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PICTORIAL LANGUAGE IN CHEMISTRY CLASSROOMS

Gains and losses: Pictorial language in chemistry classrooms

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Abstract

This paper reports on findings from two data sets in chemistry learning; one from a multidisciplinary project on teacher lead whole-class teaching, and one from a small-scale study on teacher students' animations of chemical reactions. The data was analysed as to the use of pictorial language in relation to atoms and ion formation with an intention to shed light on students' scientific understanding as well as their enculturation into the disciplinary discourse. Theoretically we draw on social semiotics, allowing analyses of language use in its widest sense, comprising verbal language, images, action, gestures, etc., though here with a main focus on verbal language. In both learning contexts, we identified common disciplinary metaphors as well as more occasional metaphors. By the use of analyses based on systemic functional grammar (SFG) we also noted more "hidden" metaphoric use, with particles, atoms, and ions being humanised with intentions and feelings. Also, we identified interesting patterns as to the ways students use metaphors to sort out difficulties in understanding chemical processes. The study has implications for the design of classroom practices, not the least as regards possibilities to use meta-discussions to enhance a more reflective use and understanding of the gains and losses around analogies; both as regards teaching material and student-generated analogies.

Keywords: chemistry teaching, classroom practices, analogies, metaphors, social semiotics

Introduction and background

The complex nature of the scientific language and its representations in different semiotic modes (verbal language, concrete models, visualisations etc., see *e.g.* Jewitt, 2011; Kress et al., 2001) has proved to be challenging for students (*e.g.* Fang, 2005; Halliday & Martin, 1993; Lemke, 1990, 1998; Norris & Phillips, 2003; Yore & Treagust, 2006), suggesting needs for ways of creating classroom practices that scaffolds students both in their understanding of the scientific content and in their disciplinary literacy.

Based on the multimodal character of the scientific field it has also been argued that learning science to a great extent is “learning to think with representation” rather than acquiring resolved scientific concepts (Klein and Kirkpatrick, 2010: 88). In relation to this, Tang and Moje (2010) claim that students “need to learn the specific literacy practices of integrating the multimodal elements of representations according to scientific conventions in order to construct the canonical meaning of accepted scientific concepts” (p. 83).

The present study focuses on one aspect of the discourse of science and representations in areas of science, namely figurative language, such as analogies or metaphors¹. This is an interesting area both as regards scientific discourse as such, and as regards science learning as learning to think with representation. Metaphorical expressions are integrated parts of science discourse (*e.g.* ‘electronic clouds’, ‘electrical fields’) (*e.g.* Sutton, 1992) as a way of creating new knowledge (see also Ogborn, 1996). Also, in

¹ Research and theory around metaphors and analogies is vast (one key volume is Lakoff & Johnson, 1980) and there are several definitions of these terms. Here we use Cameron’s (2002) definition of metaphor, which includes similes and analogies: “A stretch of language that creates the possibility of activating two distinct domains is said to be a ‘linguistic metaphor’; such language forms can include similes and analogies, provided there are grounds for claiming distinct underlying domains” (p. 674).

educational contexts, analogies and metaphors are suggested as pedagogic tools to make abstract or complex content more accessible (*e.g.* Sutton, 1992; Aubusson et al., 2006).

Self-generated analogies made by the students have also been seen as important tools for teachers as a means of understanding how students think around new concepts, and as a basis in formative assessment procedures (Haglund, 2013; Harrison & Treagust, 2006; Jakobson & Wickman, 2007). Harrison and Treagust (2006) view self-generated analogies as a "personal construction of meaning" (p. 12), that encourage students to link familiar experiences with new contexts and problems. Such view fits within a constructivist teaching approach where the use of analogies is seen as a valuable tool for conceptual change in science education (Duit, 1991).

However, from a sociocultural perspective, science constitutes of social, historical and cultural practices (Rogoff, 1990), and consequently, learning science also involves understanding and appropriating specific norms, meaning, concepts and ways of communicating and acting, all of which combine to create meaningful activities in the science classroom (Lave & Wenger, 1991). In line with this perspective is the view of the importance of disciplinary literacy (the ability to interact and communicate through the specialized language in a wide sense, comprising verbal language and various forms of representations) for a person to be able to participate effectively in the knowledge construction and social practices of the discipline (*cf.* Lemke, 1990). Here, working in explicit ways with analogies and metaphors has been regarded an effective way of helping students with this border-crossing (Tobin 2006).

However, metaphors can also be challenging for students. This accounts for expressions that have been integrated in the scientific discourse and that might no longer be perceived as metaphoric, such as 'magnetic fields', as well as more provisional metaphors. As opposed to more obvious scientific terminology (like 'protons' or 'neutrons'), which do

not build on everyday concepts, these metaphoric expressions can be wrongly understood in their everyday sense, thus creating unexpected obstacles (*e.g.* Askeland & Aamotsbakken, 2010; Golden, 2010).

Some metaphors used for pedagogical reasons have come to be used quite frequently and across cultures, such as the analogy between electronic movement and planetary orbits, while others are more provisional, and in some cases dependent on the language in use (we will present some examples from our data). However, all types of analogies can be challenging for learners, not only from the linguistic perspective, but also as regards the relation between the source and the target, or as to the reach of the analogy (*e.g.* Haglund, 2013).

To sum up, the use of metaphors is central for the scientific disciplines as such, as well as for science education. At the same time metaphoric language is a phenomenon which has gained a lot attention in linguistic research (*e.g.* Lakoff & Johnson, 1980; Svanlund, 2007). Thus, metaphoric language can be described from a linguistic point of view, and possible obstacles in relation to learning can be discerned from such a perspective (*e.g.* Askeland & Aamotsbakken, 2010; Golden 2010). However, to fully understand the gains and losses² with metaphoric use, and to better develop teaching practices within the area, there is a need for cross-disciplinary research and cross-domain collaboration among science teachers, science educators and linguists (see *e.g.* Tibell & Rundgren, 2010, for a discussion). The present article is an attempt to contribute to the field, meeting these requirements.³

² The discussion around “gains and losses” is informed by the concept of semiotic *affordance*, introduced by Gibson (1977) and later used in social semiotic perspectives of multimodality (*e.g.* Kress, 2009, Danielsson, under review).

³ The authors comprise of a linguist focusing on disciplinary literacy within the science field, a science educator (chemistry), and a PhD student in science education, with a background as a science teacher (chemistry).

Aims

This study builds on two sets of data from chemistry teaching (for details, see below). One from whole-class teaching at the secondary school level, where we focus on teaching episodes where teachers explain the structure of the atom or ion formation, as well as equivalent explanations in the textbooks in use. The other set of data was collected during a university course where students made animations to explain ion formation based on experimental work on batteries and rust. Here we analyse group discussions in connection to the plans for performing animations after the experiments.

The aim of the study is to describe and analyse how teachers and students use metaphors when working with chemistry content, in this case to explain and discuss the atomic structure and ion formation. We will also describe if, and in that case how, metaphors are made explicit for the students through meta-discussions. We relate the results to “gains and losses” (*cf. affordance*, Gibson, 1977; Kress, 2009) in the learning process, for example in relation to the reach of analogies. An important aspect of the study is whether we can discern possibilities or hindrances for students border-crossing and participation in a science practice (including an enculturation into the disciplinary discourse).

Our research questions are:

1. What characterizes the metaphorical language used by teachers and students in science teaching (in teachers' expositions, in meaning making among students when working with animations, in learning resources such as textbooks)?
2. What possibilities or hindrances for students' understanding of the content and for their border-crossing and participation in a science practice can be discerned in relation to the use of metaphorical language?

Data

The data from the whole-class project was collected within the multidisciplinary project *Chemistry texts as tools for scientific learning*, financed by the Swedish Research Council (the present study is independent from the overall project) (Eriksson, 2011). The overall project followed a series of lessons in a number of Swedish (in Sweden) and Finland-Swedish (in Finland) secondary school chemistry classrooms during a content area dealing with the atomic model, the periodic chart and chemical bonds (students aged 14–15 years). In focus for the present analyses are instructional episodes when teachers explain the structure of the atom, the relative stability of different substances in the periodic system, and ionic formation. The data used in our study are video recordings of classroom communication and digital photographs of texts used in three of the studied classrooms (two Finland-Swedish and one Swedish). In the following, we have made close analyses of a selection of instances where teachers use metaphoric language in relation to the atomic model or ion formation as well as equivalent sections in the textbooks.

The data from teacher students' animations of chemical reactions was collected during a four-week intervention which was carried out within the primary teacher training program. The participating students ($n=37$), who were divided into smaller groups for the activity, had completed one semester of science courses prior to a course in electrochemistry where the intervention was carried out. The underlying idea about letting students make animations was to try out alternative methods building on activities that could harness the students' learning in a course that previous student groups had perceived as difficult. The students' main task was to create a video aiming at explaining observable (at the macro-level) phenomena around everyday chemical phenomena in the field of electrochemistry (batteries and rust), at the sub-micro level (ion formation) through a multimodal animation, using

colored clay to build models. The activities consisted of a number of steps, including experimental work, storyboard making (here the students draw sketches before making the animation), and the actual animation and video recording. The data used in our study consists of video recordings from group work in one of the small student groups, when the students discussed the storyboard and made their clay animations. The intervention began with four lessons where – apart from focusing on the chemistry content itself – the teacher explicitly addressed disciplinary representations in relation to the content. The use of analogies was not specifically addressed during the intervention, and it was not until after it was completed that the decision was made to investigate these aspects of the discourse. The university teachers were present during the activities. The degree of teacher tutoring during the activity varied between the groups, depending on the students' expressed needs for help.

All names in the article are made up, to maintain the integrity of the participants (Swedish teachers were given names beginning with an /s/ while Finland-Swedish teachers were given names beginning with an /f/). The teacher students were given numbers.

Analytical methods

Both the video recordings of teaching episodes from the secondary chemistry classrooms chosen for analyses, and from the intervention within teacher education were transcribed multimodally, to capture the use of verbal figurative language as well as visual images, gestures and use of artefacts.

To answer our first research question, detailed analyses of the instances of use of metaphoric language were made from a social semiotic point of view (van Leeuwen, 2005). From this theoretical stance, a sign in itself (for example a certain word, a metaphoric expression, or a gesture) carries no meaning. Instead, it is dependent on the communicative situation, including participants, cultural aspects, etc. Also, the choice of sign in a certain

communicative situation is a result of social, cultural and situational factors in the context in which the communication takes place, including participants and available semiotic modes and resources.

Here we analysed our data using the *systemic functional grammar* (SFG) framework (Halliday & Matthiessen, 2004). This framework was developed for analyses of verbal language, though it has been developed for other modes of communication, such as visual images (Kress & van Leeuwen, 2006), gestures (Martinec, 2004) or combinations of semiotic resources in different modes (Danielsson, under review).

Systemic-functional grammar focuses on the function of language, and the theoretical framework is based on three meta-functions of language use: the *ideational* (the field of knowledge, what the text is about), the *interpersonal* (the relation between the writer/speaker and the reader/audience), and the *textual* (how the text is organised). Analyses based on these meta-functions give different perspectives on the ways in which the linguistic resources are used. In the present study we analyse our data (spoken language as well as visual images etc.) in relation to the ideational meta-function and specifically *processes*, *participants* and *circumstances*, which are basic parts of the transitivity system (see Halliday & Matthiessen, 2004: 302, for a model). The basis of the *transitivity analysis* is to identify the type of *process* (that something *happens*, *is said*, *is* or *is perceived*), what *participants* are involved in the process (*who/what* does/is/says/owns *what*, etc.), and the *circumstances* around the process (*where*, *how*, *when*, etc. the participant did/thought/said). In our analysis we consider four basic process types, namely *relational*, *material*, *verbal* and *mental* processes⁴ which can be

⁴ In Halliday's and Matthiessen's (2004) framework, there are two more processes: *behavioural* (e.g. 'yawn', 'stretch') and *existential* (e.g. 'live', 'exist'). Here we have merged *behavioral* and *material* processes, and *existential* and *relational* processes respectively. The rationale behind merging existential and relational processes is the fact that both types can be considered as belonging to a "world of abstract relations". Also, at

connected to three different “worlds of meaning”: a world of abstract relations (relational processes), a mental world (mental and verbal processes), and a physical world (material and verbal processes) (Halliday & Matthiessen, 2004: 172). Relational processes typically deal with the ways in which something is related to something else, such as “the atom *consists* of different particles”. Material processes typically demand some kind of energy from the first participant which can be seen as an *actor*, such as “the electrons *move* quickly around the nucleus”. Verbal processes imply that something is said, for example “we *say* that the nucleus is positively charged”. Mental processes, finally, are inner processes, and they imply some kind of mental activity of the first participant, who functions as an *experiencer*, as in “before, scientists *thought* that the atom was the smallest particle”. In the participant analysis you also differ between *first* and *second* participants: “*Mendelejev* (first participant) developed the *periodical system* (second participant)”.

By performing the transitivity analysis, patterns in the use of metaphorical language can be discerned, for example to pin down what domains are used in the analogies (scientific, other specialised domains, or the everyday domain), what aspects of the transitivity system that is used to express the metaphor. This in its turn can be used as a basis to discuss what connections the students need to make in order to understand the metaphor.

In order to analyse participation and meaning making in scientific practices (our second research question), we have used Rogoff’s (1995) three aspects of analysis: apprenticeship, guided participation and participatory appropriation. Apprenticeship corresponds to the community processes and focuses on the specific nature of activity as well as relations to institutional structures in which it occurs. Guided participation refers to an

least in Swedish and Danish contexts, it has been argued that existential processes can be regarded as a subgroup of relational processes, and that behavioral processes can be regarded as a subgroup of material processes (*e.g.* Andersen, Petersen, and Smedegaard, 2001; Holmberg and Karlsson, 2006).

interpersonal plane and attempts to describe what happens “between people as they communicate and coordinate efforts while participating in a culturally valued activity” (Rogoff, 1995: 142). Guidance refers to a direction of the activity offered by the cultural and social values. Wenger (1998) points out that the participation dimension must be balanced by the *reification dimension*. Artefacts such as tools, procedures, stories and language will reify some aspects of its practice. Wenger claims that participation and reification form a duality, with the two aspects being analytically inseparable from each other (*ibid.*). Finally, the participatory appropriation refers to the “the process by which individuals transform their understanding of and responsibility for activities through their own participation” (Rogoff, 1995: 150). These three planes are interconnected, and to describe one of them one must also take the other two into account. In this text we will focus on the interpersonal plane in order to describe and analyse how students’ participate and reify aspects of the scientific practice, primarily how the sub-micro level of the atom and ion formation is interpreted by the students by use of different representations of the atom or of the electron movement, where the metaphorical language is central.

Results

In the data from both settings, we noted a number of instances of metaphoric use around the structure of the atom, including electronic movement, the electronic configuration of elements, and ionic bonds. In whole-class data, teachers used metaphors in their explanations of the content. These were sometimes picked up and elaborated by the students. The textbooks, too, used metaphorical language in explanatory parts of the text. In the data collected during the intervention study, we noted that teacher students at times used metaphors, mainly when they seemed to have trouble understanding the content. If the university teachers were around, they sometimes noted this and commented on it.

Through the transitivity analyses, we were able to discern interesting patterns in the data, where metaphors became salient through the process (e.g. “electrons *jump* between atoms”), the participant(s) involved (e.g. “this *electronic cloud* moves around the nucleus”, “if you think of *an apple*”), attributive aspects connected to the participant (“noble gases *are content*”) or in circumstances (“the electrons swirl *in the electronic cloud*”). Another interesting result is that metaphors either led to a discourse where disciplinary terminology to some extent was avoided, or was used as a bridge between everyday expressions and disciplinary discourse. In some cases, metaphoric expressions were part of explicit similes, as in “think of the atom *like an apple*”), i.e. expressions where the speaker/writer make explicit that the listener/reader should interpret the statement as metaphoric.

In the following, we present the results thematically in relation to the domains that the source of the metaphor can be connected to. As the above description indicates, the sources can become salient through any part of the transitivity analysis (process, participants, circumstances, etc.), or in combinations of the different aspects of the analysis. Here we noted two basic domains: everyday life and the scientific domain. In the domain of everyday life we also include instances of connections to other subject domains that the speaker/writer could expect their (fellow) students to be familiar with.

Metaphors from the everyday domain

Metaphors connected to the everyday domain were mainly of two kinds: metaphors based on concrete everyday objects, like apples or highways, or anthropomorphic metaphors, where chemical objects became humanized, with intentions and feelings. These types were found in both sets of data, including textbooks used in the secondary school chemistry classrooms.

Scientific content as highways, sports arenas, and apples

Metaphors based on concrete everyday objects were relatively frequent in the data. Examples of this are the use of a well-known Swedish sports arena (the Globe), bicycle spikes, apples, combs and hair, bridges and highways. Some of these metaphors were used to explain the atomic structure and its particles (*e.g.* the Globe, bicycle spikes, and apples), while others were connected to ionic bonds (*e.g.* bridges and highways, combs and hair). The SFG-analysis revealed that in teachers' expositions, these metaphors were often introduced as second participants, where the first participant typically is the student or an indefinite 'you', and the process is mental (*e.g.* think), as in "if you think of *an apple*" or "if you think about *the spikes in a bicycle wheel*". Such constructions make it clear that the teacher is introducing some kind of analogy.

When talking about the atomic structure, teachers in Swedish secondary schools used a big and well-known sports arena outside Stockholm, the Globe (shaped as a globe), to illustrate that atoms consist of a lot of empty space. This analogy typically involved other metaphors as well. Here we will illustrate how this was done in Sture's classroom. Sture starts out talking about the fact that there are many different substances, and that they have a similar structure. He is explicit that he is going to present a simplified model, but before doing that, he shows the students a concrete model of the coal atom (see, Figure 1), and asks the students what it "looks like inside". However, these wooden models are usually used to build molecular models, and when he now uses it to talk about the inside of an atom, tossing the wooden ball in the air, the students appear to feel uncertain, and it takes some time before they respond, but one student mentions the different particles (protons, neutrons, and electrons) and another student adds "and nothing".



Figure 1. Concrete model of coal, Sture's classroom, lesson 1

With the probable intention of picking up “and nothing”, Sture goes on, introducing the Globe, making a drawing on the whiteboard while talking (Figure 2).

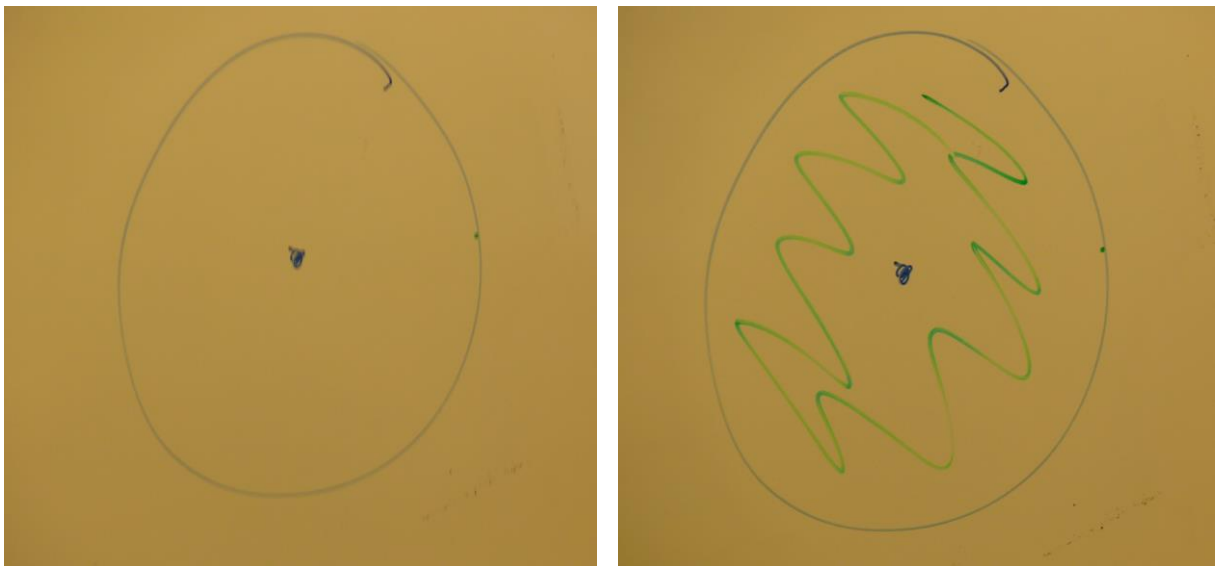


Figure 2. “The Globe”, two stages. Sture's classroom, lesson 1

From a student comment (“this is exactly what you said before”), it is obvious that Sture has used the metaphor previously⁵. Coming back to it now, he asks a student whether he has been to the Globe and then he says: “it's pretty big in between . I really do not know how big . but it is amazingly large .. there is room for horses and stuff and hockey and

⁵ A student says that at the beginning of this episode, and Sture responds that then they will get it one more time.

everything”. Then he continues using ‘a football, size 5’ as an analogy to the atomic nucleus: “now we are thinking like this that we hang up a football in size five like this . ok . huh?” (dot in the middle of the circle) and ‘a small green pea’ (small dot on the outer circle) as an analogy to the electron. He emphasizes that there is a lot of space in the arena, marking the area between the “football” and the “pea” with a green pen, saying that this is empty space. Interestingly, throughout the metaphoric explanation, Sture does not stress that the analogy is used to illustrate the atomic model. Also, throughout this analogous explanation, disciplinary language is more or less non-present (the nucleus and electrons are not mentioned). Further examples below will reveal that this pattern is typical for Sture’s classroom.

Sture introduces the Globe metaphor after the student comment “and nothing” as a response to what is inside an atom, but the students in this example show obvious difficulties participating in the reasoning about the Globe as an analogy for an atom, and they receive no guidance for how to reify the model of the atom. Instead the discussions at times evolve around the actual sports arena, and a student responds “places to sit” instead of providing a useful analogy to the electron as a response when the teacher asks “what was it out there?”.

In other classrooms, teachers use the apple as an analogy for the basic atomic structure, stressing that the atom has a nucleus surrounded by electronic shells. What is important to note here is that in Swedish, the same word is used for ‘nucleus’ and ‘core’, or ‘seed’ (Sw. *kärna*), and similarly, the Swedish word *skal* can be used both for (electronic) ‘shell’ and ‘peel’, something which makes the apple a possible metaphor in that linguistic context.

Here we use Fredrika as an illustration. It is the first lesson in the content area, and Fredrika goes through the different parts of the atom in a typical example of “chalk talk” (see Artemeva and Fox, 2011), writing on the blackboard (see Figure 3) while talking to the students, allowing them to answer questions about the particles of the atom using the typical

classroom dialogue with teacher initiation, student response, and teacher evaluation (IRE, Mehan, 1979).

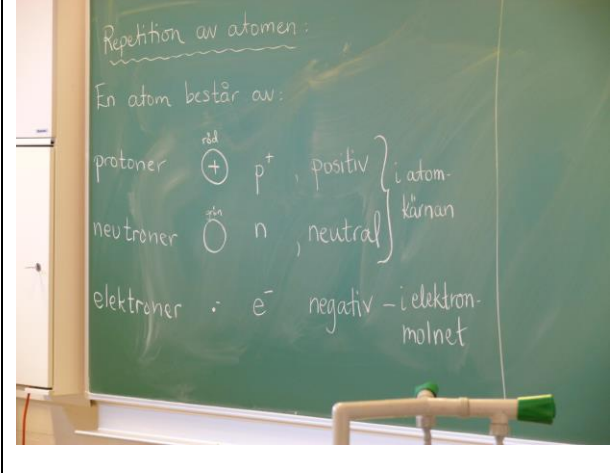
	<p><u>Repetition of the atom:</u></p> <p>An atom consists of:</p> <table> <tr> <td>protons</td> <td>positive</td> <td rowspan="2">in the nucleus</td> </tr> <tr> <td>neutrons</td> <td>neutral</td> </tr> <tr> <td>electrons</td> <td>negative</td> <td>– in the electronic electronic cloud</td> </tr> </table>	protons	positive	in the nucleus	neutrons	neutral	electrons	negative	– in the electronic electronic cloud
protons	positive	in the nucleus							
neutrons	neutral								
electrons	negative	– in the electronic electronic cloud							

Figure 3. Blackboard note, Fredrika's classroom, lesson 1.

After having stated that the protons and neutrons are in the nucleus, Fredrika introduces the apple as a metaphor:

if you have trouble understanding what kind of nucleus [Sw: kärna] this is or what is meant by it . . . so it is in the middle . the furthest inside you can get . . . if you think of an apple it is like the core (Sw: kärnhus) inside . . . where the grains (Sw: frön) are . here are the protons and neutrons . while the electrons . they move and are spinning around it [makes circular gestures with her arms] (Fredrika, lesson 1)

As opposed to Sture's exposition, we can note that Fredrika combines the metaphoric language with subject specific terminology (protons, neutrons, electrons). In her blackboard notes, only subject specific terminology is used (involving metaphors that are integrated in the scientific discourse, for example 'electronic cloud', which she also introduces as a metaphor, see below).

Both Fred and Fredrika talk about electronic clouds, which will be commented on in relation to disciplinary metaphors. However, when speaking about the electrons spinning around the nucleus like a cloud, Fred introduces another metaphor, bicycle spikes (and a thin

film), to explain the speed of the electrons. At the end of this extract we can also note how Fred touches upon the subject specific ‘electronic cloud’, but through the explicit simile, using the everyday word ‘cloud’:

the electron [in the hydrogen atom] moves at the same distance from the nucleus but it spins around and around and around . quickly quickly . if you think about the spikes in a bicycle wheel [“draws” lines like bicycle spikes from a center point with his hands in the air] . . you can see them when they are still . . . but when you spin the bicycle wheel [gestures as if giving a wheel speed] you cannot distinguish the spikes and instead it is like a thin film when they spin [gestures with his hand in a two-dimensional circle]. /.../ this is similar . they spin around and you get the impression that they are everywhere . thus it is like a cloud (Fred, lesson 3)

In these teaching episodes, both Fredrika and Fred are very careful about naming the elementary particles and making drawings. Atomic models and placement of electrons in different shells (orbits) also occupies a large portion of their lessons. Similar to Sture, Fredrika and Fred are careful to explain that the models are simplified, and in their attempts to explain the structure, they introduce analogies. Both Fredrika and Fred are explicit that it is an analogy (e.g. “if you have trouble /.../ think of an apple”, “it is like a cloud”), though neither of them ask the students how they interpret the analogy, or discuss the reach of the metaphors. The students do not pick up the analogies in the discussions, nor do they participate in the use of analogies for the atomic model (cf. Rogoff, 1995).

In the textbooks used, metaphors were frequent. However, metaphors connecting to everyday objects were not as frequent as in classroom discussions. In one textbook, though, (*Spektrum*, used in some of the Swedish classrooms), frequent connections to everyday life are made. Here chemical substances can be compared with pieces of Lego, or the change in structure and color when you fry eggs is used as a starting point for the fact that atoms can be

connected in new ways. Another example of connection to everyday life was found in the Finland-Swedish textbook, *Oktetten*, where ionic bonds are explained as similar to what sometimes happens when you comb your hair: “When you comb your hair, it sometimes becomes electrically charged. Then electrical charges move from the hair to the comb, and in that way an electrical attraction arises between the comb and the hair. In the same way, chemical bonds are kept together by electrical attraction.” (*Oktetten*, p. 111, our translation). Both textbooks are explicit that the examples are meant to be understood as analogies.

In the data from teacher education, students generated different kinds of analogies during the storyboard workshop when trying to grasp the content after having made a “cucumber battery” during experimental work. While attempting to explain why the ionic bond between zinc and copper will not appear without a conductor (in this case a cucumber), metaphors including concrete everyday objects were noted: “but if we put it into a cucumber then it will be like . aa now there’s like a *highway* . aa like a *bridge*”⁶.

Just like the way most everyday metaphors were handled by teachers (apart from Sture) and textbooks, the student uses expressions that make it explicit that it is an analogy (“like a highway /.../ like a bridge”). However, the students do not continue their reasoning between the source and the target of the analogy (*e.g.* Haglund, 2013).

Chemical particles with feelings and intentions

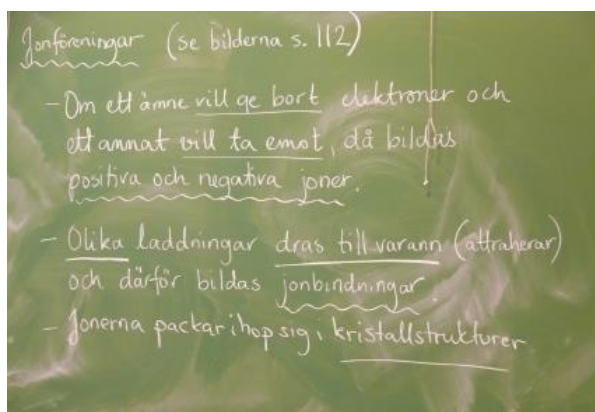
Throughout both sets of data, including textbooks, numerous anthropomorphic metaphors were used, where chemical particles become humanized, with intentions and feelings. Examples are noble gases or ions being *content* or *lazy*, *jumping* electrons, or atoms

⁶ By using particles that signal citation in everyday spoken language, and a changed tone of the voice, the student also “give voice” to copper, thus letting the (humanized) copper express the metaphors (see also below where we discuss anthropomorphic metaphors).

striving to become stable, or *giving away* and *taking* electrons. Many of the not so obvious metaphors are of these types and they are expressed through processes (like the last two examples). In the data, these processes are quite often material, thus implying some kind of action, with a participant being an actor with a clear intention. Other examples of this are when electrons “*place themselves* in shells” (textbook), or “*jump* to another atom” (classroom dialogue). But in some cases chemical particles are first participants involved in mental processes as in “atoms *want* to have a full outer shell” (classroom dialogues). Other metaphors were attributive, as “the noble gases are *content*” (classroom dialogue) or “*Lazy* noble gases” (textbook heading). Expressions like “Halogenes *gladly* (Sw. *gärna*)⁷ form chemical bonds” also imply feelings as well as intentions.

What is particularly interesting is that anthropomorphic metaphors usually are not explicitly talked about as metaphors, neither in classroom discussions nor in textbooks. This is especially true for the “hidden” metaphors, with particles *striving*, *placing themselves*, *giving away* and *taking*, but also when the metaphor is more obvious, like the textbook heading “Lazy noble gases”. Here, the text does not explain the metaphor. Instead it only states that “for a long time noble gases were considered substances that did not react with other substances”, leaving for the reader to interpret this as “laziness”. In classrooms, too, anthropomorphic metaphors were seldom explained. In most classrooms these metaphors were of the less obvious types, like ions *wanting* to have a full outer shell and such metaphors were used both in speaking and writing (see, for instance, Figure 4).

⁷ The Swedish word *gärna* can be translated as ‘willingly’, ‘gladly’, ‘readily’, all of which presume an actor with intentions. The antonym, *ogärna*, was also used in similar ways.



Ionic bonds (see pictures p. 112)

- If a chemical substance wants to give away electrons and another one wants to take, then positive and negative ions are formed.
- Different charges are drawn towards each other (attracts) and therefore ionic bonds are formed.
- The ions are packed in crystalline structures.

Figure 4. Blackboard note from Fredrika's classroom, lesson 7.

However, as regards humanizing metaphors, Sture's classroom stands out, and here we will look a bit more closely at one of his first lessons. When introducing valence electrons, Sture uses Sodium as an example, and he draws a model with three electronic shells with one electron placed on the outer shell. He points at the electron saying: "and this little *beggar*. how do you think it *feels*?", with a student responding "*lonely*", then another student clarifies: "you said before that they *like* to be in pairs but this one is *lonely*". Sture comments that "he she or it does not have any feelings" but that they could try to imagine the situation for the electron, further elaborating the humanization of the particles: "does this *feel* good do you think? . . . *this is really harassment* . . . and what do you think the main office [points at the nucleus] *thinks* about it?". The metaphoric way of explaining why some substances are more reactive than others is also filled with metaphoric language in Sture's explanations, and interestingly enough, after having stated that the atoms or particles have no feelings, Sture consistently uses these metaphors during the rest of the teaching period, rather than using disciplinary language. Also, the fact that the expressions are metaphoric is seldom brought to the fore. Instead, from now on Sture talks about Noble gases as having "*reached their Nirvana*", "not *wanting to play* with others" or being "*drunk* (Sw. 'full') and *happy*"⁸, and the reactive substances in the eighth group of the periodic table are "the *meanest*

⁸ This is a word game that works in Swedish, since Swedish *full* means both 'drunk' and 'full'.

substances". The students pick up these metaphors and use them both in talking and writing in the classroom.

The teacher students, too, use numerous anthropomorphic metaphors in their discussions. They talk about *sacrificing* ions and using electrons as bodyguards, and they even give voices to chemical substances or particles (see also footnote 6):

Student 3: the copper is much stronger than the zinc

Student 1: but is it the case that the copper . like aa you are much weaker than me I will take your electrons . but if we put it into a cucumber then it will be like . aa now there's like a highway . aa like a bridge . now I can take your electrons

This student group also discusses the difficulty with understanding that atoms losing electrons become positive ions, while atoms receiving electrons become negative ions.⁹

Finally Student 3 comes up with a metaphor as a solution that might be used for memorizing:

Student 3: if he has it stolen something it is an ion . if he has been robbed it is also an ion.

Student 1: that is what is so wrong because the one who has been robbed is positive and the one who took is negative.

Student 3: the one who gave away he was very kind and gave away so he is positive . the other who just want to have and have ... he is [psst-sound] negative... so I have learned which is which

The teacher comments on the use of analogies and concludes that this was a great analogy which she will consider to use herself, thus giving the students an explicit support in using self-generated analogies for their understanding of the content. The teacher also connects to the disciplinary content in relation to sacrificing ions: "what happens then /.../

⁹ This is a difficulty we noticed throughout our both sets of data: students have problems using the appropriated plus and minus signs from mathematics when dealing with electric charge in chemistry (*e.g.* the use of a plus-sign when there is one electron less in the atom).

what is going to increase here?”, however without further discussing or elaborating on the specific metaphors.

Metaphors from the science domain

Not surprisingly, throughout our data, we found quite a few examples of metaphors that are more or less integrated into the disciplinary discourse. Examples of this are *nucleus* (Sw. *kärna*)¹⁰, electronic *clouds* or *shells*, and *attraction* between ions. As was mentioned in the introduction, such metaphors can be challenging both as regards their reach and in relation to the fact that many of the expressions have an everyday sense that students might already be familiar with, leading to risks of misinterpretations. Some metaphors were connected to other parts of the scientific field, like *planetary orbit* (Sw. *planetbana*, where *bana* can also be used for Eng. ‘track’), or *circulating satellites*. Here we can also note the use of concrete models in the classrooms (see Figure 1, above)

The SFG-analysis revealed that many of these metaphors functioned as participants, like “the *electronic cloud* /.../ swirls around”. At times they were also expressed through material processes like “ions with opposite charges *attract* each other”. In other cases the metaphor was expressed in circumstances, like “electrons on a *shell*”. The metaphors could also be introduced in circumstances, like “as a kind of first explanation we say that they [the electrons] are *in the electronic cloud*”. By “we say that” the teacher indicates that this is some kind of metaphoric expression. Explicit similes were also found, like “Electrons circle around the nucleus in orbits (Sw. *banor*) similar to *satellites circulating around the earth*”.

When first introducing the atom, many teachers chalk-talk, drawing a model on the blackboard (or equivalent), talking about the different particles.

¹⁰ The fact that *nucleus* and *seed* is the same word (*kärna*) in Swedish makes the Swedish term more obviously metaphoric than the English *nucleus*, which is probably perceived as non-metaphoric for most English speakers.

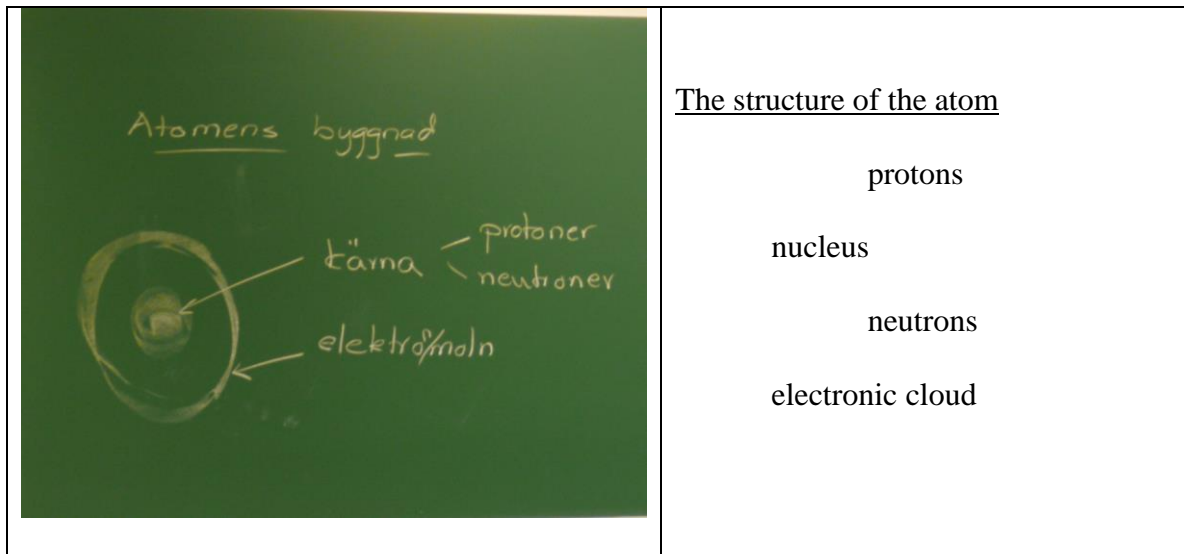


Figure 5. Model of the atom, Fred's classroom, lesson 2

Figure 5 shows Fred's drawing during one of the first lessons in the content area. Here he uses two disciplinary metaphors, *nucleus* (Sw. *kärna*) and *electronic cloud* (Sw. *elektronmoln*). It is not until the next lesson that he uses the bicycle spikes as analogies to the electronic movement (see above). When making the drawing he tries to explain what is meant by electronic cloud:

there are two central parts of the atom... /... / . something in the middle and something around it /.../ the electronic cloud which is around this atom . . swirls around in a high speed . not in well-defined orbits but at a certain distance . they swirl around there freely . around and around . (makes a circular gesture with the chalk around the "electronic cloud" in the blackboard drawing) (Fred, lesson 2)

The metaphoric term *electronic shell* is often introduced as an explicit analogy, both by teachers and in the textbooks: "The electrons in an atom can circulate in different orbits. We say that the electrons are in different shells." (Lpo, p. 15).

Coming back to the atomic model during the third lesson, Sture chalk-talks, using Lithium as an example, and now he tries to involve the students in deciding where to draw the electrons. He has just drawn two circles indicating the numbers of electrons writing 2⁻ at

the first circle and 1⁻ on the second: “two electrons on one ring¹¹ . or *you usually say a shell* . . I will write that here [draws a line from the outer circle and writes “electronic shell” at the end of the line] . electronic shell.” This is an example where a teacher makes it possible for the students to participate and to reify the use of the atomic model (Rogoff, 1995). Here by using the periodical table of the elements to explain how the student’s self-generated analogy of the rings (see footnote 11) could be connected to the periods.

Conclusions and discussion

Through the analyses of what characterizes the metaphoric language used in our different data sets, we discerned interesting patterns that were found more or less throughout the data. Firstly, the metaphors used could be connected to two larger domains: the everyday domain or the scientific domain. Connected to the everyday domain were everyday objects like apples, bridges, and bicycle spikes, or expressions where scientific concepts were humanized (anthropomorphic metaphors, such as “lazy noble gases”, or “they [noble gases] don’t want to play with others”). Connected to the scientific domain were metaphors that have been integrated in the scientific discourse, such as attraction, electronic clouds, and atomic shells, or metaphors connected to other scientific fields, like planetary orbits.

Secondly, through the SFG-analysis (Halliday and Matthiessen, 2004) we discerned patterns as to how the metaphors were expressed linguistically, with metaphors being expressed as processes (“atoms *want* to have a full outer shell”, “electrons *jump*”), first or second participants (“*this electronic cloud* swirls around”, “think of *an apple*”), or attributes

¹¹ A few minutes earlier, a student has come up with the word “ring” (another word for circle, Sw. ‘cirkel’) when Sture pointed at a period in the periodical chart asking what that was (he had drawn the inner shell of the Lithium atom on the whiteboard and wanted the students to note that you probably needed a new shell for the third electron). Somewhat surprised, Sture picks up the word and goes to the white board to draw a new circle around the first shell.

connected to the participants (“*Lazy noble gases*”) and circumstances (“the electrons swirl *in the electronic cloud*”). Metaphors expressed in processes were often anthropomorphic, and what was especially interesting was the fact that a number of these were mental processes (*want, like*) with chemical particles or substances as the first participant having a role as an *experiencer*. When anthropomorphic metaphors involved material processes (*jump, give, take*), the processes imply a first participant with the role as an *actor* with an intention of doing something. An important finding was that metaphors were only seldom presented through explicit similes (“you can think of the atom *as an apple*”) or through other linguistic choices indication analogies (“*as a kind of first explanation we say that they are in the electronic cloud*”). Such expressions were mainly connected to relatively obvious metaphors such as *apples* or *clouds*.

There are both gains and losses connected to the use of metaphors in our data sets. Each metaphor put to the fore by teachers or educational resources like textbooks, is used to highlight a particular aspect of the content. When talking about electrons, different metaphors were used. A number of metaphors have been integrated in the scientific discourse, such as ‘electronic cloud’, ‘electronic shells’ or ‘orbits’. The cloud metaphor focuses on the fact that electrons do not move in exact circles. However, the everyday concept ‘cloud’ does not imply any particular movement at all. The shell metaphor is useful for analyses of chemical reactions, but it implies something concrete. The orbit metaphor, on the other hand, implies no concrete object and involves a movement. However, this orbital movement appears to be quite exact. Thus, each of these metaphors as resources to explain scientific aspects of the electrons has different *affordances* (e.g. Gibson, 1977; Kress, 2009). Depending on the choice of resource, different aspects of the electrons will be foregrounded, at the same time as other aspects are disregarded. This is as true for metaphors that have been integrated into the scientific discourse as for more provisional metaphors, such as apples or bicycle spikes. In

our data we also noted that at times the use of metaphors could lead the focus from the science content to the actual source, as when teacher and students started talking about horses, hockey and places to sit, when a sports arena, the Globe, was used as an analogy to the atom.

As regards our second research question, around possibilities or hindrances for students' understanding of content, or their border-crossing into the field of science, our analyses revealed that teachers surprisingly seldom picked up self-generated metaphors, or elaborated their own metaphoric choice in ways that could harness their students' understanding and participation in the science field (Rogoff, 1995). We believe that in order to enable students' border-crossing into the scientific arena the metaphoric language used in science activities must be made explicit to the students (Tobin, 2006). An important aspect of the use of metaphors as pedagogic tools for explaining the scientific context through connections to the students' previous knowledge or everyday lives is the risk that the everyday expressions are used at the expense of disciplinary language. If you normally talk about noble gases as "lazy" instead of stable, or reactive substances as "mean", students will not get the opportunity to gradually appropriate the disciplinary language (Lemke, 1998). In relation to researchers' proposal to use students' self-generated analogies for understanding how they think about new concepts (Hagberg 2013, Harrison & Treagust, 2006; Jakobson & Wickman, 2007), our data from teacher education reveals interesting opportunities. The students had not been encouraged to use metaphors, yet they did so in their free group discussions, revealing their conceptions about ion formation. Here we noted that the university teacher commented positively on the use of analogies, and re-connected to the scientific content ("what happens then /.../ what is going to increase here?"). Had the teacher further combined a meta-discussion about the specific choice of analogy (for example around

“sacrificed ions”) with an explicit connection to the scientific content, this could have been an excellent learning opportunity (*cf.* Tobin, 2006).¹²

To sum up, our close analyses of data taken from a variety of resources (spoken and written texts, teaching/learning at different levels) reveal similar patterns, with ample use of metaphoric language connected to different domains. Even though teachers clearly express that models are just simplified models, a striking result is the relative lack of meta-discussions around why metaphors are used, how far the analogies reach or what affordances (gains and losses) can be connected to the respective choices. Linguistic choices signaling analogies (“you can think of it like...”) were mainly noted in relation to quite obvious metaphoric language, such as *apples*, or *bicycle spikes*. In connection to anthropomorphic metaphors, no such signals or explanations were noted. Instead, chemical particles were presented as actors with intentions (atoms *take*, or *give away* electrons) and feelings (ions are *content*) or with human attributes (*lazy* noble gases). The extent to which such metaphors were used throughout the data indicates that this way of presenting the content is more or less a normal part of the discourse of school science (even in teacher education). We also noted that the tendency to use metaphoric expressions sometimes led to a situation where scientific language was avoided, thus hindering the students’ border-crossing into to field of science. Based on our results, we can see a need for a greater awareness among science teachers and science educators as regards gains as well as limitations around the use of analogies. Also, we believe that meta-discussions around metaphoric language have a great potential in science teaching and learning. Here we do not only refer to the obvious analogies, but also to linguistic choices that depict chemical particles as actors with intentions and feelings. To

¹² Here it is important to stress that the roles of the teachers had not been discussed previous to the intervention, and therefore they were not sure about how much to intervene during the group discussions.

make such teaching practices possible, science teachers and science educators need a greater awareness of what expressions could actually be perceived as metaphoric (apart from the obvious analogies used in classrooms) and a greater awareness of the importance of linguistic choices in the teaching practice.

We believe (or at least we hope) that our study can be a contribution in raising such an awareness among science educators and teachers. By the close collaboration between experts from language and science as well as qualified science teachers in the present study, we have ourselves experienced the value of cross-disciplinary analysis in order to meet these requirements (*c.f.* Tibell & Rundgren, 2010).

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