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Creative drama in chemistry education: a social semiotic approach

Abstract

Drama is a way of teaching that has been suggested to support learning, but studies in science education are limited and the potential of using drama needs further scrutiny and design development. In this study, we investigate how creative drama may afford students' meaning-making of abstract non-spontaneous chemical concepts related to chemical bonding, by exploring what kind of semiotic work students are engaged in when given the opportunity to use their own bodies as semiotic resources. We combine sociocultural theory of learning with multimodal social semiotic analysis. Our results show how creative drama opens up for different types of transductions and transformations that have consequences for students' meaning-making. A conclusion is that the creative drama activities may afford student exploration of intermolecular forces in new ways in particular when students use bodily mode in combination with other semiotic resources.

Introduction

Chemistry in upper secondary school is a subject that students often find challenging. In chemistry, students encounter many terms that are new to them (Markic, Broggy & Childs, 2013) and they are expected to interpret a variety of symbolic representations to develop their understanding of concepts (Taber & Coll, 2002). In short, chemistry is often found to be abstract and hard to grasp (Smith, 2011). Hence, there is a need to develop teaching methods that can make chemistry more vivid and tangible. In this study, we investigate the ways in which drama can be used to support student chemistry learning in upper secondary school. More specifically, the aim is to investigate how creative drama may afford student meaning-making in relation to chemical concepts.

Creative drama in science education

Drama is a way of teaching that may arouse affect, support cognitive learning and participation. However, research in science education is limited and the potential of using drama in science education needs further scrutiny and development (Ødegaard, 2003; Yoon, 2006; Dorion, 2009). There are various forms of drama for educational purposes, and Ødegaard (2003) has categorized different forms of drama in the natural science classroom; explorative, semi-structured and structured. The structured drama is essentially initiated and guided by the teacher and has more features of theater, where something should be communicated to an audience (e.g. a teacher, peers or parents), while exploratory drama is more initiated and guided by the students who are both actors and audience. In this study, we explore a special form of drama for educational purposes called creative drama. Creative drama has features similar to both structured and explorative drama, and can be seen as a semi-structured form of drama (Ødegaard, 2003). When integrating creative drama in science teaching the teacher guides students to dramatize a story or concept relevant to the ongoing teaching. Creative drama is an improvised activity created in the classroom where there is no manuscript. The rationale for using creative drama as an activity to support student conceptual learning is that the process may open up for students to transfer science concepts into personally meaningful forms (Arieli, 2007). The idea is that students use their own bodies in a process of materializing abstract science terms and processes, which provide students opportunities to think about the concept in a way that makes it meaningful (Arieli 2007).

Cokadar and Yilmaz (2010) showed, in a study on creative drama about ecosystems and matter cycles in Turkish elementary school, that the participating students had significantly improved their conceptual knowledge from pre- to post tests. Arieli (2007) points to similar results in a study of six classes of pupils aged 11-12. Arieli's results showed, based on pre- and post tests, that the students' conceptual development had improved in the group of students who had to perform creative drama. Thus, there is support in previous research to conclude that creative drama may contritbute to students' conceptual science learning with younger students. However, the research conducted has primarily been based on pre- and posttest metholdogy. Few attempts have been made to investigate how drama works in classroom practice (cf. Braund, 2014). Hence, there is a need for research zooming in on student participation in drama activities in the science classroom and also for research involving older students working with more complex subject matter.

Theoretical background

In the study we combine sociocultural theory of learning, drawing on the work of Vygotsky (1934/1999), with multimodal socialsemiotic analysis, drawing on the works of Kress and Bezemer (2015).

Non-spontaneous chemistry concepts in creative drama

Chemistry in upper secondary school predominantly involves concepts that may be classified as non-spontaneous scientific concepts (Vygotsky 1934/1999). Non-spontaneous concepts are concepts that, unlike spontaneous concepts, do not originate from personal experience and do not develop spontaneously through participation in everyday life. Initially the concepts are entirely abstract but they can be acquired through teaching. For example, in everyday language we may say that a pot of water boils. In this case, boiling can be consider as a spontaneous concept. However, when we introduce the terms phase and phase transition to account for the transformation of the water in terms of transition from liquid phase to gas phase, we have introduced non-spontaneous concepts.

Some central non-spontaneous concepts of chemistry identified in previous research concern the different organizational levels of chemistry (cf. Johnstone, 1982; Gilbert & Treagust, 2009; De Jong, Blonder & Oversby, 2013). Drawing on Gilbert and Treaugust (2009), we use the terms *macro*, *submicro* and *symbolic* to describe the different organizational levels in chemistry education: the *macro* level, describing properties and phenomena of chemical substances observable with our senses such as phases and colors, the *submicro* level, describing arragements of particle units such as atoms, molecules, ions and electrons and the *symbolic* level, the language of chemical formulas and symbols for describing the substances and particles. Gilbert and Treaugust (2009) emphasise switching perception between the macro and the submicro levels requires the practice of visualization and is found difficult by many students. This is in line with the review of research in the field by Harrison and Treagust (2002), that shows that students display particular difficulties in moving between the different levels of organization. Drawing on Othman, Treagust and Chandrasegaran (2008), transitions between submicro and macro representations should be explicity conveyed to students. In addition, for students to understand chemical observations at macro level, they must use submicro scale models (Oversby, 2000). Such models need to make 'the invisible visible' – that is, the models need to describe, or explain, macro level observations with the submicro model (Harrison & Treagust, 2002; Wu, 2003; De Jong, Blonder & Oversby, 2013).

Another key non-sponateous concept of chemistry is the particulate nature of matter (Taber & Coll, 2002; Harrison & Treagust, 2002). For example, Jong, Blonder and Oversby (2013) describe how students often represent the water molecule as a diatomic molecule of hydrogen and an atom of oxygen or the water molecule is drawn as three separate atoms. The particulate nature of matter is strongly linked to chemical bonding (Taber & Coll, 2002; Harrison & Treagust, 2002). Several studies show that students have difficulty distinguishing between intra- and intermolecular forces (Jong, Blonder & Oversby, 2013; Taber & Watts, 2000; Peterson & Treagust, 1989). One explanation of students' difficulties in distinguishing between intra- and intermolecular forces (Taber & Coll, 2002) may relate to students' lack of understanding the non-spontaneous concept of *electronegativity* – the atom's ability to attract electrons from other atoms (Harrison & Treagust, 1996; Nahum et al., 2008; Taber & Coll, 2002).

According to Vygotsky (1934/1999), the theory of development of non-spontaneous concepts asserts that students´ conceptual understanding develop when they are provided opportunities for concepts to grow into their concrete personal experience. Previous research point to that creative drama may provide students with opportunities to transfer the two-dimensional models from the textbook to a three-dimensional live model, which enables the students to reconstruct their own knowledge and increase their understanding of scientific concepts (Ødegaard, 2015). However, further research focusing on the development of non-sponaneous abstract concepts is needed. Drawing on Vygotsky (1934/1999), we seek to explore how creative drama in chemistry education may open up for chemical concepts, particularly the concepts dealing with different organizational levels of chemistry, to grow into the concrete personal experience of students.

Multimodal social semiotic perspective

Meaning making is a result of interactive work in a social environment with socially shaped cultural resources by socially formed actors/agents (Kress, 2010; Kress & Bezemer, 2015). In social semiotics, the learning process is seen as an interaction of communication, of semiotic work. Learning is the result of interaction and/or commitment to sign-making (Kress & Bezemer, 2015).

The multimodal perspective acknowledges that several forms of semiotic modes work together to make meaning in a particular environment. According to Kress (2010) "*Mode* is a socially shaped and culturally given semiotic resource for making meaning" (p. 79, italics in original). A mode may be explained as "an organized set of *semiotic resources*" (Björkvall, 2009, p.13, italics in original). Semiotic resources refer to the "building materials" available within a mode, for example words for text production. In other words, meaning is created by many semiotic modes in addition to speech and writing, always in specific combinations, where speech and writing are not necessarily central (Kress & Bezemer, 2015; Kress et al. 2001; Kress, Jewitt, Ogborn & Tsatsarelis, 2001; Björkvall, 2009). In creative drama, several semiotic modes may be drawn upon by the students; including speech, writing, image, bodily formations, bodily movements and physical artifacts.

When the students create signs in social interaction with others, meaning is transformed from a semiotic mode ore complex of modes into meaning in another semiotic mode or complex of modes. Kress and Bezemer (2015) write about different types of transformation through terms of *transformation* and *transduction*. Transduction refers to *inter*-modal changes; when the units change from one semiotic mode to another. For example, when a student reads a text in a book and draws a picture (text to picture). Transformation refers to *intra*-modal changes; this means that units/elements within a particular semiotic mode are reshaped. For example, when a student writes a new text based on the reading of another text (text to text), how the units, the words are the same within the semiotic mode text, but how the words can be rearranged and gain a new meaning when the student writes a new text. No matter what change of mode, either intra- or intermodal, change in meaning is produced. Such meaning production constitutes learning (Kress & Bezemer, 2015).

Regardless of mode, communication must involve resources for expressing specific meanings that the meaning-maker seeks to express; meaning making is always functional. If there is a lack of resources available in one mode, meaning may be expressed by other means (Björkvall, 2009). This study builds on the assumption that the functional potential of meaning can be extended through making new semiotic resources available in a drama activity.

In creative drama, allowing students to creatively imitate each other and even "be" different molecules and atoms, can be a way for students to identify oneself with "chemistry's submicro world" in terms of both forms and processes, which can facilitate learning in the communicative chemistry classroom. Thus, creative drama would potentially open up for students to use their own bodies as semiotic resources when they transfer the model or description from the textbook to a three-dimensional living model, in which students' needs to reconstruct their own knowledge by moving between semiotic modes (Kress & Bezemer, 2015). However, research is needed to explore the potentialities of creative drama in chemistry classroom practice.

The specific research question addressed in this study is: *What kind of semiotic work do students engage in when exploring abstract non-spontaneous concept related to chemical bonding in creative drama?*

Method

This study is part of a larger design-based research study that was conducted in three cycles during 2015 – 2017 in upper secondary chemistry in Sweden. The data presented here stem from the second cycle, conducted in 2015 with a class of students in the natural science programme.

Designing an intervention

A research lesson involving creative drama was designed on the topic of chemical bonding. Chemical bonding is central to the upper-secondary Chemistry curriculum in Sweden and involves many challenging non-spontaneous concepts, e.g. electronegativity, dipole and polar molecule. The research lesson was intended to develop students' understanding of intra- and intermolecular forces and electronegativity at chemistry's different organizational levels.

The research lesson included the following creative drama tasks:

Task 1: To form a hydrogen fluoride molecule in small-groups with their own bodies and show which of the atoms was most electronegative.

Task 2: To form the liquid phase of hydrogen fluoride in whole-class and then to alternate between the different phases of matter.

Task 3: To form a water molecule with the body in small-groups and show which of the atoms was most electronegative.

Task 4: To form the liquid phase of water in whole-class and then to alternate between the different phases of matter.

During the lesson, the students were seated in small-groups grouped around the classroom, while a free space in the middle of the classroom had been reserved for whole-class activities. On all tables there were artifacts in the form of white and colored paper, clothes pegs in different colors, pens, scissors and tapes. The artifacts were chosen to allow students to use a range of semiotic resources when creating their molecules. The students were also given Ipads to document the molecules produced in the small-groups.

The small-groups were given the task to visualize molecules and electronegativity with their own bodies. After initial discussion in the group, the group had to enact their molecules, in terms of bodily formation, and provide an oral account of how they had reasoned. The second task, performed in whole-class, was to enact the liquid phase of the matter in the space in middle of the classroom, and then to alternate between the different phases of matter. The first small-group and whole-class task involved exploration of hydrogen fluoride, and the second task, exploration of water. The whole-class activity was intended to be a key activities to provide students with opportunities to explore how several molecules interact with each other. The activity would allow the teacher to visualize the students' models and discuss their possibilities and limitations.

Data collection

The intervention was conducted during a lesson in upper secondary school chemistry with a group of 26 students aged 16-17 years, who studied the first year on the natural science program. The students were divided into five groups of 4-6 students in each group. During the intervention, the first author acted as teacher and the second and third authors observed and filmed the drama activity. The drama activity lasted for 60 minutes and was recorded with five video-cameras. One video-camera was moving in the classroom and four other video-cameras were used as stationary, placed at the four student groups participating in the study. The discussions in the four student groups were also recorded with four audiorecorders. A fifth group, consiting of four students who did not consent to being recorded, was placed at a table outside the reach of the video cameras and audiorecorders. All students who participated in the study had given their written consent to be filmed for research purposes.

Data processing and analysis

The analysis, influenced by Heath, Hindmarsh and Luff (2010), started with a preliminary overview of the audiovisual material while notes were taken over different events in the classroom, such as when the various tasks started and ended. After that, the parts of the audiovisual material where the students worked with the water molecule was transcribed in verbatime (tasks 3 and 4). We chose this part of the drama activity because after the overview of the audiovisual material we found it interesting to analyze the students' exploration of the more complex molecule, where a need was created for the students to explore the angle of the water molecule. In our analysis, we then examined the audiovisual and transcribed material dealing with the water molecule (tasks 3 and 4) and noted the semiotic modes used by the students when exploring the non-spontaneous concepts. In order to discern the processes when meaning is translated we used the operational concepts *transduction* and *transformation* (cf. Kress, 2010). As noted on page 4, transduction refers to *inter*-modal changes; when the units change from one semiotic mode to another. For example, when students in creative drama use a written structural formula of a molecule and visualize the molecule in a bodily mode. Transformation refers to *intra*-modal changes; which means that units/elements change within a particular semiotic mode. For example, when students, in creative drama, transform a visualization of a molecule made by another group to a molecule visualized with their own bodies. In a thematic analysis of the audiovisual and transcribed material, we noted the inter-modal and intra-modal changes that became visible when the students explored the non-spontaneous concepts in the drama activity (tasks 3 and 4). The inter-modal and intra-modal changes were then categorized into different types of transductions and transformations.

Results

In this section we describe and illustrate the semiotic work in form of different types of transductions, in three episodes. Thereafter, we describe and illustrate the different types of transformations that became visible in the drama activity. The episodes presented are chosen to illustrate how the different types of student semiotic work may unfold within the drama activity.

Semiotic work in the form of transductions

Transduction refers to the remaking of meaning from one mode to another. In the drama activities the students engaged in five major types of transduction:

a. *Transducing multimodal complex in form of textbook and notes to writing mode.* Semiotic work in form of transductions when the students prepared their presentations and used the textbook and notes to draw a structural formula of the water molecule, chemical symbols for electronegativity or elements. The notion of *multimodal complex* stems from Kress (2010) and is used to account for a collection of many different modes. In transdcution of *type a*, the textbook and notes constitute a multimodal complex including different modes such as pictures, symbols, text and layout.

b. *Transducing written mode to bodily mode and/or verbal mode.* Semiotic work when the students' written expressions of the water molecules structural formula were transducted to bodily positions.

c. *Transduction through a discursive chemical model.* Semiotic work when students used discursive chemical models and transduced them to bodily mode or written mode. Drawing on Gee (2014) and Foucault (1971), this notion of *discursive chemical models* is used to refer to simplified, taken-for-granted models, created in social and cultural groups, in the form of stories, ideas or images of how the world works. In chemistry teaching, discursive chemical models are created for purposes such as grappling with the chemistry in front of us. In this study, one example of a discursive chemistry models used is "The Mickey mouse model".

d. *Transducing bodily mode to written and/or verbal mode.* Semiotic work when students in a group worked with the task and other groups bodily positions served as prompt to the group to transduce bodily mode to written and verbal mode, and when students used other students, or their own bodily positions, to verbally explain non-spontaneous concepts.

e. *Transducing verbal mode to bodily mode.* Semiotic work when the students displayed electronegativity with bodily movements .

The different types of transductions are presented below as they unfold in the students' work in three different episodes.

Episode 1: The Mickey Mouse model

In this episode three types of transduction is exemplified: *transducing multimodal complex textbook and notes into written mode (type a), transducing written mode into bodily mode and/or verbal mode* (type b) and *transduction through a discursive chemical model (type c),* when the group is working on the task to form a water molecule and show which atom is most electronegative.

The students, Aro and Hani, were sitting opposite to each other and drew the chemical signs for hydrogen and oxygen on colored paper. Ron and Karl were watching them. Hani quickly looked into her notes and then draws a structural formula of the water molecule on a paper. When she had finished drawing, she presented an idea to her group on how they should form a bodily water molecule:

1. Hani: We have to be three people, One has to stand up, * be oxygen.
   ** points and looks at Aro, laughs**
2. ** Aro draws the letter H on a blue paper **
3. Karl: Well, * are we going to stand up?
   ** laughs, watching Hani **
4. Hani: ... you also have to * sit down
   ** Looking at Karl and Ron, doing a downward motion with shoulders and head, laughs**
5. Ron: We have to look like, what is it call * ed Mickey Mouse"
   ** watching Hani**
6. ** Hani quickly looks down in her notes with a thoughtful facial expression**
7. Karl: Yes, he * (Aro) should be in the middle
   ** watching Hani **
8. Hani: It * doesn't matter
   ** watching Ron**
9. Ron: He in the middle * has to go down
   ** Bend his head down and look at Hani **
10. Karl: Wait * should he be hydrogen?
    ** points to Hani's paper **
11. Hani: Yes, but that's the same, * it can also turn around like this*
    **shows by turning her hands in the air **
    **looking at Aro*.*
12. Karl: Then you have to bend down * sit down.
    ** still drawing on the paper**
13. Aro: Eh, mee!
14. Hani: Okay!
    ** stretches out her arms in an exhausted gesture, laughs, looks at Aro, then Karl and Ron**
15. Aro: Wait now, * I'm the one who's tallest. I wont sit!
    ** Smile, still drawing on the paper **
16. Karl: Wait * who's the tallest of you and me?
    ** turns his head against Ron **
17. ** Ron and Karl get up from the chair to measure which one is tallest **
18. Aro: Wait, how tall are you? You're still hydrogen and are about the same height.
19. ** Hani looks at Karl and Ron, laughs and touch her forehead with her hand while her head bends downwards **

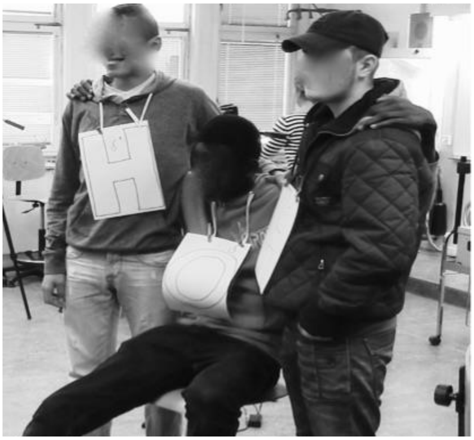

Figure 1. Bodily formation of a water molecule

In the above excerpt, when posing for a picture (Figure 1), Ron, Karl and Aro express that oxygen should be placed below hydrogen in the water molecule. Figure 1 illustrates how the students use their own bodies as visual semiotic resources. The same element was represented by students of approximately the same length, as shown in Figure 1 where the students who formed hydrogen were placed on each side of the student acting as oxygen. That height was of significance is shown in the excerpt lines 15-18 where Ron and Karl are measuring their height and when Aro (line 18) says "Wait, how tall are you? You're still hydrogen and are about the same height". Students also create meaning through the use of semiotic resources in the form of chemical symbols on colored paper where the same element is represented by the same color on the paper. In Figure 1 hydrogen is represented by the symbol H on blue paper.

After using the multimodal complex textbook as a semiotic resource, the students recreate meaning from the multimodal complex textbook to the writing of chemical symbols on paper, which are then attached to the students' bodies. The papers contribute to the formation of the bodily water molecule. The semiotic work performed by the students is an example of transduction (type b) where the written mode is transduced and used together with the bodily mode to express meaning about the form and structure of the water molecule .

The analysis of the audiovisual data showed that the group did not agree on how the oxygen would be placed in the molecule. Hani provided an idea of how the water molecule should be formed when saying "one should stand up" while pointing to Aro and then saying it will be oxygen (line 1) while she says to Ron and Karl "... you two should also sit down" while doing a downward motion with shoulders and hands (line 4). The excerpt displays how Hani uses semiotic resources in the form of gestures and speech to argue for her idea.

The textbook and notes constitute a multimodal complex including different modes such as pictures, symbols, text and layout (Kress, 2010). In the above episode, Hani transferred the multimodal complex to writing on a paper in the form of a structural formula of the water molecule. This semiotic work is an example of transformation or transduction (type a) – depending on the semiotic resources used in the textbook and notes. When Hani used the mode speech to explain how the group members should form the water molecule with their bodies, this was an example of transduction where the written expression of the water molecule was recreated from the image in the textbook to a model for bodily formation of the water molecule (type b). However, the other group members did not agree with Hani's idea. Ron objected with reference to "what is it called Mickey Mouse". Mickey Mouse is a commonly used metaphor for the water molecule that can be considered a discursive chemical model, where the ears of Mickey Mouse represent the two hydrogen atoms and the face the oxygen atom.

Hani tried to convince Ron that it does not matter if oxygen is up or down using the semiotic modes of speech and body movements, which excerpts show in line 11 when she says, “Yes, but that’s the same, it can also turn around like this” and shows by turning her hands in the air. Karl supports the discursive model of the water molecule with the oxygen positioned downward, when he says to Aro after Hani’s utterance in line 11 “Then you have to bend down, sit down” (line 12). This is reflected in the picture (Figure 1) where the three students; Ron, Karl and Aro, pose to be photographed with Ipad. Figure 1 above shows how the water molecule is formed with Aro that have longest body height, sitting on a chair, forming an oxygen atom and the other two students Ron and Karl standing next to Aro forming hydrogen atoms. The discursive chemical model of the water molecule, such as “Mickey Mouse”, has been transduced into bodily mode, which shows that a semiotic work in the form of transduction has occurred in the drama activity when Ron, Karl and Aro make meaning of the form and structure of the water molecule (type c).

Episode 2: Why do they have oxygen at the top?

This episode illustrates the type of semiotic work when *transducing bodily mode to written and verbal mode (type d)*. In all groups the analysis showed that the students’ bodily formations of molecules in some groups prompted semiotic work in other groups. When the students performed and prepared their bodily formations of the water molecule and posed for photo documentation, the students drew on resources within the bodily mode.

Figure 2a. Martin poses a question

Figure 2b. Eric points with his fingers over the written representation of the water molecule

In this episode, Martin, wearing the paper with the symbol for hydrogen on his cheast (Figures 2a and 2b), had been silently watching the student group next to him. He then posed a question (Figure 2a) to the group “Why do they have oxygen at the top? ”. He pointed to the group next to him where the student who form oxygen stands on a chair. Eric uses Anders’ paper with the written representation of the water molecule and points his fingers over the electron pairings to show the shape of the water molecule (Figure 2b). Here, Eric transfers meaning from the visual bodily mode of the water molecule (his fingers) into an image of the written mode (transduction type d). Martin displayed with his question that he had not appropriated why the water molecule has an angle. After having seen the other group’s bodily formation of the molecule he discerns that there is something he has not understood. Hence, the bodily mode in another group prompted semiotic work in form of transducing bodily mode to written and verbal mode in Martin and Erics group.

Episode 3: Eric display electronegativity

This episode illustrates how students perform transduction in the form of *transducing written mode to bodily mode* (type b) and *transducing verbal mode to bodily mode* (type e). In the excerpt and the images below, one group presents their bodily formation of the water molecule while showing electronegativity. The group consist of Anders (sitting on the left in the picture who has drawn a structure formula of the water molecule on a paper), Eric (who represent oxygen, is in the middle of the picture) and Martin and Pela (representing hydrogen atoms placed on each side of Eric).

Figure 3a. Anders explain electronegativity

1. Eric: I am oxygen and they * are hydrogen
** Points with his hands on his ”hydrogenfriends**

2. Anders: And oxygen has higher electronegativity because it has less distances to the electrons so that it can pull them more
Shows his textual representation drawnon paper to the audience

Figure 3b. Eric grasps the friends´arms

3. Eric: **Grasps the friends’ arms*

Figure 3c. Eric display electronegativity

4. Anders:**Rolls the paper and looks at the student molecule**

5. Eric: I, I’m pulling the other two, yes, oxygen has higher electronegativity so I’m pulling these ones * but never becoming an ion
Pulls the arms of the friends closer

In the episode, Anders used notes to draw a structural formula of the water molecule on an orange paper. When Anders explained electronegativity, he did not use the written structural formula of the watermolecule. Instead he rolled the paper (lines 2 and 4) and looked at the bodily mode of the water molecule performed by Eric, Pela and Martin. Eric (oxygen in the water molecule, Figure 3c) elaborated on the meaning of electronegativity by saying " I, I'm pulling the other two, yes, oxygen has higher electronegativity so I'm pulling these ones but never becoming an ion" (line 5) and at the same time pulling Pela and Martin's arms closer. Eric thus uses bodily mode to display a movement with his arms to display how the electrons "pull more" toward the oxygen. Eric performed semiotic work in the form of transduction (type e), as he recreated meaning from Anders' verbal explanation into bodily movement while emphasizing the bodily mode by means of verbal utterance. Thus, by means of transduction, Eric and Anders extended the meaning of electronegativity and the connection between electronegativity and chemical forces as a continuum.

Summary of semiotic work in the form of transductions in creative drama

Common to all groups was that most students used the textbook or their own notes as the primary semiotic resource. The textual information was then transduced (or transformed) into written mode in the form of notes or scrabbles. When the students performed the water molecule, the written mode in the form of structural formulas of the water molecule was transduced to bodily mode. In one group (episode 1), the discursive chemical model of Mickey Mouse was transduced to bodily mode. All groups were also influenced by bodily enactments of the molecules in other groups. The students sometimes emphasized the verbal utterances by means of bodily mode in the form of movement when they were talking about electronegativity (for example episode 3). In the above episodes, the students worked exclusively on submicro levels and related the submicro level to the symbolic level by representing the water molecule both in written mode and bodily mode.

Semiotic work in the form of transformations

Transformations refers to the remaking of meaning *within* a particular semiotic mode. In the drama activities the students were engaged into a main category of *transformations within the bodily mode,* observed when students transformed expressions within the bodily mode of another group/person to their own expressions within the bodily mode. *Transformation within the bodily mode* are presented in two episodes below. Episod four describes in general how transformations between different groups are expressed and episode five zoom in and describes in detail from a students perspective how transformation within the bodily mode are expressed in the drama activity.

Episode 4: All groups form the liquid phase of the water

When all groups were given the task to form the liquid phase of water in the middle of the classroom, the students functioned as learning resources to each other and a need arose for changing the bodily shapes of the water molecule in different groups. One student exclaimed "we must get moving" whereby one group of molecule after another began to move on the spot to form vibrations. Initially, all water molecules were in the same two dimensional shape that the students had enacted in the presentation of the single formed molecules. However, when dramatizing liquid water a need arose for the students to position their bodily molecules in relation to the other student molecules, to show where the intermolecular forces arose in a three-dimensional pattern. Figure 4 illustrates how some of the student groups had placed themselves in relation to each other. Each water molecule was formed by three students who displayed their unity as a molecule by holding each other's arms or hands. The water molecule's positive pol (hydrogen atoms) in one molecule are directed to the negative pole (oxygen atom) of the other water molecule, to show the attraction between the poles of the water molecules that give rise to the intermolecular bonds.

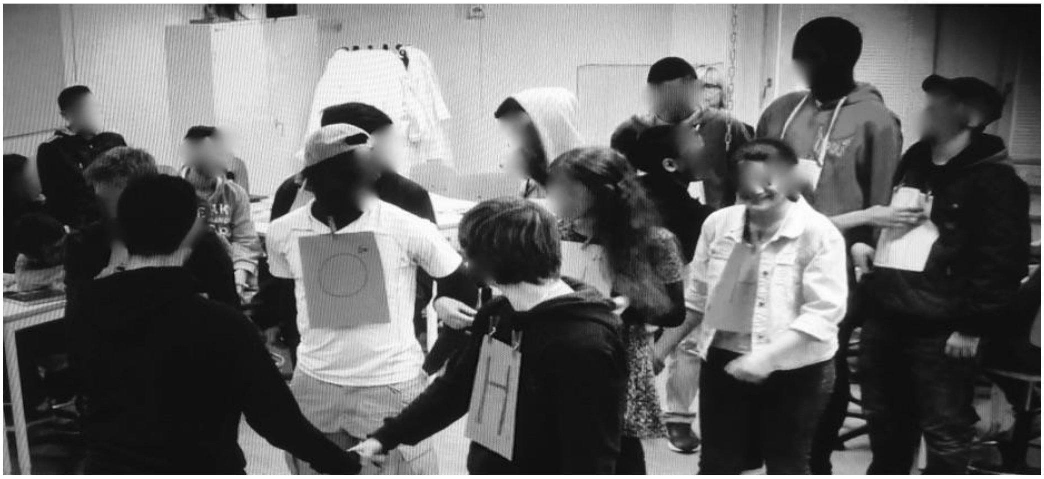

Figure 4. Collective semiotic work in the formation of liquid phase of water

The student groups helped each other to find the right positions between the molecules on the classroom floor. The students who displayed that they had appropriated how the water molecules would bind to each other in the liquid phase, organized and acted as learning resources. Some students appeared confused in how to place themselves in relation to the other bodily molecules, which may be interpreted as they had not yet appropriated the concept of intermolecular forces.
When the students enacted the intermolecular forces with their body movements and body positions in relation to the other students' bodies they performed a collective semiotic work in the form of transformations; the students in one group transformed bodily mode in another group by the bodily mode of their own group. The episode, is thus an example of *transformation of meaning within bodily mode.*

Episode 5: Riann works as a learning resource
In this episode, Riann (at the center of picture 5a and 5b with a paper on the chest) demonstrates how intermoleculares force may be represented in the drama activity by forming with her own body the positive part of the water molecule with Eric (on the left side of Riann in picture 5a and 5b) forming oxygen and the negative pole in another water molecule.

Figure 5a. Riann demonstrates how the intermolecular force is represented in the drama activity.

Figure 5b. Riann reacts when Erin and Pela tied their arms together.

1. Riann: I am the hydrogen
   * looking at Eric *
2. Eric: You * should connect to her * here
   ** look at Erin **
   ** toutch with his finger on Pelin's shoulder **
3. **Erin and Pela connect their arms **
4. Riann: Noooooooo !!! (see figure 5b)
   ** turns her head against Eric and points to Pela and Erin's paired arms and looks at Eric with a grim facial expression**
5. ** Riann moves her hand to the left in front of Erin and Pelas arms in a sweeping movement and shows that they should let their arms apart **
6. Eric: Stand behind
   ** point to Erin **
7. ** Pelin releases Eric and stands beside Erin **
8. ** Riann puts her hand on Erin's shoulder and removes her away from Pelin **

In the epsiode Riann reacts strongly (line 4, Figure 5b) when Pela and Erin from two different water molecules, tied their arms together. She said "nooooo" and showed a grim look while she placed Erin at the place she considered to be the right one (line 8) in relation to the other water molecules. In the drama activity, tieing ones hands together had become a gesture of the stronger intramolecular covalent bond that occurs within the water molecule. Erin and Pela's "wrong" body movements functioned as prompts for Riann to show how the water molecules should bond to each other in the drama activity.

Riann used her own body as a semiotic resource when she displayed with her body how the intermolecular forces should be formed while using her classmates' bodies as visual semiotic resources. To communicate what she thought was the right form she placed herself close to Eric's body, she also pointed to Erin and Pela and brought them apart with her hands. In the episode, Riann conducts semiotic work in the form of *transformations of meaning within the bodily mode*. She *visually uses the bodies of herself and other students in the transformation process*. Riann demonstrated through her semiotic work that she had appropiated the theoretical concept of intermolecular forces in the liquid phase of water, in contrast to Erin and Pela. To Erin and Pela the episode opens an opportunity to discern differences between intra- and intermolecular forces.

Summary of semiotic work in the form of transformations in creative drama

The analysis show that transformations in bodily mode occurred in many different occasions in the drama activity. Both in preparation for presentation and in the actual presentation of separate molecules when the students observed each other's bodily formations and transformed bodily mode from another group to their own. Transformations within bodily mode became evident when all groups together formed the liquid phase of water. This particular task established a need for the students to discard the two-dimensional form in favor of a three-dimensional. When the students displayed the intermolecular forces with their body movements and body positions in relation to the bodies of the other students, they performed collective semiotic work; the students in one group transformed the bodily formations in another group to bodily formations of their own. In the episodes, the students performed semiotic work at the chemistry's submicro level when they presented the separate molecules, and the task to form the liquid phase of water afforded the linking of the macro and submicro level.

Discussion

When the students explored non-spontaneous concepts related to chemical bonding in the creative drama, we observed different types of semiotic work in form of transductions and transformations. Common to all groups was that most students used the textbook or their own notes as the primary semiotic resource and transduced and transformed meaning from the multimodal semiotic complex to written, verbal and then bodily mode. In addition some students transduced the discursive chemical model of the water molecule as “Mickey Mouse” to bodily formations. In all groups, the bodily formations of the water molecule enacted by other groups functioned as prompts for the students’ semiotic work to recreate mening from bodily mode to verbal and written mode. Most of the transformations observed in the study concerned transformations within bodily mode. For example, when all groups engaged in the collective semiotic work of forming the liquid phase of water. In the episodes accounted for, the students performed semiotic work at the chemistry’s submicro level when presenting separate molecules but were afforded opportunities to link macro and submicro levels when they explored intermolecular forces in the whole-class task to form liquid water.

The whole-class drama activity allowed the students to explore intermolecular forces in a grid structure including many molecules instead of between two separate molecules, which Taber & Coll (2002) claim is a common representation in textbooks. When opening opportunities for students to explore intermolecular forces in new ways student participation in creative drama may afford abstract non-spontaneous chemical concepts to grow into the concrete personal experience of the students (cf. Vygotsky 1934/1999). Our findings support Ødegaard’s (2015) suggestion that creative drama may be a way to provide students with opportunities to transfer two-dimensional models from the textbook to three-dimensional live models that may enable students to deepen their understanding of scientific concepts.

This study provides insights into how creative drama in chemistry may afford students to engage in semiotic work involving several different semiotic modes (e.g. bodily, verbal and written modes). Kress (2010) points to that different types of semiotic modes may result in different types of semiotic work, which in turn has different consequences for the meaning-making that is made possible. When the students in creative drama created meaning in *bodily mode together with verbal and written mode* other types of semiotic work were afforded than usually offered in chemistry education. Transductions between written mode and bodily mode as well as between verbal mode and bodily mode enabled semiotic work where students recreated meaning from one mode to another. Because transduction involves an ontological change, transduction is considered to be more far-reaching than transformation where the units remain the same (Kress, 2010). When the students in the drama activity used bodily mode to display molecular structures and electronegativity, they had to transfer meaning from other modes, which means they have to reinterpret semiotic resources. This finding is in line with Arieli’s (2007) conclusions that creative drama allows students to analyze and synthesize information and transfer natural concepts and processes into a personally meaningful form. In other words, creative drama may extend the functional potential of meaning-making and increase the potential for learning.

When the students worked with the tasks in small groups, the semiotic work performed involved transductions (e.g. written mode to bodily mode) exclusively at chemistry´s submicro level. Although the semiotic work in the form of transduction may be considered more farreaching than transformation the small-group task did not open up for relating macro and submicro levels of chemistry. Thus, creative drama does not per se open up for students to recreate meanings on the relationships between particle nature of matter and macro properties of matter. A challenge for chemistry teachers is to design creative drama activities that open up for students to link the organizational levels of chemistry while at the same time performing semiotic work in the form of transductions. Further research is needed to investigate what it takes to design such creative drama activities.

In all groups, the student formations of the molecules functioned as prompts to other student groups in their work to make sense of the form and structure of the molecule. The students' bodily formation of the molecules in the classroom served as prompt for semiotic work which also involved transformations whitin the bodily mode. This was applied both when the students worked with the task and when they presented the separate molecules as well as in the collective presentation of the liquid phase of water. The students inspired each other and incorporated each other's bodily formations and changed them into their own creations. The students' bodily movements and positions were transformed from one group of students to another. This is an example of creative imitation, in the form of *mimesis,* which Christoph Wulf (2008) has emphasized to be one of the most important forms of learning. Semiotic work in the form of transformation within the bodily mode was afforded in creative drama and drawing on mimesis this process may extend the functional potential of meaning-making, which in turn may increase learning. However, a risk with mimesis may be that the visualization of a chemical concept, not consistent with the scientific discourse, enacted by one group travels across the classroom and becomes transformed into the visualizations performed by others groups. Hence, bodily formations of chemical concepts that limit students' potential learning may circulate around the classroom.

Thus, to allow students in creative drama to use their bodies as semiotic resources to visualize chemical concepts and processes is a way to simplify the chemical language with bodily models that can afford students' appropriation of the non-spontaneous concepts. However, there is research pointing to risks associated with the use of simplified models in chemistry in that such models may hinder students to learn higher level chemistry (Nahum et al., 2008; Taber & Coll, 2002; Bergqvist, 2017). It is therefore important that teachers using drama activities are aware of limitations of simplified models and act to provide students with opportunities to reflect on such limitations. In this way, the bodily models may serve as an anchor for more scientific descriptions and explanations (Taber & Coll, 2002; Taber, 2002), and provide a foundation for students to master the scientific discourse.

In conclusion, we observed a flow of transductions and transformations in the classroom that continually prompted each other and stimulated students to explore abstract non-spontaneous concepts- not prompted by the teacher. This is in line with Butler (1989) and Dorion (2009) who emphasize that one major benefit of using drama in science classrooms is that it allows students to openly learn from and with each other. Creative drama may provide students greater freedom in their semiotic work by providing a more open learning ecology (Cobb, Confrey, DiSessa, Lehrer & Schauble; 2003). In this study, we observed how students bodily mode prompted semiotic work from one student to another in an non-authoritarian environment. This flow of transductions and transformations may extend the functional potential of meaning-making and increase the potential for learning non-spontaneous chemical concepts in the chemistry classroom.

Reflections on tentative design principles for creative drama in chemistry education

The analysis of transductions and transformations of meaning in creative drama provides a basis for the formulation of tentative design principles on the design of creative drama, to teach chemical bonding in upper-secondary chemistry education. Below, we suggest principles that are important to consider in order to afford students' meaning-making of abstract non-spontaneous chemical concepts when implementing creative drama in chemistry.

1. Creative drama in chemistry should open up for students to use bodily mode in combination with a variety of other modes. Our results point to the importance of transduction of meaning for enhancing students' conceptual understanding of chemical forces. As teachers, we can provide a range of semiotics resources to students; including resources that are commonly used (e.g. notes, textbooks, mobiles and iPads), resources that are not so frequently used in chemistry teaching (e.g. colored paper, crayons, scissors, clothes pegs, etc.) and the students' bodies. When student groups work with tasks that make, for example molecules visible in the classroom in the form of bodily mode, it allows them to observe each other's creations, which can be enhanced by allowing students to take pictures of their molecules with iPads or mobiles. Hence, when students pose for pictures their bodily formations become visible in the classroom. Based on the pictures, the teacher and the students can discuss how chemical concepts are performed differently in the drama activity.

2. Creative drama in chemistry should enable students to engage in collective semiotic work.
Our results show that the interactions between the student groups were pivotal to enabling them to link the submicro and macro levels of chemistry. The semiotic work, in the form of transformations within the students' bodily mode, can be considered to strengthen the link between submicro and macro level. Hence, the students were given the opportunity to link groupwise bodily formations, representing separate molecules at the submicro level, to a collective whole-class bodily formation of a molecular grid structure, representing how molecules are organized on the macro level (e.g liquid water). It is therefore important to provide plenty of time to allow students to interact with each other, move between different states of matter, and talk about why they position oneself to one another the way they do.

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