Chemistry Education Research and Practice

Accepted Manuscript

Chemistry Education Research and Practice

ARTICLE

The role of gestures in a teacher-student-discourse about atoms

Simone Abels[a]

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

www.rsc.org/

Recent educational research emphasises the importance of analysing talk and gestures to come to an understanding about students' conceptual learning. Gestures are perceived as complex hand movements being equivalent to other language modes. They can convey experienceable as well as abstract concepts. As well as technical language, gestures referring to chemical concepts can be a challenge for students and cause misunderstandings. The study presented here focuses on a chemistry teacher's use of gestures in a discourse about atoms. The question of interest is how the teacher uses certain gestures, if her intentions can be reconstructed and if students seem to understand the content-related gestures. Analysis is done by applying the steps of Documentary Method. The results show that the teacher uses imagistic gestures , because of the assumption that students can remember and understand the abstract concepts of chemistry faster by using scaffolding in forms of visualisation. Challenges of using gestures to visualise abstract chemistry concepts are discussed.

Introduction

Chemistry teaching without language seems impossible. Technical and symbolic language is very dominant in and necessary to communicate about chemistry in oral and written form. Language is one of the main issues that fosters or hinders learning in chemistry (Markic, Broggy & Childs, 2013). However, students are able to generalize their experiences during practical work, for example, and form concepts without using language explicitly (Taber, 2015). The case is different when chemical concepts cannot directly be experienced, e.g. the concept of an atom, an electron, of bonding, of a halogen etc. Then some kind of representation has to be applied, perceived and interpreted to achieve a conceptual understanding on a submacroscopical level[2]. Whether the used language really means the same thing to every communication partner often remains unclear for teachers and students (ibid.). Teachers can hardly control every individual interpretation and association that students make out of representations.

The chemistry teacher is responsible to use language tools that are suitable for the addressed learners in relation to their prior knowledge, their conceptions, their language skills, their cultural background and other influencing pre-conditions (Hart & Lee, 2003). As not only the technical language can be a challenge for students, but the language of instruction (or academic language) anyway – being very different from everyday language (Gibbons, 2009; Riebling, 2013), teachers need high expertise in using appropriate language and support strategies.

For a long time, educational research in the area of language was focused on talk and texts only. In the meantime and also due to technical developments, the foci broadened to "a range of modes to express meaning in the classroom" (Jewitt, Kress, Ogborn & Tsatsarelis, 2001, p. 5). "Language is a system of resources for making meanings" and researchers need to know how language is used to make meaning in a social situation, in "a community of people who share certain beliefs and values" (Lemke, 1990, p. 11f). The problem is that teachers and students often are not a community with shared understandings. Research interest of this paper is focused on what understandings students and teachers share, when teachers only assume understanding is shared, when obvious misunderstandings occur and how this can be reconstructed.

It is important to notice that the modes, i.e. "culturally shaped resources for making meaning" (Kress et al., 2005, p. 2), used by teachers in classrooms are not limited to verbal means, but also include non-verbal aspects like body-language, hand movements, facial expressions and gaze motion, to express meaning and to facilitate conceptual learning. Therefore, recent studies propose a multimodal approach of teachers' and students' communication, where all culturally shaped resources are considered, to learn about the meaning making and misunderstandings in classroom discourses (Givry & Delserieys, 2013; Givry & Roth, 2006; Kress et al., 2005; Pozzer-Ardenghi & Roth, 2007). Goldin-Meadow (2014) demands to include gesture in research studies to understand learning, as children can express meaning in a manual modality way earlier than in spoken language. Gestures are inter alia used as a substitute for missing verbal expressions (ibid.), a result which seems to be relevant for conceptual learning in the chemistry classroom as well, where the technical language is often not developed yet, although a certain concept is on the agenda.

[a] Leuphana University of Lüneburg, Germany, Institute of Sustainable and Environmental Chemistry, simone.abels@leuphana.de

Electronic Supplementary Information (ESI) available: Two videos showing a recreation of the teacher's gestures are available. See DOI: 10.1039/x0xx00000x

This paper here will set an emphasis on the manual mode, on the role of gestures, in teacher-student-discourse to find out if gestures are a helpful strategy to support students understanding of abstract chemistry concepts. The fact is well-established that students learn abstract concepts better during direct instruction instead of during hands-on phases (Hmelo-Silver et al., 2007; Johnstone, 2000; Wickman, 2002; Bergqvist & Säljö, 1994). That is why teacher-student-discourse is considered for the data analysis here and not an inquiry-based setting, for example. The case study presented here is explorative in nature and provides a starting point for further research in this field.

Theoretical Background

Language and gestures

Speech and gesture are semantically equal modes of communication (Quek et al., 2002), even though they do not follow the same rules of syntax. The authors understand gestures not only as hand movements, but include body motion, facial expressions and gaze shifts into the definition (ibid.). Abner et al. (2015) cluster gestures in accordance with the part of the body used to produce a gesture. McNeill (1992, 2005) classifies gestures as hand and arm movements with symbolic features, closely linked or even simultaneously produced to spoken language (co-speech gestures). Kendon defines gestures as actions with "manifest deliberate expressiveness" (Kendon, 2004, p. 15). It depends on the situation, the context and the counterpart if a gesture is perceived as deliberately expressive. Thus, a gesture attains distinction by the interpreter making gesturing a social endeavour. In any case, gestures are dissociated from self-touching (like itching the nose), from expressions of affect, from object manipulations and also from sign languages.

Gestures can fulfil different purposes in an utterance of a person. They can either substitute verbal expressions; they can be used as lingual support in a communication process; or they can be independent carriers of meaning eventually interacting with verbal utterances (Clement, 2008). Also, important parts of verbal utterances can be emphasized by gestures (Wagner et al., 2014). Kendon (2004, p. 1) points out that "visible actions" can complement, supplement, substitute or alternate verbal actions. So, gestures can also be classified according to their function: they are either interactive or representational (Abner et al., 2015). Interactive gestures do not convey content, but frame the verbal utterances in a dialogue. Representational gestures communicate the topic or content of speech. That is why they are mostly in focus of educational research, which will be the case in this study as well. Accordingly, Novack et al. (2014, p. 904) define gestures as "representational hand movements that vary in how veridically they represent actions."

Gestures are either non-imagistic, like emblems and beats (simple and fast movements with a finger or hand), or imagistic. Imagistic gestures are mostly representational gestures (Abner et al., 2015) which can be coded as deictic, iconic or metaphoric. A gesture is deictic when a pointing movement is conducted with any part of the body. The pointing does not need to be directed to real entities. 'Iconics' relate to the semantic content of an utterance, a concrete event or object, whereas 'metaphorics' refer to the image of an abstract concept (McNeill, 1992). Givry and Delserieys (2013) recommend concentrating on deictic and symbolic gestures in educational research. The latter summarize iconic and metaphoric gestures. "Due to the multifaceted nature of most gestures, he [McNeill, 2005] prefered [sic] a dimensional, rather than category-based characterization of gestures, with dimensions including iconicity, metaphoricity, deixis, temporal highlighting (beats), and social interactivity. This acknowledges the fact that the majority of gestures can be characterized along several of these dimensions" (Wagner, Malisz & Kopp, 2014, p. 211f), i.e., one gesture can have different blended meanings (Abner et al., 2015). Crowder (1996, p. 179) separated McNeill's gesture types into process and content gestures: beats are process-oriented; iconic, metaphoric, deictic and functional gestures are content-oriented. Functional gestures are co-speech gestures functioning "in three ways – as redundant to ideas expressed through speech, enhancing of them, or as an alternative carrier of scientific meaning" (ibid., p. 175).

Hand motions represent entities or movements of these entities (Clement, 2008.). They can carry the full range of meaning designated by the operator. Gestures simplify communication and help encoding messages: "By using our hands, we avoid having to produce precise verbal descriptions of spatial dimensions" (Wagner et al., 2014, p. 209). This means, that the symbolic representation of gestures can be distinguished from that of spoken language. Gesture allows for different representations of space and time overcoming linearity (Kendon, 2000). More, clearer or different information can be transported at the same time when using gestures while speaking. These co-speech gestures, although they may not be perfectly in time with the verbal expression, set the context of how to interpret verbal actions, what people easily seem to manage as long as the gestures are culturally familiar to them (Abner et al., 2015). Gestures allow for insights into the thoughts of speakers and can thereby be a helpful tool to understand and foster learning processes.

Gestures and learning

The use of gestures effects learning. Only by analysing speech *and* gesture, a full understanding of how utterances are intelligible to people is possible (Kendon, 2004). Goldin-Meadow realised in her studies that children "use gesture to express more global ideas that do not fit neatly into word-like units" (Goldin-Meadow, 2014, p. 9). Gestures help students to come to an understanding of and communicate about conceptual ideas, they cannot put in words yet. Students with cognition and language as developmental areas compensate their difficulties by using gestures (Stefanini et al., 2007). Also, people gesture more on conceptually complex tasks (Hostetter et al., 2007). The reason is that speech and gesture are based on different representational formats: “speech is categorical and discrete, whereas gesture is gradient and analog” (Abner et al., 2015, p. 441). Gestures seem to be more suitable to convey visuo-spatial details (ibid.), which is an important notion for the learning of abstract concepts in chemistry education, where visualisation (e.g., by using models or animations) is often used to support learning on the submacroscopical level (Eilam & Gilbert, 2014).

Also, the results of Ping and Goldin-Meadow (2010) show that cognitive load is reduced when speakers talk about abstract concepts using gestures. This is a helpful hint for teachers to free up cognitive capacity (Kelly et al., 2008). However, there seems to be a difference for novices and for experts. While expert adults need gestures to match speech to lighten cognitive load, students’ performance can develop better when there is a mismatch between gesture and speech. “[W]hen the novices in our study produced gesture-speech mismatches, they remembered more on a concurrent secondary memory task than when they produced matches” (Ping & Goldin-Meadow, 2010, p. 617). Of course, one of the modes has to relate to a correct concept to show nascent understanding. For observers these mismatches give insights into students’ knowledge: they know more than they say and subsequent instruction can be designed accordingly (Kelly et al., 2008).

It has to be questioned if gestures also transport clearer information in an academic context while using technical language. Technical language is not necessarily part of students’ communication (Riebling, 2013) and as the terms the gestures could lead to mis- or non-understanding. “It is my hunch (but only a hunch) that the more abstract and metaphorical the content the gesture pertains to, the more likely we are to observe consistencies in the gestural forms employed. To the extent that metaphors are socially conventionalized, to this extent also we may find that gestures used to represent metaphorical concepts will show social conventionalization also” (Kendon, 1996, n.p.). Hence, gestures for technical terms would be rather precise, but they also have to be developed to become common sense.

So far, gestures have shown to be a powerful teaching and learning tool, however, the use of gestures in science education is a rather new topic. For example, in physics education a study was designed by Carlson et al. (2014), who compared two groups of adults. They either watched a video instructing them about gear movement with speech only or with speech and gesture. It was found that “the video instruction improved performance from pre- to posttest and the instruction that included gesture improved performance more than instruction that did not include gesture” (ibid., p. 36).

Concentrating on math education, where the manual mode is longer established as a research area than in science education, Goldin-Meadow et al. (2009) compared how children problem solve by using concrete actions on objects or by using gestures. The children were supposed to learn the novel concept of solving a certain type of math equations. Results show that using gestures led to the generalisation of the concept behind the task whereas using concrete objects did not lead to this stage of conceptual understanding. “On a continuum from action to abstraction, gesture is more abstract than action but still less abstract than verbal language” (Novack et al., 2014, p. 909). This could give gesture the power for learning. Teachers especially use gestures, when they perceive their students struggling with concepts (Kelly et al., 2008).

On the basis of her analysis, Crowder (1996) suggests students gesturing differently when they either describe pre-thought or explain in-the-moment science content. While describing thought-out ideas, gesture and speech are synchronized, i.e. gestures are redundant to speech. “While explaining in-the-moment, speakers often gesture iconically to enhance meaning and elaborate their points and beats to assist with predicting from and relating elements in a spatial model.” (ibid., p. 202)

Pozzer-Ardenghi and Roth (2007) found out that biology teachers rather use deictic gestures when referring to static phenomena or when integrating schemes or 3D-models; they use iconic gestures when referring to dynamic processes (like blood circulation), always striving for students’ “comprehension of a particular scientific concept” (ibid., p. 111). The authors conclude that teachers can better grasp students’ conceptual learning progresses when other resources apart from or in addition to speech or writing may be used.

Again, this stresses the importance of multimodal approaches not only focusing on the verbal mode of communication (Givry & Delserieys, 2013). The two authors simultaneously analyse talk, gestures and salient elements of the context using videotaped teaching lessons and interviews. Only this combination helps them understand students’ ideas about gas.

This perspective is also favoured by Flood et al. (2014), who concentrate on the use of gestures in chemistry education. “As a readily available, visible, three-dimensional, spatio-dynamic mode, gesture is particularly well-suited to meaning-making at the molecular level” (ibid., p. 12). Chemistry concepts involve spatial, dynamic and sub-microscopic aspects, which makes gesture an important tool to visualise and thereby explain unobservable aspects of chemistry. Flood et al. (2014) used video-taped interviews to analyse gestures of students by an in-depth, ethnographic approach. They aim at reconstructing the meaning-making of students talking about the Bohr model. Results of the study show that teachers can conclude on misunderstandings from analysing speech and gesture. Meanings can be negotiated even if academic language is missing. Furthermore, teachers can come to know more about students’ conceptions, when involving gestures into assessment in comparison to paper-pencil-tests, as three dimensional visualisations are possible. Teachers need to integrate the use of gestures into their teaching. “Many topics in chemistry, for example, appreciating stereochemistry, imagining symmetry operations, or predicting frontier orbital interactions, require an understanding of the respective phenomena in three dimensions. Gesture provides a useful medium for students to share and explore their understanding of these topics in three dimensions with others" (ibid., p. 19).

Flood et al. (2014) are one of the rare studies on the use of gestures in chemistry education. They see the necessity to compare their results with other cases studied in such detail to find out more about the meaning-making during classroom discourse. The project here is dedicated to the teachers' use of gestures in a teacher-student-discourse on atoms in an inclusive chemistry classroom, where technical language is under developed.

Research Design

Research field

Data was collected at an urban integrative middle school in Austria (5th to 8th grades) where students with and without special needs learn together. The school consists of two to three classes per age group, which is each taught by a team of general and special educators. Each class has about 20 students. Up to a quarter of students is diagnosed with special needs following the special needs curriculum. Or they are assigned with special needs in one or more subjects where they get extra support following the general education curriculum. The school has established conducive developmental measures to support all students as best as possible. For example, students can take part in learning to learn courses, in reading and writing support courses, in therapeutic vaulting etc. The school program is reform-oriented with elements of project-based and discovery learning (Abels, 2015).

During school year 2013/14 the researcher was at the school being a participant observer in the chemistry classes. About 20 hours of chemistry were observed. Only the eighth graders, i.e. two classes, had chemistry lessons. Each class was divided into semi-groups being taught one lesson (= 50 minutes) of chemistry per week by the same chemistry teacher. Also all students with special needs took part except for the students with severe mental disabilities. The teacher decided it that way because of safety and complexity issues. Thus, about nine to ten students form a semi-group.

During the chemistry lessons different teaching settings were orchestrated: for one, inquiry-based phases took place, for another, teacher-student-discourses were observable. These discourses were initiated during theoretical and practical phases of the lessons. The focus of this paper is on a theoretical discourse of one semi-group about atoms and atomic structure to facilitate a microanalysis of the used gestures. During this chemistry lesson the teacher and seven 8th graders were present, three female students (in the following abbreviated by sf#) and four male students (sm#), two students were missing. Two students officially had special needs. Overall, the achievement level in the class is rather low.

The project was authorised by the responsible Austrian education authority in accordance with the school education law, § 46(2). The author signed the declaration of commitment to data secrecy. The head of school officially approved the project as well; the chemistry teacher agreed in writing that she welcomes the research project. All parents were informed by letter about the study and that data would be used only for scientific purposes in an anonymised way. They signed an agreement. All students were enlightened about the focus of the project as well as about the video data not being published. They were offered to take part in the computer science class, which took place parallel with the other semi group. All students stayed.

Research question

The research question for the study at hand focuses on the teacher's perspective to find out what influences the teachers' way of using gestures during a teacher-student-discourse on atoms in an 8th grade chemistry lesson. In what ways does gesturing function as a teaching and learning tool in a discussion about the abstract concept of atoms? It is of interest to explore what understanding is transported by the use of gestures to facilitate students' conceptual learning. It shall be reconstructed if students and teachers share understanding.

Data collection and analysis

Data were collected by videotaped participant observation. The chemistry lessons were videotaped, either with three cameras during small group work or with one camera during plenum phases. During the lesson of interest here, the teacher and the seven students sat in a circle around a table (Figure 1). Parts of the lesson were orchestrated as small group work. These phases are not in focus of the analysis presented here.

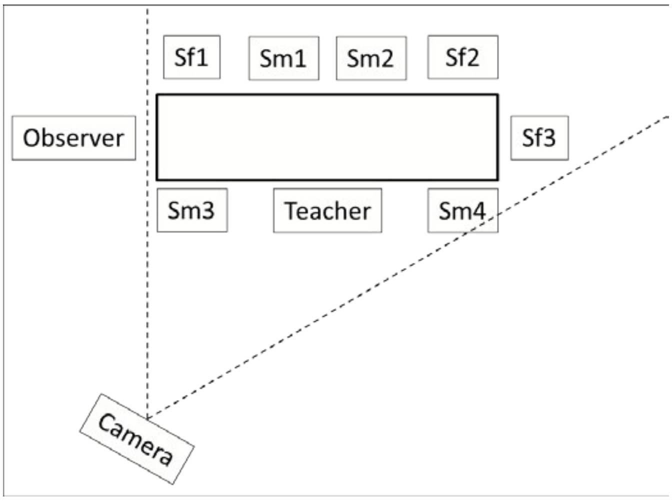

Figure 1. Camera script during teacher-student-discourses in plenum phases

For the microanalysis, an in-depth, ethnographic approach like in the study of Flood et al. (2014) is applied. The difference to the study of Flood et al. is that no interviews were orchestrated, but the regular chemistry lessons were videoed to include an authentic focus on the teacher's use of gestures. As it is not only of interest WHAT kind of gestures were used, but also HOW they were performed and what implicitly guided the teacher using them, data analysis was conducted by applying the systematics of the Documentary Method (Bohnsack, Nentwig-Gesemann & Nohl, 2013). The Documentary Method is based on Mannheim's sociology of knowledge. This method distinguishes between the *communicative* and the *conjunctive* realm of communication. The communicative realm refers to WHAT is explicitly said and done. The conjunctive realm refers to HOW this reality is constructed. As a researcher you interpret the performance to conclude incorporated, habitual knowledge and practices. You want to find out which 'orientational frameworks', i.e. implicit mental images or beliefs, guide the action or decisions of the subjects and if the conjunctive realm is shared by all discourse participants (Przyborski & Wohlrab-Sahr, 2010), which cannot be assumed in a classroom discourse (compare introduction of this article). How teacher and students differ in their understanding can be reconstructed by using the Documentary Method. "Orientational frameworks (..) embody knowledge a person may not necessarily be aware of, but which nonetheless regulates how he/she talks about a particular topic and takes action. In this study, it will be assumed that a teacher's orientational framework regulates both *what* and *how* he/she is talking (…)" (Ruhrig & Höttecke, 2015, p. 451, orig. emphasis). Here, it will be assumed that orientational frameworks also regulate gesturing.

The Documentary Method was also chosen, as orientational frameworks can be interpreted from body language and gestures taped on video or saved in pictures (Bohnsack, 2013). Bohnsack (2011) developed the approach further explicitly focusing on visual data before analysing speech, which give the researcher the possibility to reconstruct how meaning is established among the communication partners. Thus, the Documentary Method itself is a multimodal approach being in line with the requests of other researchers (see above) demanding multimodal analyses to grasp teachers' and students' mutual understanding when discussing conceptions.

This means gestures reveal a valid access to interpret the orientational frameworks of the discourse participants in the chemistry classroom (ibid.). To analyse the visual data, three steps are taken in the Documentary Method:

1. the pre-iconographic interpretation, which is very important to distance oneself from the context of the situation to understand the formal structure (the WHAT) of the gesture; in this step the focus is on the image without listening to speech,
2. the iconographic interpretation, where the formal description of the gesture is contextualized with general institutional knowledge of the situation and with the spoken text afterwards, and
3. the iconological interpretation, where the HOW of the action is analysed and reflected to discover what implicitly leads the action respectively to determine the orientational frameworks of the participants (Bohnsack, 2011).

These three steps will be presented in the results section using two short cut outs of the video scenes of the teacher-student-discourse phases on atoms and atomic structure. The interpretation was done by the author first and then conducted in a research group with three science educators at the University of Vienna (the former working place of the author) to ensure an interpretation from a variety of perspectives.

To transfer the Documentary Method to science education research, Bonnet (2009) proposes to distinguish between the content level and the relationship level in a classroom setting. In regard to Erickson (1982), he contrasts the *Academic Task Structure* (ATS) and the *Social Participation Structure* (SPS). Science lessons are successful if participants and task are in line with each other, when all participants share the same interpretation of the situation (Bonnet, 2009). It has to be acknowledged that some students may interpret the task as not meaningful so that they cannot share the same interpretation with their classmates or teacher. Furthermore, in educational research the ATS and the SPS have to be collated with institutional standards, e.g. curricula (ibid.). Concerning the content Bonnet equates the orientational frameworks with teachers' and students' conceptions.

Results

Two scenes of the teacher-student-discourse were chosen to represent the data analysis and to illustrate the orientational framework of the chemistry teacher. The aim is to understand what guides the teacher's use of gestures and what conception is transferred by the gestures. Do teachers and students share a conceptual understanding?

The first hand movement is a complex accumulation of gestures, which originally lasted 13 seconds in total. The video shows a recreation of the gestures to ensure anonymity and to reduce complexity (video 1).

Video 1. Gestures of the chemistry teacher (recreated)

All three interpretation steps of the Documentary Method are presented in the following.

The pre-iconographic level – gesture 1. The teacher shows three fingers of her left hand at the same time: the thumb, the index finger, and the middle finger. The palm of the hand points to herself. Her arm is flexed. The hand is in shoulder height, but moves once down and up again. Two students raise one hand and take it down again. The back of the teacher's hand is then put down at the table; the hand is closed to a fist. Afterwards, the thumb, then the index finger and last the middle finger is stretched out. After each finger stretching, the hand moves slightly several times from left to right. The three fingers are then rubbed against each other.

The iconographic level – gesture 1. Without listening to the speech, the hand movement was interpreted by the research group as follows based on general institutionalised knowledge. The teacher is either asking for or explaining or pointing to an entity consisting of three different aspects. The entity is maybe stressed as a whole or moving or changed in some way, indicated by the down and up movement of the hand. Two students put their hands up to answer, but the teacher is continuing. All three aspects are individually counted. It is also possible that the teacher asks for a decision between the three aspects. In the end, she is relating the three aspects (by rubbing the fingers) – she wants to indicate an interaction – or she asks the students to establish a relation between the three aspects. The rubbing seems to be a symbolic gesture and is thus more unclear than the enumeration. The enumeration is a familiar, non-imagistic, everyday gesture. The rubbing of three fingers rather reminds the research group of the institutionalised sign for money, but this would not be conducted with a hand lying on the table. Another idea comes up that it means 'luring somebody' like an old witch in a fairy tale. The rubbing needs further consideration and is not understandable without knowing the context.

The context of the just described situation is given as a short summary of the concerning lesson phase in the following box 1.

> In the beginning of the lesson, the teacher instructs the students to write down all the information they have in their notes and textbook concerning atoms and atomic structure. The seven students work in two pairs and a group of three. Different questions arise among the students, which the teacher does not answer.
>
> The teacher ends the small group work and starts a plenum phase (orchestrated like in figure 1). She collects the ideas of the students asking each student in turn. This phase enters in a discussion about models in general followed by a discourse about the Bohr model and **the differences between protons, neutrons, and electrons**.

Box 1. Thematic overview of the lesson phase – gesture 1

The teacher says the following while conducting the described hand movements:

Good, well, we have three three (..) particle kinds so to say. OK? We have the protons, the neutrons and the electrons, OK. How are the three different from each other?[1]

Considering the context and the spoken text, the hand movements are interpreted as follows. The hand on shoulder height with three stretched fingers symbolizes the entity "particle kinds" consisting of three different 'aspects'. The focus is clearly on the number; the gesture is not creating an image of particles and does not visualize any other property of the entity 'particles'. The down and up movement of the hand has no content relation. It occurs parallel to the hesitation ("*three three (..)*"), as if the teachers was unsure about the technical term or unsure about which term she introduced already in class. Instead of saying 'three different elementary particles', she chooses the term 'particle kinds'. Saying 'so to say' supports the interpretation of her being insecure about wording. Mostly, people use this expression when they feel they did not find a precise expression.

The three kinds of particles are then itemised. The thumb is stretched out saying protons, the index finger for the neutrons, and the middle finger for the electrons. Why the hand moves left and right after each stretch-out, is unclear so far. Maybe she wants to direct attention to each of the items. That she wants to represent the movement of particles can be excluded in this case, as this is not part of the prior knowledge of the students yet.

Then, the fingers are rubbed against each other asking for the differences between the three particles. The rubbing is not a common gesture for 'difference'. The question would be consistent with the gesture if asked what the difference is between the three particles when you compare them with or relate them to each other.

The iconological level – gesture 1. Here a reflective interpretation is done by especially taking into account HOW the gestures are conducted. First, let's look again at the hand moving down and up: the teacher has problems in finding the right term (*"we have three three (..) particle kinds so to say"*). The gesture is illustrating the trouble. Is "particle kinds" an appropriate term here? Why is she unsure about the term? What else could she have said? Probably, she used the term 'particle' for atoms, molecules or ions so far with the students. Here, she wants to refer to elementary particles, but has not introduced this term. Maybe she tries to use easy language with the students whom she knows of having difficulties with technical terms. She wants to adapt to their language. 'Particles' is also a common term in everyday language, being rather indefinite and general then. She directly explains what she means by "particle kinds" by elaborating, "*We have the protons, the neutrons and the electrons"*. This elaboration is necessary for the students to follow the topic further.

The hand moving from left to right after each counting seems to be a nervous, stressful or urging gesture. Maybe the teacher is impatient, because the lesson is a repetition. This interpretation is supported by the facts that she does not give the students much time to answer and that not every elementary particle is explained in detail. She names the elementary particles although two students signalized the wish to name them. All these facts could show that she is asking for knowledge that the students should already have. She assumes the students to remember some facts and checks only on certain aspects. Otherwise she could have used more content representative gestures, 3D-models or animations. It could be that she does not want to provide too much help, because the content is repeated here.

Also the whole setting supports this interpretation. It is a small group setting, but the interaction is authoritative and directive as if she would stay in front of a whole class. She requests information. Only one answer is correct. She could facilitate more interaction by asking openly, for example, 'what do you know about the different particles?'. But this would not correspond to her teaching goal of repeating precise facts concerning the atomic structure.

Rubbing the three fingers was first interpreted as a gesture of relating, but the question is directed to differences. This seems to be a contradiction. Distancing from the context by only watching the video made it possible to discover this contradiction. Already before the rubbing, it would be possible to distinguish between the three "particle kinds" by using gestures symbolizing a much stricter and larger separation than the numeration indicates. But the three elementary particles are rather indicated as being closely located (in an atom) and conceptually interrelated. The differences are not very big. Thus, the gestures could be metaphoric, symbolizing abstract entities and their features. However, the question arises if students can recognize this gesture of rubbing fingers as a hint on the content level. Probably, for them it is rather an interactive gesture to structure the dialogue (cp. Abner et al., 2015). The teacher is demanding and 'luring' short and precise answers from the students. Her body language seems impatient and sends the message, 'you should already know this'. So, in this case the gestures seem to have their main function in structuring the social participation. They cannot support meaning-making by visualizing the submacroscopic level, as the gestures do not correspond specifically enough to the content or to students' prior knowledge. Additionally, the gestures could serve to lighten cognitive load of the teacher (cp. Kelly et al., 2008).

A second accumulation of gestures will be interpreted in the following shown in video 2. The complex hand movement originally lasted 15 seconds. They happened shortly after the example presented before.

Video 2. Gestures of the chemistry teacher (recreated)

The pre-iconographic level – gesture 2. The teacher points with her left index finger at a point at the table. Afterwards she circles anticlockwise around this point with her left hand (index finger is still stretched out). She tilts her wrist to the right, the wrist lies on the table. The index finger continues to circle around the same point. Afterwards, she shortly points with her left hand into the air at shoulder height. Thumb and middle finger are pressed together during this motion, the other fingers are stretched. The movement is taken up by a student: The student holds a pencil in her right hand. The pencil circles clockwise around a point in the air at shoulder height. The teacher lowers and raises her head. Then the teacher points three times into the air with a flexed arm at shoulder height. The hand is formed like a claw. Each pointing is more to the right, the second is higher than the one before, the third is lower again.

The iconographic level – gesture 2. Just watching the video without sound, it becomes clear that the teacher says or asks something that causes a student response. The teacher nods and thereby agrees to the students' answer or at least signalises that she has heard the student. The teacher continues the discourse.

The discourse seems to be about something circular, something circulates around a centre. This entity could also circulate in itself indicated by the continuously circling finger. This means, the gesture is not just deictic (pointing to something), but symbolizes a moving entity. The student expresses that she understood the important point (the circulating entity) by picking up and continuing the teacher's kind of gesture in front of her own body. Bohnsack (2011) qualified the picking up of a gesture as mutual understanding. Thereby the teacher's gesture becomes significant. The teacher adapts to the student by staying in the same plane: she continues with her hand movements in front of her body instead of at the table pointing to three entities or one entity which is lifted and replaced, maybe with a crane or a claw.

Box 2 summarises the context of the respective lesson phase.

In this teacher-student-discourse mass, charge and location are discussed as distinguishing features of protons, neutrons, and electrons. The teacher asks again how the particles are different from each other. The students give one-word-answers: "*charge*" and "*weight*". The teacher corrects the latter by saying and evaluating, "*the mass, yes*". The teacher introduces the location as third distinguishing feature by asking, "*which ones are located in the nucleus?*". The students first say, "*neutrons, protons*". The teacher wants to know how these two can be distinguished. A student's answer is "*different charge*". The teacher picks this up and asks, "*one positive, one negative?*". The students determine the electron as negative. The teacher asks again which particles are in the nucleus. One student says, "*electrons and protons*". The teacher corrects him, "*no, we just said, in the nucleus are protons and neutrons*". She wants to know which word is contained in the word 'neutron'. The students answer, "*new*", "*neutral*", which means neither positive nor negative to one student, "*it stands in the middle*" to another student. A third student classifies it as "*fill mass*". The teacher agrees to the last answer and wants to know the charge of the nucleus. A student says, "*positive*".

Box 2. Thematic overview of the lesson phase – gesture 2

Afterwards the teacher (T) says the following while conducting the described hand movements:

T: a positive nucleus in the middle and then I have around it
Sm2: negatives
T: the?
Sf2: electrons
T: electrons, and where does one imagine these to be?
Sf3: in shells
T: in shells, exactly, ok, and these electrons are they as big as the protons?

Considering the dialogue before the chosen scene and the spoken text, the hand movements are interpreted as follows.

The iconological level – gesture 2. Here again a reflective interpretation follows by especially taking into account HOW the gestures are conducted. First, the teacher points to an abstract entity, "*a positive nucleus*", and wants to know what 'circles' around the nucleus. The circling gesture is interpreted as a support, a kind of scaffolding for the students to find the answer "*electrons*". The wrong answer 'negatives' is ignored. The circling on the table creates the image of the Bohr model the students have in their exercise books. Thus, the circling gesture represents the content of the discourse. It creates a dynamic model of the figure in the book. Both the gesture and the figure are created in 2D. Thus, the teacher does not relate to a vision of an atom in a spatial dimension, but she relates to the drawing of the model that is familiar to all students. She does not refer to the spheres (or shells) of the Bohr model in speech, but her gestures kind of draw them on the table. Thus, she adds information by using gestures.

Putting the wrist on the table and just continuing the circling with the index finger could refer to, concerning the ATS, the electron spin, but the students have no idea of this concept yet. Therefore, this gesture can rather be interpreted at the SPS level as an interactive gesture, maybe directing attention or as continuously reducing help. The finger is still circling, but the teacher does not want to reveal too much information. Again, it could also be 'luring' information that was already developed and has to be known now – just like in the last example.

When the teacher asks, "*where does one imagine these to be?*", she changes the plane. The gesture is not placed at the table anymore, but in the room, as if she switches from 2D to 3D or from the real, tangible, familiar world (the figure in the book) to a vision of the electrons in a spatial dimension. Interestingly, she does not ask 'where do YOU imagine these (electrons) to be', but "where does ONE imagine these to be". Thus, she signalises that the imagination of electrons is common sense and only one vision appears as technically correct. If she had asked 'where does the Bohr model suggest the electrons to be', one answer is technically correct. Here, the features of models are not reflected and the students do not know yet that the Bohr model is only one way of representation. Here, it seems to be a shared understanding that electrons have to be imagined in shells. Otherwise, the student could not have answered correctly "in shells" and could not have represented her knowledge in a suitable gesture: drawing circles into the air with a pencil in her hand. Co-speech gestures can be easily interpreted when they are culturally shared (cp. Abner et al., 2015). Here, the concepts, models and language of chemistry constitute the 'culture'.

As mentioned, the student copies the circling gesture and enlarges it by making bigger circles with the pencil in her hand, also in the room, not at the table. The teacher also stays in this plane with her gestures. It seems as if she wants to make the imagination vivid in the room. The content is abstract and has to be visualised to be tangible so that everybody 'sees' what the discourse is about. It is assumed in this case that the teacher wants to facilitate participation for all students by extracting the world of thought into a visible plane. Thus, she invites the students to participate in the discourse on atoms. One recommendation to support students with special needs is to use concrete pictures to visualise abstract concepts. The teacher seems to use this strategy by applying gestures. Because of the students' pre-conditions, the teacher could assume that the students probably need to concentrate a lot to follow the talk, so she uses supporting hand movements to reduce cognitive load.

To support the interpretation that the students need visualisations to make meaning of abstract concepts, other scenes of the lesson can be adduced. For example, one student suggests, that "*when there is a magnet now, then there will be a lot of negatively charged atoms on it*". He mixes an abstract concept with a familiar experienceable one to better imagine the idea of an atom. The gesture he simultaneously uses is a hand formed like a claw representing the "negative atom" moving fast towards his other hand formed like an open fist as if he holds a magnet there. This shows how the student imitates the gesture of the teacher and makes sense of it in a spatio-dynamic dimension. The teacher reacts by rephrasing the student's statement ("So you mean that …") and by imitating the gesture, however, in an excessive manner. The student reacts by distancing from his statement. Thus, without explicit clarification in words, the teacher signalises by gesturing that the imagination of the student is not appropriate. An appropriate concept is, however, not developed at this point.

The movements of the teacher are often conducted in an intense and determined way. Earlier, this was interpreted as impatience, because the lesson is a repetition that reveals a lot of missing knowledge on the students' side. The way of gesturing could also stand for the intention to represent the content as clear as possible to put it into the students' mind so that they remember this time.

Interestingly, the teacher did not bring an atomic model. The gestures seem to replace an atomic model, they make the abstract concepts visible. The gesture is more outlasting than words (cp. Novack et al., 2014). Later the students have to draw a Bohr model of Sulphur, for example, which contributes to a longer lasting visualisation of the abstract concept. More outlasting would be a 3D-animation or a tangible atomic model, the real entity even more and the real entity in the lifeworld context of the students the most, but this is, of course, not possible for the content of this chemistry lesson.

Discussion

The two cases or the two sets of gestures presented here in detail show how the teacher either uses interactive gestures to structure the discourse (SPS) or she uses representative gestures to help the students remember facts (ATS). Her teaching goals seem to be two-sided. On the one hand, she wants to push the discourse forward. She wants to repeat the topic of atomic structure – fast if possible – to build up on this knowledge when starting the next topic (atomic bonding). However, this does not work out, as the students cannot provide the correct answers immediately. So, on the other hand, she needs to provide some support for the students to make them remember and understand the content. Therefore, the teacher uses different metaphoric gestures to help the students 'see' and thus understand details about the elementary particles and the Bohr model. The use of gestures seems to be a way of supporting the students to develop a chemical concept (again), to make them remember. To achieve this goal she uses gestures that visualise the concept (e.g., the nucleus in the middle and the shells around it). She kind of 'draws' the Bohr model on the table or in the air by her way of using gestures. The underlying orientational framework of the teacher, implicitly guiding her practice, could be characterised as: 'the students can remember and understand the abstract concepts of chemistry faster/better by using scaffolding in forms of visualisation'. It seems as if the teacher tries to change the submacroscopic representation of chemistry concepts into a macroscopic representation through the use of metaphoric gestures (Taber, 2013). This gives an important hint how to support students in making a connection between the macro and micro level.

It has to be questioned, however, if the gestures used in this case are really helpful in learning abstract concepts of chemistry. Unlike institutionalised gestures which are commonly used in school or emblems, which are part of a shared understanding (like pointing to someone to pick him/her in a discourse, a wagging finger or thumbs up for praising someone), imagistic gestures referring to subject-matter are not as familiar. Their understanding cannot be taken for granted. The gestures are supposed to allow for higher participation, but they also have to be carefully used to avoid misconceptions. It becomes clear, for example, that the students take up the gestures of the teacher and thus express their understanding of elementary particles. For example, one student thinks that the particles 'fly' through the room imagining a magnet with lots of negatively charged atoms attracted by it. The student is not only mixing different concepts here, but also different representational levels, which could be a consequence of using metaphoric gestures to visualise the abstract concepts, the submacroscopic level. Like technical terms, gestures referring to technical terms have to be introduced clearly on a certain representational level. If the levels of speech and gestures diverge, teachers should make this explicit to foster understanding.

As well as technical language, gestures referring to technical terms are not intuitively part of a shared understanding, especially when language skills are under developed. Gestures are interpreted on the basis of individual prior knowledge and individual conceptions. Thus, meaning making is eventually not happening as intended by teachers. The understanding of technical terms and gestures has to be established over time, e.g., by introducing gestures explicitly referring to the same content consistently or by providing other corresponding even less abstract resources in addition to speech and gestures.

Like Flood et al. (2014) suggested, teachers should foster the use of gestures also on students' side to achieve a shared understanding. In their study, the content level was much more complex, however, gestures were also used to represent spatio-dynamic aspects of chemistry concepts. When students pick up the established gestures, it is possible to grasp their misunderstanding. Teachers can relate to students' conceptions represented in the gestures. This study here adds to the results of Flood et al. and other studies of Goldin-Meadow, for example, by emphasising the role of visualisation as an important scaffolding tool used by teachers in (inclusive) classrooms and by discussing the potential misunderstandings that can emerge especially in chemistry classes, when gesture and speech are on different representational levels.

Conclusions

For educational researchers, the Documentary Method can be recommended to analyse gestures and talk in-depth. It provides a clear structure of how to approach the data. The strict separation of image and talk at first helps researchers to distance from the context and to concentrate on the gestures alone. However, the Documentary Method is extremely time consuming and demanding. Only few data can be analysed in a team with a lot of effort. Although results of this study could be compared with the results of Flood et al. (2014), results presented here need to be contrasted with more cases to come to a broader sense of the use of gestures in chemistry teaching and learning with the aim of building a typology. This could not be accomplished in this explorative case study. Thus, the validity of the results is limited and they cannot be generalised so far. Further research in chemistry education is necessary to understand how and why teachers use gestures and how students' meaning-making is influenced by the use of gestures.

So far, we know that gestures can be a helpful teaching tool to support students' understanding in science, as gestures are less abstract than speech. In chemistry they are very useful to represent spatio-dynamic aspects on molecular level (Flood et al., 2014). In this study non-imagistic, interactive gestures seemed to be used to structure the discourse and achieve implicit teaching goals concerning the social participation (here: make the students remember content easier). Imagistic gestures were used to facilitate participation in a discourse about subject-matter, when the teacher had no concrete materials prepared or available, but wanted to scaffold students' understanding of abstract chemistry concepts. Content representitive gestures serve to visualise concepts that are not experienceable or observable directly. They are more impressive than just a spoken word, but less sustainable in comparison to images, tangible models or 3D-animations. Furthermore, gestures can be as unfamiliar and as confusing as technical language is. They can also provoke misunderstandings when their levels of representation (macroscopic or submacroscopic) diverge and the levels are not made explicit. This chemistry specific aspect should be studied further in future projects.

Acknowledgements

I am thankful for the support of the research group at the University of Vienna, Austria, concerning data analysis from multiple perspectives: Christine Heidinger, Thomas Plotz, Rosina Steininger and Judith 't Gilde. My thanks also go to Elisabeth Hofer for her support in making the videos and to the reviewers, whose comments helped to improve the original version substantially.

Notes and references

1 Original text is in German. Translations are made by the author as close as possible to original wording. Underlined speech occurs with gestures. Each point in a bracket stands for a pause of one second. (..) = two seconds pause

2 Parchmann, Lienau, Klüner, Drögemüller and Al-Shamery (2010) propose to say subm*a*croscopic instead of subm*i*croscopic, because of the recent technical developments of microscopes on nanoscale.

Abels, S. (2015). Scaffolding Inquiry-Based Science and Chemistry Education in Inclusive Classrooms. In N. L. Yates (Ed.), *New Developments in Science Education Research* (pp. 77-96). New York: Nova.

Abner, N., Cooperrider, K. & Goldwin-Meadow, S. (2015). Gesture for Linguists: A Handy Primer. *Language and Linguistics Compass*, **9/11**, 437-449.

Bergqvist, K. & Säljö, R. (1994). Conceptually Blindfolded in the Optics Laboratory. Dilemmas of Inductive Learning. *European Journal of Psychology of Education*, **9**(1), 149-158.

Bohnsack, R. (2011). *Qualitative Bild- und Videointerpretation. Die dokumentarische Methode*. Opladen, Farmington Hills: Barbara Budrich.

Bohnsack, R. (2013). Dokumentarische Methode und die Logik der Praxis. In A. Lenger et al. (Eds.), *Pierre Bourdieus Konzeption des Habitus* (pp. 175-200). Wiesbaden: Springer.

Bohnsack, R., Nentwig-Gesemann, I. & Nohl, A. M. (2013). *Die dokumentarische Methode und ihre Forschungspraxis. Grundlagen qualitativer Sozialforschung* (3 ed.). Wiesbaden: Springer VS.

Bonnet, A. (2009). Die Dokumentarische Methode in der Unterrichtsforschung: ein integratives Forschungsinstrument für Strukturrekonstruktion und Kompetenzanalyse. *Zeitschrift für Qualitative Forschung,* **10**(2), 219-240.

Carlson, C., Jacobs, S., Perry, M. & breckinridge Church, R. (2014). The effect of gestured instruction on the learning of physical causality problems. *Gesture*, **14**(1), 26-45.

Clement, J. J. (2008). *Creative Model Construction in Scientists and Students. The Role of Imagery, Analogy, and Mental Simulation*: Springer.

Crowder, E. (1996). Gestures at work in sense-making science talk. *The Journal of the Learning Sciences*, **5**(3), 173-208.

Eilam, B. & Gilbert, J. (2014, eds.). *Science Teachers' Use of Visual Representations*. Heidelberg: Springer.

Erickson, F. (1982). Classroom Discourse as Improvisation: Relationships between Academic Task Structure and Social Participation Structure in Lessons. In L. C. Wilkinson (Ed.), *Communicating in the classroom* (pp. 153-182). Bingley, UK: Emerald.

Flood, V., Amar, F., Nemirovsky, R., Harrer, B., Bruce, M. & Wittmann, M. (2014). Paying Attention to Gesture when Students Talk Chemistry: Interactional Resources for Responsive Teaching. *Journal of Chemical Education*, **92**, 11-22.

Gibbons, P. (2009). *English learner, acadmic literacy, and thinking. Learning in the challenge zone*. Portsmouth, NH: Heinemann.

Givry, D. & Delserieys, A. (2013). Contributions of talk, gesture and salient elements of the setting to analyse student's ideas in science through video. In C. P. Constantinou, N. Papadouris & A. Hadjigeorgiou (Eds.), *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning. Part 3* (pp. 509-518). Nicosia, Cyprus: European Science Education Research Association

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**(10), 1086-1109.

Goldin-Meadow, S. (2014). Widening the lens: what the manual modality reveals about language, learning and cognition. *Philosophical Transactions of the Royal Society B*, **369**: 20130295.

Goldin-Meadow, S., Wagner-Cook, S. & Mitchell, Z. (2009). Gesturing Gives Children New Ideas About Math. *Psychological Science*, **20**(3), 267-272.

Hart, J. & Lee, O. (2003). Teacher Professional Development to Improve the Science and Literacy Achievement of English Language Learners. *Bilingual Research Journal,* **27**, 475-501.

Hmelo-Silver, C., Golan Duncan, R. & Chinn, C. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, **42**(2), 99-107.

Hostetter, A., Alibali, M. & Kita, S. (2007). I see it in my hands' eye: representational gestures reflect conceptual demands. *Language and Cognitive Processes*, **22,** 313-336.

Jewitt, C., Kress, G., Ogborn, J. & Tsatsarelis, C. (2001). Exploring Learning Through Visual, Actional and Linguistic Communication: The multimodal environment of a science classroom. *Educational Review,* **53**(1), 5-18.

Johnstone, A. (2000). Teaching of chemistry - logical or psychological? *Chemistry education: research and practice in Europe*, **1**(1), 9-15.

Kelly, S., Manning, S. & Rodak, S. (2008). Gesture Gives a Hand to Language and Learning: Perspectives from Cognitive Neuroscience, Developmental Psychology and Education. *Language and Linguistics Compass*, **2/4**, 569-588.

Kendon, A. (2004). *Gesture: Visible action as utterance*. Cambridge: University Press.

Kendon, A. (2000). Language and gesture: unity or duality? In D. McNeill (ed.), *Language and Gesture* (pp. 47-63). Cambridge: University Press.

Kendon, A. (1996). An Agenda for Gesture Studies. *The Semiotic Review of Books*, **7**(3), 8-12. Online: http://www.univie.ac.at/wissenschaftstheorie/srb/srb/gesture.html (14 Apr 2016)

Kress, G., Jewitt, C., Bourne, J., Franks, A., Hardcastle, J., Jones, K. & Reid, E. (2005). *English in urban classrooms. A multimodal perspective on teaching and learning*. London, New York: RoutledgeFalmer.

Lemke, J. L. (1990). *Talking Science: Language, Learning, and Values*. Norwood, NJ: Ablex.

Markic, S., Broggy, J. & Childs, P. (2013). How to deal with linguistic issues in chemistry classes. In I. Eilks & A. Hofstein (Eds.), *Teaching chemistry – a studybook* (pp. 127-152). Rotterdam, Boston, Taipei: Sense.

McNeill, D. (1992). *Hand and Mind: What Gestures Reveal about Thought*. Chicago: University of Chicago Press.

McNeill, D. (2005). *Gesture and Thought*. Chicago: University of Chicago Press.

Mortimer, E. F. & Scott, P. (2010). *Meaning making in secondary science classrooms* (Reprinted ed.). Maidenhead: Open University Press.

Novack, M., Congdon, E., Hermani-Lopez, N. & Goldin-Meadow, S. (2104). From Action to Abstraction: Using the Hands to Learn Math. *Psychological Science*, **25**(4), 903-910.

Ødegaard, M. & Klette, K. (2012). Teaching activities and language use in science classrooms. Categories and Levels of Analysis as Tools for Interpretation. In D. Jorde & J. Dillon (Eds.), *Science Education Research and Practice in Europe: Retrospective and Prospective* (pp. 181-202). Rotterdam, Boston, Taipei: SensePublsihers.

Parchmann, I., Lienau, C., Klüner, T., Drögemüller, S. & Al-Shamery, K. (2010). „Kann man Atome sehen?" – Eine Reflexion aus Sicht verschiedener Wissenschaften. *Chemkon,* **17**(2), 59-65.

Pozzer-Ardenghi, L., & Roth, W.-M. (2007). On performing concepts during science lectures. *Science Education*, **91**(1), 96–114.

Przyborski, A. & Wohlrab-Sahr, M. (2010). *Qualitative Sozialforschung. Ein Arbeitsbuch* (3 ed.). München: Oldenbourg.

Quek, F., McNeill, D., Bryll, R., Duncan, S., Ma, X.-F., Kribas, C., . . . Ansari, R. (2002). Multimodal Human Discourse: Gesture and Speech. *ACM Transactions on Computer-Human Interaction,* **9**(3), 171-193.

Riebling, L. (2013). *Sprachbildung im naturwissenschaftlichen Unterricht. Eine Studie im Kontext migrantionsbedingter sprachlicher Heterogenität*. Münster: Waxmann.

Ruhrig, J. & Höttecke, D. (2015). Components of Science Teachers' Professional Competence and Their Orientational Frameworks when Dealing with Uncertain Evidence in Science Teaching. *Interantional Journal of Science and Math Education*, **13**, 447-465.

Seidel, T., Prenzel, M., Rimmele, R., Schwindt, K., Kobarg, M., Herweg, C., . . . Allolio-Näcke, L. (2006). Unterrichtsmuster und ihre Wirkungen. Eine Videostudie im Physikunterricht *Untersuchungen zur Bildungsqualität von Schule. Abschlussbericht des DFG-Schwerpunktprogramms* (pp. 99-123). Münster: Waxmann.

Stefanini, S., Caselli, M. & Volterra, V. (2007). Spoken and gestural production in a naming task by young children with Down syndrome. *Brain and Language*, **101**(3), 208–221.

Taber, K. S. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice,* **14**, 156-168.

Taber, K. S. (2015). Exploring the language(s) of chemistry education. *Chemistry Education Research and Practice,* **16**(2), 193-197.

Wagner, P., Malisz, Z. & Kopp, S. (2014). Gesture and speech in interaction: An overview. *Speech Communication,* **57**, 209-232.

Wickman, P-O. (2002). Induction as an empirical problem: How students generalize during practical work. *International Journal of Science Education*, **24**(5), 465-486.

