same as raw eggs as squeezing an orange is.

Brian continued to insist that frying an egg is a physical change and asserted that the use of taste and reversibility cannot reliably differentiate between chemical and physical changes.

Brian: Are you REALLY basing this on taste? 'Cause you can't turn/ once you squeeze an orange, you can't make it an orange again!
Mr Darius: Oh, but the idea/
Brian: Once you fry an egg you can't put it back in the eggshell so/ ((Several students begin shouting again in support of Brian's argument.))
Mr Darius: Does it taste the same?
Brian: No, 'cause you add your own SEASONING.
Mr Darius: No/
Brian: You add stuff to it so that it doesn't taste the same. But it's doing the same thing/
Mr Darius: So, as (?) this is/ you've got a very good point/ Brian's got an excellent point. The idea that we can't/ I can't reverse the orange juice back to the normal, back to a normal orange that you (?)/ Right here! But the thing is this/ the orange juice could not/ I could always try to freeze the orange juice the make it solid again and similar to an orange.
Brian: But it WON'T be an orange!
Mr Darius: You're right it won't be an orange. Whole^ like the orange.
Brian: The pulp/ the skin/ It won't be an orange. It's just JUICE!

In this exchange, Brian referred to the similarity of the two phenomena on the macroscopic level—both squeezing an orange and frying an egg involve dramatic changes to the overall shape of an object that can never be returned—and argued that if a juiced orange is still an orange then a fried egg must be still an egg. To Brian, squeezing an orange cannot be a physical change because orange juice cannot be reconstructed into an orange, in the same way that a fried egg cannot be reconstructed into a whole egg ("you can't put it back in the eggshell"). As students argued in Stanza 1 that crumpling a paper is not a physical change because the unfolded paper would not be smooth as the original paper, Brian asserted that squeezing an orange is not reversible in the sense that not all features of an orange are restored. Therefore, by way of the reversibility heuristic, he reasoned that squeezing an orange must be a chemical change. Here it becomes evident that the students maintained the idea that every macroscopic feature of an object should be restored in the event of a physical change and that they had been referring to the macroscopic level alone throughout the discussion.

In the above exchange, Mr Darius made a confirming move that acknowledged the validity of Brian's argument that the phenomena under discussion cannot be restored after physical changes on the macroscopic level. Recognizing that Brian was firmly fixed on the macroscopic level, however, Mr Darius made an explicit re-orienting move to direct him to submicroscopic level in an attempt to resolve the confusion.

Mr Darius: It's JUICE, but doesn't it taste the same?
Brian: UH huh.
Mr Darius: Doesn't a regular orange taste the same as orange juice?
Brian: Yes!
Mr Darius: It tastes EXACTLY the same. Right. The change, did any like one of the atoms rearrange itself? Like, did the sugar atoms change like into a salt atom or something untasty? So the idea right here is that/
Brian: Huh?

In this exchange, Mr Darius appealed to the submicroscopic level with direct reference to submicroscopic objects within the contexts of chemical reaction processes (*e.g.*, "atoms rearrange itself," "sugar atoms change... into a salt atom or something untasty?"). This suggests that his taste heuristic, the descriptive level of which remained ambiguous in Stanza 2, was indeed based on the submicroscopic identity of substances. By connecting taste with a particular arrangement of atoms, Mr Darius indicates that the heuristic has always referred to the submicroscopic level. Unfortunately, the discussion concluded with no clear indication that intersubjective agreement had been reached. Brian and the other students, clearly frustrated, moved to table the discussion, and Mr Darius concluded the lesson.

Although the beginning of this discussion show instances of intersubjective agreement, as the dialogue continues Mr Darius and his students have more frequent occurrences of intersubjective disagreement. Our analysis of each of these interchanges between Mr Darius and his students suggests that students consistently justify their application of the reversibility heuristic with appeals to the macroscopic level while the teacher uses the very same heuristic with appeals to both the submicroscopic level. Notably, the heuristic applies on both the submicroscopic and macroscopic levels in many examples. For instance, in determining whether an explosion of fireworks is a chemical or physical change, the change is irreversible on both the submicroscopic and macroscopic levels since the original compounds are converted to new compounds and the macroscopic shape of a firework is irreversibly changed after the explosion. Therefore, students may often appear to agree with the teacher's explanation despite maintaining a distinct level of reasoning.

Furthermore, it is evident that although Mr Darius attended to the discrete descriptive levels that are in play throughout the discussion, he made a concerted effort to acknowledge that the students were providing reasonable arguments on the macroscopic level. Using confirming moves, Mr Darius established intersubjective agreement with macroscopic references to create a leverage point that re-oriented the classroom to appeal to submicroscopic phenomena (Stanza 1). As the discussion evolved, he strived to encourage the students to use sensory evidence (*i.e.*, taste) to discriminate between changes that occur macroscopically and submicroscopically. Unfortunately, the students did not transition with him following implicit re-orienting moves as evident in Stanza 2. Mr Darius recognized the lack of intersubjective agreement and employed explicit re-orienting moves to the submicroscopic level (Stanza 3). Although frequent occurrences of IS+ and IS− like this are characteristic of productive argumentation (*cf.*, Nathan *et al.*, 2007) and a necessary feature of any method that attempts to resolve levels confusion, in this case Mr Darius and his students were unable to reach agreement by the end of the discussion.

Conclusions and implications

Chemical and physical changes are considered elementary topics in the chemistry curriculum. However, as we have shown in this study, students face significant instances of levels confusion in this entry level topic, which may later complicate their learning of more advanced topics. Various factors may contribute to the levels confusion that students experienced in our two cases. As other scholars have argued, those factors may include the structure of high school chemistry curricula (Kozma *et al.*, 2000) and teacher lack of adequate chemistry knowledge (Thiele and Treagust, 1994). However, our analysis indicates that the way the teachers and students communicate their understanding in discourse raises challenges for students. We believe it is entirely feasible for a teacher with advanced content knowledge to make the same epistemological moves seen in the two cases presented in this study given the intersubjective nature of classroom discourses. That is, although teachers and students bring their own reasoning frameworks, they have only partial access to each other's framework.

Although we do not claim the present work is generalizable to all teachers or classrooms, we do believe our analysis offers important insights into the generation, maintenance, and the act of addressing levels confusion among chemistry students. Notably, the two cases presented here, taken from unrelated classrooms geographically distant from one another, suggest that students are prone to levels confusion from their initial introduction to chemistry in multiple settings. Specifically, students readily rely on their everyday experience to reason about fundamental chemistry topics with appeals to the macroscopic level. Students' understandable reliance on prior everyday experiences may result in misapprehension and levels confusion when asked to reason about imperceptible submicroscopic objects and phenomena in chemistry not easily resolved over short learning activities.

By adapting the analytical framework of Nathan *et al.* (2007) and Lidar *et al.* (2006), we have demonstrated that teachers and students face significant challenges reaching intersubjective agreement about mechanistic explanations in chemistry and the relevant descriptive level in any given discussion. Teachers and students enter discourse spaces predisposed to reason from different descriptive levels comprising distinct phenomena, yet each does not readily acknowledge the lack of intersubjective agreement at the outset of a discussion. In each case above, the initial interchanges demonstrated that students respond to teacher questions under the assumption that the macroscopic level is valid. In contrast, the context of the teachers' questioning and their replies to students' responses indicate that submicroscopic level is the relevant level. Moreover, these cases illustrate the challenges teachers and students face reaching intersubjective agreement. Despite the variety of discursive moves made by both teachers to draw students' attention to the submicroscopic level, there was evidence that intersubjective agreement was not reached in either class.

The present work does not identify all of the underlying factors responsible for the failure of each classroom to reach intersubjective agreement; however, it does illustrate how specific discursive practices may not result in intersubjective agreement. Here, we have demonstrated how teachers use re-orienting and confirming moves to encourage students to attend to one or more descriptive levels. In different ways, teachers can encourage students to consider phenomena and processes that occur on the submicroscopic level as well as discourage students from considering macroscopic phenomena. For example, Mr Darius acknowledged his students' appeals to the macroscopic properties of an orange before he dismissed the relevance of those properties to the definition of a physical change. Likewise, Mrs Brown encouraged her students to speak directly about particle behavior when describing the differences between solids, liquids and gases. Of note, these teachers employed such epistemological moves implicitly and explicitly over the course of discussion. Although it would seem that explicit re-orienting and confirming moves are necessary to foster intersubjective agreement, they were not sufficient to resolve levels confusion in either classroom. In each case, the teachers' use of implicit and explicit re-orienting moves failed to bring the class to intersubjective agreement on the use of the submicroscopic level to classify chemical and physical changes.

The present analysis suggests that the failure of explicit re-orienting moves to resolve levels confusion results from three distinct discourse practices that involve 'speaking across levels'. First, teachers and students employ ambiguous terms in discussions of chemical phenomena that are valid across different levels. As such, teachers use specific terms in the classroom to reference objects and phenomena on the submicroscopic level while students use those same terms to refer to macroscopic events from everyday experience. The predisposition of teachers and students and the selective association of terms to different levels were evident in Mrs Brown's class where students used terms, such as "water," to appeal to both macroscopic phenomena despite the teacher's use of the same term to appeal to submicroscopic particles. Second, teachers engage in fluid transitions among descriptive levels during a lesson, yet engage in discourse practices that encourage students to fix their reasoning on one specific level. Both Mrs Brown and Mr Darius illustrated such transitions by offering rich explanations to their students with reference to the submicroscopic level while simultaneously confirming students' appeals to the macroscopic level. Finally, teachers may provide students with heuristics or rules to reason about events that exist on the submicroscopic level; however, students use those same heuristics to reason about events that exist only on the macroscopic level. As in Mr Darius' classroom, students' application of such heuristics to macroscopic objects and phenomena is often successful and may go unnoticed by teachers unless students explicitly express confusion about using such heuristics.

Although it is not clear from our cases whether speaking across levels in these ways exacerbates pre-existing levels confusion, it is clear that levels confusion is not resolved when teachers and students speak across levels. Moreover, these cases provide distinct implications for practice in the chemistry classroom. Students face many challenges learning chemistry that include connecting macroscopic and submicroscopic observations as well as creating and reasoning with multiple external representations (Banerjee, 1995): discourse practices in the classroom can either intensify or address these challenges. Our analyses indicate that the distinct descriptive levels referred to by teachers and students are often tacit. That is, students and teachers appear to understand one another as they assume the other is reasoning on the same level at times.

An obvious pedagogical implication then is to include opportunities for students and teachers to make explicit their level of reasoning during discussion. Given the evidence here that students come to chemistry instruction with a bias for reasoning about molecular phenomena from macroscopic experiences, we argue that professional development opportunities should be provided to help teachers make descriptive levels explicit in the classroom. For instance, teachers must be encouraged to discuss descriptive levels at the outset of his lesson rather than waiting until students become overtly confused and frustrated. Similarly, teachers require training with instructional strategies that encourage students to state their descriptive level explicitly whether in drawing or verbal narratives. Finally, training should be provided for teachers to practice identifying descriptive levels tacitly referenced by their students and re-orient them when needed.

These cases also suggest design principles for new curricular innovations that can better support teacher and student discourse. As discussed, typical chemistry curricula do not provide students with direct access to submicroscopic chemical phenomena or effectively relate the three levels in chemistry. These oversights can be addressed with new innovations that offer direct access to representations of the submicroscopic level and systematically relating these representations to macroscopic depictions and symbolic representations. For example, novel computer-based curricula, such as *The Connected Chemistry Curriculum* (Stieff *et al.*, 2012), provide interactive computer simulations that include visualizations of submicroscopic entities alongside macroscopic and symbolic descriptions. These features help students become conscious and explicit about their descriptive levels and support their claims with appeals to the submicroscopic level. Likewise, students need support to understand how specific heuristics, terms, and definitions have different meanings when they are applied across levels and that transitions between levels are warranted for specific types of claims. Curricular materials that provide representations of submicroscopic phenomena without justifying the relevance of such representations to students' everyday experiences are likely to reproduce the levels confusion seen here.

Our analysis also offers several implications for the continued use of the levels triangle to motivate research and curriculum designs in the science education community. First, the levels confusion demonstrated by the students in this study illustrate that the challenge students face understanding science concepts, like those above, do not simply derive from issues of scale. For example, students in Mr Darius' class were confused about disciplinary meanings of 'reversibility' in macroscopic and submicroscopic levels and how unchanged submicroscopic entities result in macroscopic reversibility of certain kinds, such as folding a paper. This clearly suggests that the students were confused about the underlying phenomena under discussion and the relationship between macroscopic and submicroscopic descriptions of a chemical process, not the relationship between objects of different sizes. Second, some concepts in the science classroom involve complex systems thinking, but levels confusion does not solely the result from the challenges associated with relating levels to understand a chemistry concept. As above, in some cases, levels confusion results from a far more basic failure to recognize the relevant phenomena or a misattribution of properties across levels. Additional research is needed to understand how and why such challenges complicate conceptual change within chemistry.

In conclusion, our analyses suggest that chemistry teachers, experienced in the domain, view chemistry primarily from a submicroscopic perspective, which they tacitly appeal to while teaching. As suggested by Johnstone (2010), we have shown how teachers rapidly switch between levels as they attempt to justify their explanations of chemistry phenomena. Based on the interchanges between the students and teachers in each case it would appear that teachers and students do not necessarily acknowledge the different perspectives of the other in the classroom. In turn, students' explanations may at times appear correct when the causal mechanisms students appeal to for these explanations are not. Likewise, teachers may face significant challenges in helping students to understand specific concepts with appeals to the submicroscopic level, which students are prone to ignore. As opposed to resigning ourselves to the assumption that levels confusion is an inevitable consequence of learning chemistry, we suggest that more research is needed to locate the sources of levels confusion in this domain. In particular, we offer that identifying sources of levels confusion that originate from student–teacher interactions, such as those presented here, offer a concrete learning obstacle that can be addressed directly by teachers, design researchers, and professional developers.

Acknowledgements

The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A100992 to the University of Illinois-Chicago and grants from the Maryland Higher Education Improving Teacher Quality Program (ITQ-09-708, ITQ-10-814) to the University of Maryland. The opinions expressed are those of the authors and do not represent the views of these agencies. We thank Lama Jaber for her input and recommendations regarding the manuscript. We especially thank Mrs Brown, Mr Darius, and their students for their contributions to this work.

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