Using the Schoolyard as a Setting for Learning Chemistry: A Socio-Cultural Analysis of Preservice Teachers' Talk about Redox Chemistry

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Abstract

The schoolyard as a setting for teaching and learning is rarely the focus of chemistry education research. Therefore, a chemistry unit combining activities in the classroom and the schoolyard was designed to support preservice teachers' (PSTs) learning of redox chemistry. This study was conducted to investigate the PSTs' talk about redox chemistry as they identified, photographed, and explained phenomena in the schoolyard (i.e., university campus). Video data were collected from six groups of PSTs from two different teacher education institutions in Norway. Videos from two groups were selected for deeper analyses: one with PSTs who had specialized in chemistry during their secondary education and one with PSTs who had not. The groups' talk was analyzed with respect to (1) the types of talk, (2) the levels of chemistry displayed in the talk, and (3) the schoolyard phenomena that triggered the content-related talk. The talk was mostly exploratory, and the PSTs connected sub-micro-level redox chemistry to macro-level phenomena. Moreover, the PSTs noticed several phenomena in the schoolyard that triggered chemistry-related talk. Although the talk that developed occurred differently in the two groups, this study indicates that the schoolyard can provide opportunities for learning chemistry for learners with different formal backgrounds in chemistry.

Graphical Abstract

Keywords

interdisciplinary/multidisciplinary, high school/introductory chemistry, inquiry-based/discovery learning, electrochemistry

Introduction

The aim of this study is to investigate the learning processes that may be involved when combining the classroom and the schoolyard as settings for learning chemistry, particularly redox chemistry. The study thereby addresses the need for chemistry education to relate basic chemistry to everyday phenomena.[1] Traditionally, chemistry education has been accused of being irrelevant for students' lives, consisting of isolated facts and a lack of transfer to everyday life, thus making students struggle to apply the knowledge when solving problems in other contexts.[2] Researchers therefore argue that the relevance of chemistry to everyday life needs to be emphasized and made explicit to learners when teaching chemistry.[3,4,5] One way to demonstrate the relevance of chemistry—and science in general—is to provide students with experiences of science in outdoor settings,[6] such as natural environments, science centers, and industrial sites.[6,7,8]

In Scandinavian countries, there is a long tradition of using the schoolyard and similar local environments as settings for teaching and learning multiple school subjects, including science.[9,10] Research indicates that the schoolyard and local surroundings provide a variety of learning experiences and outcomes, including enhanced learning of academic content, physical and psychological well-being, and increased motivation and interest in the topic.[11,12] Such outcomes are supported by allowing students to observe, identify, and compare phenomena, use their prior knowledge and experience, and engage in discussions both in the schoolyard and classroom.[7,12] However, examples of using outdoor settings to teach and learn chemistry seem to be lacking. One exception has been provided by Borrows,[13] who described a teaching design consisting of teacher-guided lectures in an outdoor setting. This contrasts with socio-cultural perspectives on learning, in which students learn by participating in discussions to make sense of phenomena.[14,15,] Thus, there is a need to introduce more and various socio-cultural perspectives of the learning processes that may occur when using the schoolyard and observing its associated phenomena to learn chemistry. In this study, the term *phenomenon* is used as a broad, collective term to describe natural and artificial objects (e.g., plants, buildings, statues), chemical reactions, and scientific processes (e.g., physical change).

The present study is inspired by the literature on outdoor education that builds on socio-cultural perspectives on learning in outdoor settings,[15,16] where learning is viewed as participation, meaning that students use their language to participate in collaborative interactions and discussions.[17] Accordingly, we designed and implemented a study of a chemistry unit using the schoolyard as a setting for learning basic chemistry in preservice science teacher education. The following two research questions are addressed:

1. What *types of talk* and *levels of chemistry* can be observed among PSTs during an activity identifying redox chemistry in the schoolyard?
2. What chemistry-related content emerge when the PSTs try to identify redox chemistry in the schoolyard?

The concepts *types of talk* and *levels of chemistry* are elaborated on in the following.

Theoretical Underpinnings and Analytical Frameworks

Socio-Cultural Perspectives on Learning Chemistry in the Schoolyard

Students’ opportunities for participation in learning in outdoor settings are influenced by several factors in the physical, social, and personal contexts.[16] In the *physical context*, the outdoor setting provides physical phenomena—natural and cultural—that students can use as tools for thinking and learning.[18] Thus, natural and cultural phenomena in the schoolyard are potential material tools for learning. The students’ learning potential is expressed through language during interaction with their peers; hence, it is influenced by the *social context*. [16,19] Thus, the social context allows students to use their language together to make sense of the scientific ideas and models that represent the physical phenomena.[20,21,22,23] Finally, the students’ use of language and their individual understanding of the science represented by the physical phenomena are influenced by the *personal context*.[16] This implies that learning chemistry in the schoolyard is influenced by the students’ prior knowledge and experiences of both the schoolyard and chemistry.

Socio-cultural oriented research has revealed that the type of discussion influences the opportunities for learning. Mercer[24] introduced three types of discourses to label small group talk according to their qualities: disputational, cumulative, and exploratory talk. Bungum et al.[25] built on Mercer's[24] work to categorize the productivity of small group discussions on physics among high school students. In this modified version, the *disputational talk* category was changed to *independent statements* to remove the focus on disagreements and instead to focus on PSTs not building on each other's statements. Furthermore, a fourth category, *confirmatory talk,* was included. Thus, the four types of talk identified by Bungum et al.[25] were independent statements, confirmatory talk, cumulative talk, and exploratory talk. *Independent statements* are evident when students talk without building on others' verbal contributions. *Confirmatory talk* is evident when students simply repeat or confirm their peer's statement. *Cumulative talk* happens when students build positively but uncritically on each other's utterances and construct a joint body of knowledge accumulated by individual contributions, such as repetitions, confirmations, and elaborations. Finally, e*xploratory talk* is recognized when students build critically but constructively on each other's ideas—for instance, by questioning and reasoning—to reach a decision or develop a common understanding.[25] According to Bungum et al.,[25] the four types of talk reflect an increasing level of sophistication, from independent statements and confirmatory talk, denoted as unproductive, to exploratory and cumulative talk, which are considered more productive in terms of interaction, with exploratory talk considered as the highest level. This typology of small group discussions is, in this study, applied to analyze PSTs talk.

Connecting Phenomena to Chemistry

As argued above, science in the schoolyard involves connecting physical phenomena to scientific ideas, models, and theories, and these connections are made visible through the use of verbal language. In chemistry, this requires students to move across the three levels of chemistry:[26,27,28]

- *Macro*—phenomena that can be observed.
- *Sub-micro*—using theoretical models at a particulate level that are developed to make sense of the observations.
- *Symbolic*—formulas, equations, etc.

However, students often struggle to build meaningful connections between the observable materials and phenomena at the macro level and the models generated to understand them at the sub-micro level.[29,30] This is also the case with redox chemistry, which is perceived as difficult to teach and learn, despite the fact that redox reactions are relevant in everyday life,[31] and comprise no more than electron transfer between particles.

Students struggle to use theory to interpret the everyday phenomena of redox chemistry because the teaching tends to emphasize algorithmic problems rather than understanding the environment and linking the concept to its applications.[32,33] The difficulties include classifying redox reactions,[33] understanding that oxidation and reduction are complementary reactions and the complex language related to oxidation and reducing agents.[31] The topic is further complicated by the use of up to four different definitions of redox reactions in chemistry education: the oxygen definition, the hydrogen definition, the electron definition, and oxidation numbers. The first three definitions only partly overlap, which creates difficulties in learning about redox reactions, since they must be used in the correct context. [31,34] For instance, students often believe that oxygen takes part in all redox reactions.[32,35] Students typically also struggle with the concept of oxidation numbers.[36] Despite De Jong et al.[33] recommending decades ago to remove the concept from school curricula, oxidation numbers are still taught in Norway and several other countries. Therefore, the difficulties students perceive might originate from how redox chemistry is taught and presented in written form.

Problems related to teaching and learning redox chemistry align with chemistry teaching in general, which often focuses on the sub-micro and symbolic levels without connecting these to the macro level.[30,37] Even though chemistry education requires learners to connect phenomena to scientific concepts, such connections do require a complex understanding of the concepts. Thus, Talanquer[30] argues that students should be given opportunities to explore real-life objects and events and build their own models to describe systems. In a recently proposed educational approach by Sarıtaş et al.[37] aiming at improving explanations across the macro and sub-micro levels, the authors suggest starting with observations at the macro level—searching for evidence of chemistry—before drawing preliminary conclusions through explanations at the sub-micro level. The model by Sarıtaş et al.[37] was developed for lab activities, but our study extends this, providing an empirical example of how the schoolyard can also be used to make connections across the macro and sub-micro levels.

Methods

The Schoolyard Chemistry Unit

This study is part of an action research project at two teacher education institutions in Norway focusing on the inclusion of outdoor education in the teaching and learning of chemistry. Two of the authors designed an outdoor unit about redox chemistry involving learning activities in the classroom and on the university campus (i.e. the "schoolyard" in this case) in line with the literature,[14,38] which they implemented with their PSTs and collected various types of data from. The purpose of the chemistry unit was to demonstrate the presence of chemistry in outdoor surroundings and how the schoolyard can be included as a setting for learning basic chemistry. The chemistry unit consisted of the following three activities:

1. An introductory activity that involved PSTs using their prior knowledge of redox chemistry to explain observed outdoor phenomena.
2. Hands-on practical outdoor activities for solving corrosion problems.[39]
3. Reflecting on the two activities in their role as future teachers.[40]

Here, we focus on the introductory activity within the larger chemistry unit (hereafter referred to as “the activity”). Specifically, the PSTs worked in small groups (3–5 per group) on the following tasks:

- Outdoors (15 min): Finding examples of redox reactions taking place on the university campus and documenting observations by taking pictures. (The PSTs could choose which phenomena to focus on.)
- Indoors (20 min): Discussing examples of redox reactions found during the outdoor activity, with reference to their pictures.
- Indoors (5 min per group): Presenting their pictures to the entire group and the explanations for the examples of the redox reactions found.

The topic of redox chemistry had not been discussed before the activity, and no examples of redox chemistry were given, as the aim was for the PSTs to use their prior knowledge. However, redox chemistry had been introduced in a previous course, with a focus on the four definitions of redox reactions.

Participants and Data Collection

Video data were collected from six small groups of PSTs (three groups from each teacher education institution), involving 22 PSTs who had all signed written consent forms to participate in the research project. All PSTs specialized in science education and had 30 ECTS credits in science education from a former course. Beyond this course, their prior chemistry knowledge varied greatly depending on their educational background from earlier schooling: some had no education in science after the age of 16; some had one or two years of chemistry specialization from high school; and some had prior university studies in science (which is rare for PSTs in Norwegian teacher education programs).

In each group, one PST carried a body-mounted video camera (GoPro), which captured the verbal discussions between the PSTs within the groups and their physical actions. This learning activity, which required the PSTs to document redox chemistry on the university campus, resulted in six hours of video data in total.

Data Selection and Analyses

The data from all six groups were viewed by two of the authors. From this viewing, it appeared that video data from two of the groups were incomplete due to technical issues and were thus excluded from further analyses.[41] Next, the videos from the four remaining groups were transcribed using NVivo12 software. During the transcription process, we noticed that interactive discussions were rare in two of the four groups. In one group, one of the PSTs got engaged in a longer discussion with the teacher, while the other PSTs remained passive. In the other group, the talk was dominated by the two PSTs with prior university studies in science and who, thus, were more knowledgeable and lectured for their peers as teachers. Because our study is informed by socio-cultural perspectives in which participation in discussions is central, the two aforementioned groups were omitted from further analyses, as the data had gaps that would not lead to meaningful answers to the research questions.[41]

The selection process resulted in video data from two PST groups that had collaborative discussions—one from each of the two universities. These two groups were the best illustrative cases for our research questions and are therefore presented in detail in this article. The two groups are hereafter referred to as Group A (pseudonyms: Eric, Martin, and Simon) and Group B (pseudonyms: Oscar, Rita, Andrea, Mona, and Erica). They differed in terms of their educational background, which was likely to have influenced their prior knowledge. The Group A PSTs had no prior studies in chemistry except for the course that they had taken one year earlier. By contrast, most PSTs in Group B had specialized in chemistry in high school and, hence, had been taught related content earlier. Despite differences in terms of educational background, the PSTs in the two groups did not approach their educator for guidance during the activity.

The transcripts from these two groups were analyzed in three steps. For research question 1, regarding the types of talk and levels of chemistry evident in the PSTs' talk, the transcripts were first subjected to socio-cultural discourse analysis.[24] More specifically, the PSTs' science-related talk was analyzed using Bungum et al.'s [25] modified version of Mercer's[24] typology of small group discussions described earlier: independent statements, confirmatory talk, cumulative talk, and exploratory talk. This analysis also resulted in the determination of the relative frequency of the types of talk across the small groups of PSTs, in line with the integration of quantitative aspects in qualitative socio-cultural discourse analysis.[42] The relative frequency of codes was calculated as the percentage of text assigned to the respective codes in relation to all talk. A distinction was made between the talk in the schoolyard (including PSTs moving back and forth) and the talk in the classroom. For the second aspect of research question 1, the PSTs' talk was analyzed with respect to the levels of chemistry (i.e., sub-micro, symbolic, and macro).[26]

For research question 2, which focused on the content of the PSTs' talk, the transcripts were analyzed with respect to the chemistry-related content. Specifically, we noted what phenomena the PSTs identified and what science-related discussions emerged from these phenomena, regardless of whether they were directly connected to chemistry or related to other sciences or technology.

Limitations of the Study

Selecting two groups can be seen as a limitation of this study, making it difficult to make generalizations, as only a few illustrative examples can be presented.[42] However, this was the most reasonable choice, as it allowed for an analysis in line with the aim and theoretical framing of the study and allowed us to take a closer look at the details.[41] It can thus be argued that the two selected groups provided information that was sufficient for the aim and theoretical framing of the study.[43]

Procedures were applied to enhance the qualitative reliability and validity of the study. To ensure reliability (i.e., ensuring consistency of the analysis across researchers),[44] two of the researchers coded the transcripts and videos independently before comparing and revisiting the analysis. Inter-coder agreement varied from 72–92% with regard to individual codes after independently coding one group, to 88–98% after discussing limitations of the individual codes and coding both groups independently. The remaining disagreements were solved through discussions until agreement was reached, enabled by using video data, which allowed the researchers to systematically revisit the original files along with the coding and transcriptions, and collaborate on the analysis and interpretations.[45]

Findings

The findings are presented according to the methods of analysis. First, findings from the analyses of *types of talk* and *levels of chemistry* (sub-micro, symbolic, and macro) are presented, illustrated by detailed analyses of talk excerpts. Thereafter, the analysis of *content-related talk* that emerged when the PSTs identified phenomena in the schoolyard is presented.

Types of Talk and Levels of Chemistry in the Two Groups

Groups A and B spent 10 and 14 minutes in the schoolyard, respectively, and both groups spent approximately 20 minutes on the follow-up classroom activity. The categorization of the types of talk showed that exploratory talk prevailed in both groups. As shown in Figure 1 below, Group B showed a high level of exploratory talk in both the classroom and outdoor settings. By contrast, Group A varied greatly in their types of talk across settings. Outdoors, their talk varied between confirmatory, cumulative, and exploratory talk, while exploratory talk prevailed during the part of the activity carried out in the classroom. These findings are elaborated in the following, together with the level of chemistry found in the PSTs' talk.

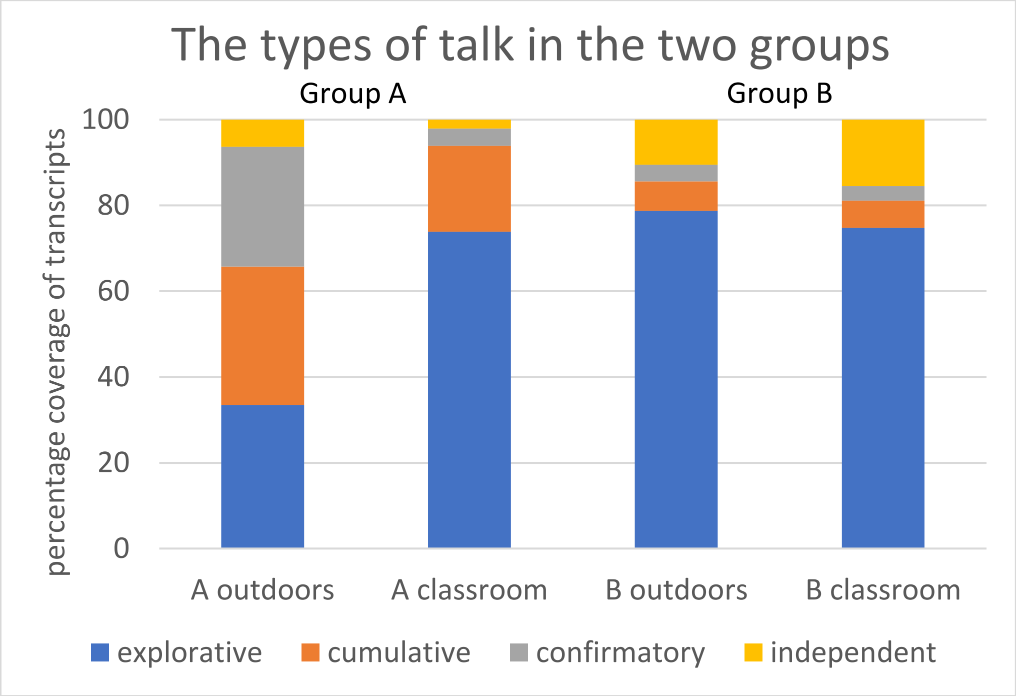

Figure 1. Findings from the analysis of types of talk in Groups A and B in the schoolyard and in the classroom. The y-axis shows the distribution of the different types of talk.

Group A: From cumulative to exploratory talk

The following example is chosen to illustrate how Group A talked about the outdoor phenomena in the schoolyard. It began when the PSTs noticed an electric bike in a bike shed outdoors (see Figure 2), which triggered a reflection on batteries in electric bikes, as presented in Excerpt 1A:

Figure 2. Chest-mounted camera view: Group A discussing batteries.

Excerpt 1A:
Martin (points at an electric bike): Battery!
Eric: Yes! (looking at the bike)
Martin: What kind of battery is it?
Eric: Powerpack 500.
Martin: We do also have a battery in the cell phone. A lithium battery.
Eric: Yes. I would guess this is lithium as well. It is most common.
Martin: Hmm.

In this excerpt, the electric bike becomes a tool for thinking about batteries. Eric and Martin focus on macro-level redox chemistry, and Eric supports and builds uncritically on Martin's suggestions, which makes it an example of cumulative talk.

The discussion from Excerpt 1A continued in the classroom when the PSTs looked through their pictures depicting evidence of redox chemistry. Explaining that the battery includes redox reactions, Eric and Martin tried to develop a shared understanding of how batteries work, and, at the same time, trying to grasp the concepts of reduction and oxidation at a sub-micro level. This type of challenge evoked the need to consult the textbook or the Internet in their discussions as seen in the following excerpt:

> Excerpt 1B:
> Eric: Battery, yes. What happens inside it?
> Martin (looking at the textbook): I struggled to understand.
> Martin (quoting the textbook): "Lithium battery. Lithium as a negative electrode. Oxidation of lithium to lithium plus."
> Martin: So, lithium gives away electrons?
> Eric: Yes. Lithium becomes lithium plus and gives away, so lithium oxidizes … no reduces?
> Martin: No, reduces? No, oxidizes.
> Eric: No, reduces. It gives away. That's why it is reduced …
> Martin: But isn't it … I wonder whether it is the opposite … Reduction is to gain electrons and oxidation is to give away.
> Eric: Ahh, that's right.
> (…)
> Simon: What did you say? It oxidized?

As seen in Excerpt 1B, Martin quoted the textbook to make sense of oxidation and reduction at a sub-micro level with a focus on electron transfer, which led to questioning and critical reflection in line with exploratory talk.

Considering the talk across the two settings, as exemplified by Excerpts 1A (in the schoolyard) and 1B (in the classroom), the discussion that was initiated by the PSTs' observation of the electric bike outdoors continued in the classroom. Hence, the macro-level observation of the electric bike served as a tool for a sub-micro-level exploration of oxidation and reduction in the classroom, leading to further meaning making. However, some of the utterances in Group A's talk are incomplete, making it unclear which definition they are referring to and, hence, how they understand the definitions. They also use the words "reduction" and "reduces" interchangeably, despite their opposite meaning. However, in presenting their findings at the end of the activity, they used the words correctly.

In summary, the discussions seen in Excerpts 1A and 1B characterize the talk in Group A. Their talk in the schoolyard was mostly cumulative and at the macro level, whereas their talk in the classroom was exploratory and included redox chemistry at the sub-micro and symbolic levels, enabled by their use of authoritative sources.

Group B: Exploratory talk across schoolyard and classroom settings

As opposed to Group A, the talk in Group B was primarily exploratory, both in the schoolyard and in the classroom (see Figure 1). The *independent talk* that occurred quite frequently, was due to one group member's individual brainstorming to find even more examples of redox chemistry. Otherwise, all group members in Group B participated actively in the discussions, although to different degrees throughout the activity.

One example of Group B's exploratory talk was a discussion between two PSTs about the difference between rust and verdigris, which started on their way down the corridor, before they entered the schoolyard:

> Excerpt 2A:
> Oscar: The first thing that comes to mind is rust, and then I think …
> Rita: And verdigris.
> Oscar: Isn't that the same?
> Rita: Well, verdigris is on another metal than rust.

> Oscar: I see.
> Rita: Verdigris is on copper.
> Oscar: True. But isn't verdigris just the notion of rust on copper?
> Rita: I didn't think so?
> Oscar: I'm not sure. I think, actually … It's quite a lot of things that can be redox reactions actually.
> Rita: That's for sure.
> Oscar: We just have to think broadly. The point is just a change in the oxidation number, right.

In this excerpt, the PSTs introduce knowledge that they anticipate being relevant in the schoolyard, already on their way out of the classroom. Rita starts with the correct macro-level explanation of verdigris, but she gets a bit insecure when Oscar challenges her understanding. The excerpt is the beginning of a longer discussion, where they challenge each other's ideas to agree on a shared understanding about the difference between rust and verdigris, which correspond to exploratory talk. The discussion continued as soon as they entered the schoolyard and found rust, after which Rita tested her explanation of the difference between rust and verdigris on a third group member, Andrea:

> Excerpt 2B:
> Someone shouts out as they enter the schoolyard: I see rust!
> Andrea: Rust is a really slow … A really slow redox reaction.
> Rita: And a verdigris coating is just another word for rust on copper?
> Andrea: Verdigris coating? Like … Verdigris?
> Rita: Yes, the green stuff …

As can be seen in Excerpt 2B, Rita still struggles to understand corrosion, and in this example, she adopted Oscar's incorrect explanation about verdigris being rust on copper. The group leaves this discussion for some time but returns to the topic, while still being outside, after discussing other redox reactions. The following discussion emerged:

> Excerpt 2C:

> Oscar: Ehh … Copper … I mean copper as rust … I'm not sure … Iron can at least become rusty. And copper can. Right?
> Rita: But it doesn't become rust. It doesn't become iron oxide.
> Andrea: Because it becomes verdigris, doesn't it?
> Oscar: No, that's true. But is it simply that we call it that? Both things are called … Oxidized copper is verdigris and oxidized iron is rust?
> Rita: Yes.

As seen in the exploratory talk in Excerpt 2C, Rita's explanation had evolved in the meantime, helping both herself and her group members to conclude with the correct scientific explanation.

Considering Excerpts 2A, 2B and 2C together, the exploratory talk leads the PSTs to collaborate about constructing their knowledge of corrosion throughout an 8-minute timespan for the activity. In this process, they also make connections between the observable phenomena at the macro level and explanations at a sub-micro level, concluding that the difference lies in the chemical composition of rust compared to verdigris.

Even though exploratory talk prevailed in Group B in both the schoolyard and the classroom, the PSTs did not always link the macro to the sub-micro and symbolic levels. In the schoolyard, they made several links, such as referring to oxidized iron in Excerpt 2C, which enabled them to jointly construct their understanding and reason about the corrosion concept. The PSTs also had some explanations referring to the oxygen model and oxidation numbers, such as when attempting to apply their knowledge of redox chemistry to reason about other phenomena, stating that assigning oxidation numbers would solve the task. However, on other occasions, the group focused on macro-level substances and reactions, deciding on whether they were redox reactions or not, and not necessarily explaining why. An example is shown in Excerpt 3 from Group B while observing the flowerbed in Figure 3 just after entering the schoolyard:

Figure 3. Chest-mounted camera view: Group B discussing redox chemistry in a flowerbed on campus.

> Excerpt 3:
> Oscar: Are there any redox reactions in plants?
> Rita: I'm bad at redox reactions.
> Oscar: […] Listen, cellular respiration ... That's a redox reaction and a foundation for our …
> Andrea: Is it?
> Oscar: Yes, it is. […] It is a combustion and combustions are redox reactions.
> Erica: […] Photosynthesis, would that be a redox reaction, too, then?

In this excerpt, they agreed on photosynthesis being a redox reaction, based on the reason of the processes being "opposite," and without discussing at a sub-micro level. Another issue that can be observed from this excerpt is that, at this stage of the activity, they were hesitant about its relevance to redox chemistry; this is exemplified by Rita's utterance, "I'm bad at redox reactions."

Content of Chemistry-Related Talk

When the PSTs noticed phenomena in the schoolyard, such as statues, plants, cars, and cigarettes, it triggered chemistry-related discussions. Specifically, the PSTs mentioned concepts like photosynthesis, cellular respiration, the greenhouse effect, the decomposition processes and corrosion. Excerpt 3 above is one example of how an observation of a phenomenon in the schoolyard was used as a starting point for talking about scientific concepts, where they included both cellular respiration and photosynthesis, based on the flowerbed. Figure 4 provides an overview of scientific concepts that were mentioned by the PSTs in the two groups in relation to the various phenomena the PSTs observed in the outdoor setting. As can be seen from the figure, the activity gave the PSTs opportunities to discuss various concepts related to redox chemistry and make connections both within and between the scientific disciplines.

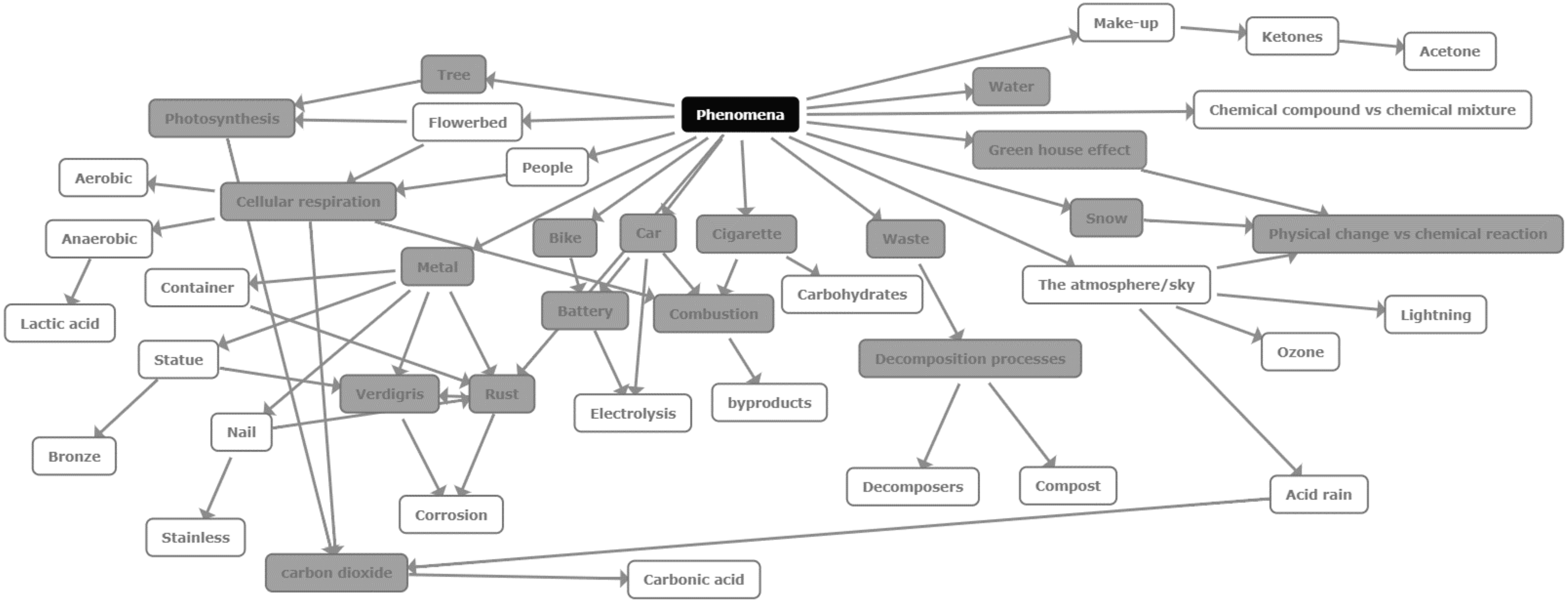

Figure 4. Connections between phenomena and scientific concepts used by the PSTs. Boxes marked in gray were mentioned by both groups, whereas boxes in white were only mentioned by one group. The concept redox chemistry is not included in the figure, since it was the topic of the activity.

Arrows in Figure 4 indicate how the discussions evolved, illustrating that the PSTs' observation of a phenomenon started a discussion that ended in a scientific concept, such as the discussions above starting from rust, a battery and a flowerbed. A discussion often emerged by establishing a connection to former content knowledge, before delving further into the reactions and why it would be legitimate to assume these to be redox reactions. For example, based on the flowerbed in Figure 3, the PSTs in Excerpt 3 discussed both cellular respiration and photosynthesis, as visualized in Figure 5 below. When discussing the picture of the flowerbed in the classroom, the PSTs further connected the picture to aerobe and anaerobic respiration.

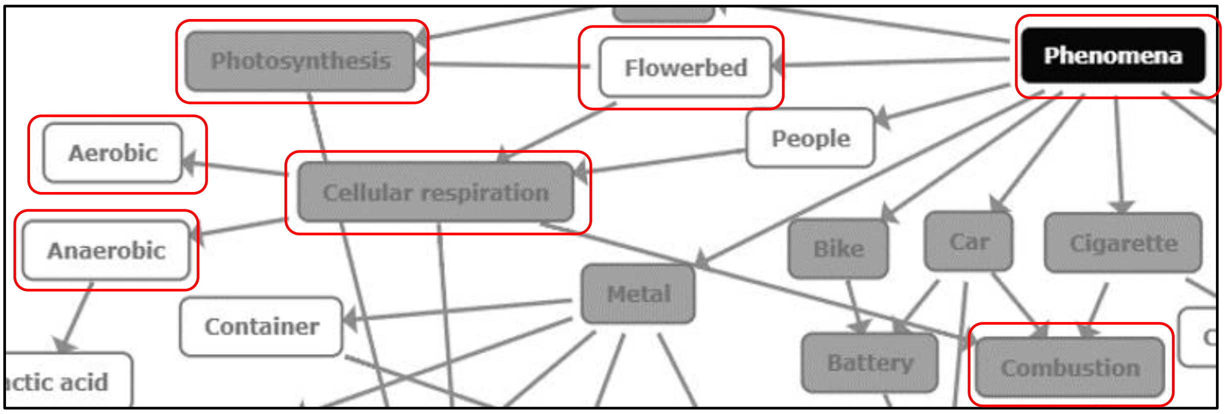

Figure 5. Zooming in on Figure 4 to show the connections between phenomena and concepts

Discussion

The aim of this study was to investigate the learning processes that may be involved when combining the classroom and the schoolyard as settings for learning chemistry and increasing learners' awareness of chemistry in their cultural and natural outdoor surroundings. The findings showed that the PSTs were able to identify various examples of redox chemistry in phenomena in the schoolyard (in this case, the university campus) and discuss the chemistry related to the phenomena, in line with their assignment. The PSTs' talk was often exploratory and cumulative and involved connecting macro and sub-micro levels of chemistry. The prevalence of exploratory and cumulative talk indicates that the discussions were productive in terms of interaction,[25] while the findings from the level of chemistry also indicate that the discussions, to a large extent, were productive in terms of chemistry content, since connecting levels of chemistry is a challenge for learners.[30] Based on these findings, we will now discuss the potential for combining the classroom and the schoolyard as settings for supporting productive learning processes in chemistry.

As displayed in Figure 4, the activity enabled the PSTs to discuss various phenomena, such as plants, cars, and building structures. This may have supported the PSTs in transferring their knowledge of chemistry to everyday phenomena. Besides chemistry-related concepts, the discussions also contained several links to other scientific disciplines, such as physics and biology. Hence, the activity provided an opportunity to consider chemistry concepts in relation to other scientific disciplines, which depict chemistry as “a bridge between various fields of knowledge” (p. 1135).[46] From a socio-cultural perspective, this may suggest that the physical phenomena in the schoolyard were used as mental tools to mediate interactive discussions between the PSTs[16,47] and created opportunities for both discussing chemistry and linking chemistry to other scientific disciplines—connections that would not be easily available in the classroom or laboratory setting.[38]

Even though utilizing phenomena in the schoolyard as tools for discussion and learning is dependent on the PSTs’ prior knowledge,[16] the PSTs were able to do so in various examples, despite Groups A and B differing in prior knowledge in terms of their formal background in chemistry. Nevertheless, the groups differed in their ways of discussing redox chemistry displayed by the schoolyard phenomena, particularly with respect to *how* they connected the levels of chemistry.

Group A, whose group members had little formal chemistry education prior to the outdoor chemistry unit, talked more exploratory in the classroom than in the schoolyard. As exemplified with Excerpts 1A and 1B, the PSTs observed and discussed a phenomenon on a macro level in the schoolyard, before continuing their discussion of the phenomenon on a sub-micro level in the classroom. The sub-micro-level discussions related to the concepts of reduction and oxidation were enabled by their textbook use, which exemplify how the use of authoritative sources can play an important role in supporting learners in linking observations of phenomena and experiences to scientific ideas.[20,22]

In contrast to Group A, the Group B talk was exploratory in both the schoolyard and classroom, and these PSTs rarely consulted authoritative sources to make sense of the phenomena. Rather, the PSTs used each other as information resources, enabling them to co-construct their understanding of the scientific concepts represented by the phenomena. For instance, their discussion of rust versus verdigris in Excerpts 2A–C reveal that they negotiated the meaning of verdigris until they reached a mutual understanding founded in a reasonable sub-micro explanation. Thus, Group B’s PSTs were able to engage critically with each other’s contributions to reach a conclusion through talk that was productive both in terms of interaction[25] and chemistry-related content.[30] On other occasions, Group B’s PSTs built their reasoning at a macro level and did not elaborate on the sub-micro explanation after having identified the redox reactions. For example, when a PST in Excerpt 3 suggested that photosynthesis had to be a redox reaction since cellular respiration is a redox reaction, the group members agreed without further reasoning than these two processes were “opposite.” Agreeing on these processes being opposite without further explanation suggests that the PSTs were able to apply their knowledge from previous science education[23] without having to specify the sub-micro-level. However, the PSTs could have been challenged to justify their statement of the processes being opposite; for example, the teacher educator could have followed up in the classroom afterwards. The guidelines for the activity could also have focused more on explaining and not only on finding examples of redox chemistry.

Considering the discussions of Groups A and B together, it can be proposed that outdoor chemistry—or schoolyard chemistry in this case—provides opportunities for productive discussions about redox chemistry on the macro and sub-micro levels both for learners whose formal background in chemistry was limited and for those who have a more extensive formal background in chemistry. The task of identifying redox chemistry in the schoolyard allowed the PSTs to adopt a strategy that aligns with the educational approach by Sarıtaş et al.,[37] who suggested starting with observations at the macro level before drawing preliminary conclusions at the sub-micro level. The approach is similar to our findings in both groups, but particularly in Group A, where the PSTs discussed the meaning of the concepts at a sub-micro level assisted by their textbook after having observed phenomena in the schoolyard.

The PSTs in the two groups chose to work independently throughout the activity and tried out their knowledge to create explanations of the observed phenomena, which can be viewed as tentative trials of identifying observations and interpreting them more scientifically.[48] Other research has shown that teachers can inhibit students' exploratory discussions when trying to connect scientific concepts to observations.[20] Thus, it is important to provide such opportunities in a way that allows productive discussions among students in the schoolyard, as opposed to the approach guided by the expert teacher.

However, the topic of redox chemistry still remains difficult to learn, and this was also evident in our groups. For instance, Group A's PSTs used the words reduces and reduced uncritically in Excerpt 1B, which relates to the complex language used in redox reactions, where nearly identical words explain opposite processes.[31] Group B's PSTs also expressed uncertainty on some occasions (such as in Excerpt 3) and needed to argue to make sense of whether a phenomenon represented a redox reaction or not. The finding that the PSTs found the task challenging is in line with De Jong et al.[33] who listed classifying reactions as a learning problem within redox chemistry. The challenge was also described in another study in which the PSTs from one of the institutions, including those in Group B, were asked to reflect on their learning experiences during the outdoor chemistry unit.[40] The PSTs seemed to find the task of identifying redox chemistry challenging because they realized that their prior understanding was superficial, even if they had specialized in chemistry in high school. Questions can thus be raised about how redox chemistry is taught and learned, both in the teacher education program and high schools, and whether the PSTs are suitably prepared to connect the sub-micro and macro levels, which is a typical problem for chemistry teaching.[30]

The activity in this study was included as an introduction to the topic of redox chemistry and aimed to raise the PSTs' awareness of their prior knowledge of redox chemistry by connecting it to phenomena observed outdoors. From the group discussions, it could be interpreted that the task developed a desire to learn among the PSTs, and that they were able to follow up in the classroom due to the proximity of the two arenas. Nevertheless, the challenges that both groups experienced lead us to question the preparation of the PSTs for this activity and whether school and higher education in Norway still focus too much on instrumental approaches to learning basic chemistry (such as oxidation numbers).

Conclusions and Implications for Chemistry Teaching

From our findings, it can be concluded that asking students to identify evidence of redox chemistry in a schoolyard setting can provide tools that facilitate productive discussions (i.e., cumulative and exploratory talk) and, hence, productive learning processes, regardless of their formal background in chemistry. These conclusions are based on a detailed investigation of discussions that occurred among two small PST groups and provide insight into the learning processes that might occur when the schoolyard is used as a setting for learning chemistry and challenging students to observe chemistry in everyday phenomena.

This study shows that using the schoolyard to learn chemistry can contribute to making sense of chemistry across levels, which is particularly important given that chemistry teaching in general rarely connects the sub-micro and macro levels.[30,37] As this linking of levels did not occur explicitly and automatically in all instances, directly asking the PSTs to explain the phenomena on the different levels may be important for enabling them to do so. Such explicit prompts for discussion could also create more opportunities for participation since such structures could act as scaffolding for the PSTs' involvement and learning.[49]

Providing outdoor education experiences during teacher education has been shown to be critical for supporting PSTs' ability to use the schoolyard as a setting in their future teaching of chemistry.[7] Experiencing schoolyard chemistry may therefore be important for enabling PSTs to connect the two chemistry levels both for themselves and their future students.

Although this study was conducted with PSTs during teacher education, the topic and, hence, the activity, is transferable to teaching and learning about redox chemistry in high schools. The activity where learners discuss phenomena outdoors is also transferable to other sciences. Thus, further research could investigate how high school students are able to identify and discuss science concepts in the schoolyard and could also include a pre- and posttest design to capture the individual learning outcomes of the participants.

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