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Student teachers' problem-based investigations of chemical phenomena in the nearby outdoor environment

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Learning science outdoors can enhance the understanding of theoretical scientific content taught in the classroom. However, learners are rarely afforded the opportunity to go outdoors to learn chemistry. This study investigates how problem-based learning outdoors can facilitate the understanding of basic chemistry in teacher education. A teaching unit was designed according to which student teachers at two Norwegian universities were asked to examine and identify corroded metals in the nearby outdoor environment and propose solutions to avoid this corrosion. Video data from this task were collected by using chest-mounted cameras for four groups of student teachers (N = 17). A thematic analysis of the videos yielded four themes related to the student teachers' use of content knowledge and experimental competence. Based on these findings, three learning opportunities were deduced for how the nearby outdoor environment allows learners to use everyday phenomena for learning basic chemistry. First, the availability of different corrosion incidents allowed the student teachers to choose and solve one of interest to them. Second, the proximity of the outdoor location to the classroom enabled the seamless continuity of discussions when switching between the learning arenas, and allowed for different approaches to solve the task. Third, being asked to conduct analyses outside customary laboratory routines led to an unexpected awareness of health and safety issues among the student teachers, indicating that outdoor chemistry is an overlooked opportunity for teaching these.

Introduction

Recent years have witnessed a spurt of public interest in chemistry-related problems in the outdoor environment, ranging from plastic pollution and climate change to renewable energies and mining. However, with such exceptions as the context- and problem-based approaches discussed below, basic chemistry education in school still tends to focus on an introduction to the academic field of science, rather than the everyday experiences of learners and general education (Talanquer, 2013; Freire *et al.*, 2019). As a consequence, learners may perceive chemistry as being difficult and irrelevant to their daily lives (Broman *et al.*, 2011; Stuckey *et al.*, 2013; Childs *et al.*, 2015). One way to gain a better understanding of chemistry and make it more relevant is to allow learners to engage with the discipline as it is related to products and phenomena in everyday life (Mandler *et al.*, 2012; De Jong and Taber, 2014; Tarkin and Uzuntiryaki-Kondakci, 2017). This approach is called context-based or problem-based learning, depending on its focus. Context-based learning embeds the learning of a chemical concept into a meaningful context for the learner, whereas problem-based learning can be seen as a subset of context-based learning that starts out with a problem focus (Gilbert, 2006; Kelly and Finlayson, 2007; Günter and Alpat, 2017; Sevian *et al.*, 2018). Despite the prevalence of chemistry-related outdoor problems in daily life, context- and problem-based approaches are often taught in the classroom or the school laboratory (Overton *et al.*, 2013; Ayotte-Beaudet *et al.*, 2017; Sevian *et al.*, 2018). Hence, there is a need to explore how problem-based learning in chemistry can be carried out in settings outside the classroom because outdoor learning has received less attention in research on chemistry education (Ceci, 2015; Ayotte-Beaudet *et al.*, 2017; Höper and Köller, 2018; Borrows, 2019).

Research in other fields of science education, such as biology and environmental sciences, supports the above argument as it has been shown that settings like nature, parks, schoolyards, and other urban and rural environments can enhance the learners' cognitive, affective, and social competence (Dillon *et al.*, 2006; Fägerstam, 2014; Fiennes *et al.*, 2015; Ayotte-Beaudet *et al.*, 2017). Outdoor learning may also help

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learners develop more environmentally friendly behavior (Sandell and Öhman, 2010; Jegstad *et al.*, 2018).

This study investigates how problem-based learning in the nearby outdoor environment can facilitate the learning of basic chemistry in teacher education. It is based on the Scandinavian tradition of outdoor education, known as *uteskole*, in which teachers and students use the local outdoor environment to teach and learn the curriculum, respectively (Fägerstam, 2014; Waite *et al.*, 2016). This is implemented within normal teaching lessons by the teacher. Hence, *uteskole* corresponds to such terms as investigative fieldwork or "embedded on-site curricular outdoor learning" (Waite, 2020). *Uteskole* differs from informal concepts like adventure learning, outdoor play, and "*forest schools*" because these approaches tend to focus on a holistic development of the learner, and are only loosely connected to school curricula (Waite, 2020). It also differs from traditional field trips far away from the school ground, which often are guided by external experts, and are not rooted in the individual interest of the learner (Beames and Ross, 2010; Fägerstam, 2014).

The nearby outdoor environment provides multiple opportunities for exploration of everyday phenomena with which the learners are familiar, thus making the learning of science more meaningful by building on prior knowledge and experiences (Beames and Ross 2010; Popov, 2015; Ayotte-Beaudet *et al.*, 2017). From the perspective of teaching, using the nearby outdoor environment addresses organizational challenges, including those related to cost and time, that often inhibit outdoor teaching to allowing for the more frequent use of the outdoor environment (Fägerstam, 2014; Ayotte-Beaudet *et al.*, 2017; Remmen and Frøyland, 2017).

Insights gained by teaching and learning about chemistry in nearby outdoor environments have occasionally been acknowledged in the literature. Borrows (2019) developed chemistry walks, similar to traditional field trips in biology or geology, where the educator explains materials and chemical reactions that the learners should observe outdoors, such as acidification, crystals, metals, and corrosion. Alternatively, learners were more actively encouraged to search for and observe chemistry-related phenomena in the outdoor environment by themselves (King and Glackin, 2010; Borrows, 2019). A common feature of these efforts is that chemistry is discussed, but not experimentally examined in such a context. When chemical analyses are included in outdoor teaching, this seems to be in the context of environmental science, and not as part of basic chemistry curricula (Fägerstam, 2014; Stern *et al.*, 2014; Ayotte-Beaudet *et al.*, 2017). This also applies to teacher education, where Engl and Risch (2016), and Höper and Köller (2018) have shown how student teachers can conduct analyses outdoors by combining biology and organic chemistry.

Still missing from the literature is empirical research on experimental outdoor activities as a part of learning basic chemistry. Therefore, this article examines the potential for including chemical analyses of a phenomenon in a nearby outdoor environment. A problem-based teaching unit was designed in which student teachers were expected to learn about corrosion by finding examples on the university campus and propose solutions after identifying the metals involved. Incorporating experiences in teacher education, can help student teachers relate to the outdoor environment and make them more willing to teach outdoors in the future (Blatt and Patrick, 2014; Popov, 2015; Barrable and Lakin, 2020).

This study seeks to answer the following research questions:

(1) *How do student teachers use knowledge in chemistry while solving a problem-based task on outdoor corrosion?*

(2) *How do student teachers deal with the experimental component of solving a problem-based task on corrosion outdoors?*

To address these research questions, groups of student teachers were equipped with chest-mounted video cameras that recorded their discussions and actions.

Learning chemistry outdoors

Exploring the potential for including phenomena from nearby outdoor environments requires us to consider theoretical perspectives on learning in general and those on chemistry in particular. As this study is based on a problem-based task with first-hand learner-centered experiences, it can be related to "experiential learning" (Fägerstam, 2014; Waite *et al.* 2016), which draws on perspectives from Dewey, Lewin, and Piaget (Kolb, 2014). Experiential learning focuses on the process of learning in particular situations. The continuous learning process is driven by an interplay between *concrete experiences* and *reflective observations* on these experiences, based on individual background knowledge (Kolb, 2014). In particular if the experience differs from the given understanding of a phenomenon or an object, the learner can develop new ideas or modify abstract concepts. Trying out what has been learned, then, leads to new experiences (Kolb, 2014). These processes are mediated by language, and become visible and influenced through dialogue with others, which makes interactions in groups important (Waite and Pratt, 2017).

If experiential learning includes outdoor learning, it is related to place-based education (Waite and Pratt, 2017). A place is a physical location, for example, in the immediate surroundings of the classroom (Semken *et al.*, 2017). As they familiarize themselves with this environment, the place has the potential to motivate the learner, and to help connect scientific concepts and practices to the local context as well as other disciplines (Waite and Pratt, 2017). Thus, it is more than simply the observable physical features; the place is constructed socially and dynamically over time (Semken *et al.*, 2017). Its meaning for the learner evolves through individual activities as well as through group interactions (Beames and Ross 2010; Popov, 2015).

The complexity of outdoor places means that the phenomenon, which the learners are supposed to work with, might not be as visible to the learner as it would when presented pedagogically adjusted in the classroom (Popov, 2015). This is especially important in learning chemistry because it requires that the learners observe, examine, and interpret visible phenomena by applying knowledge of chemistry to link observations to theory (Scott *et al.*, 2011; Höper and Köller, 2018).

The formation of successful links between the visible phenomena and their explanations through the invocation of invisible particles and processes includes reasoning across all three levels of chemistry (Talanquer, 2011; Gkitzia *et al.*, 2020): the macro- (*i.e.*, that which can be observed through the human senses or instruments), submicro- (*i.e.*, theoretical models developed to make sense of observations), and symbolic levels (*e.g.*, formulae).

Within a group of learners, strategies for approaching a phenomenon or a problem may vary considerably between learners. Overton *et al.* (2013) distinguished among three types of learners with respect to problem-solving abilities in chemistry:

• Experts – They can identify strategies to solve the problem, generate the appropriate data, and evaluate their approach.

• Novices – They are often unable to address the problem in a systematic way or generate their own data owing to a lack of relevant background knowledge.

• Transitional – They choose different strategies, a mixture of the above two types.

This division is also relevant in laboratory work, where learners are often engaged in either confirming or developing specific content independently of their level of understanding.

Incorporating an experimental component into problem-based learning can provide deeper learning experiences that foster content knowledge as well as practical and transferable skills (Belt *et al.*, 2002; Kelly and Finlayson, 2007; Smith, 2012; Günter and Alpat, 2017). However, developing experimental competence is a complex process. According to Bruckermann *et al.* (2017), experimental competence comprises procedural aspects, practical skills, and the use of appropriate models geared toward specific content and the related subject-specific knowledge. This is why Abrahams and Millar (2008) have urged teachers to critically evaluate the learning effect of practical work. Kelly and Finlayson (2007) have argued that experiments, fully integrated into a problem-based approach, allow for meaningful links to appear, and can contribute to the learning process. In this study, practical work is used as an integral part of the problem-based task, meaning that outdoor analyses are necessary for solving the problem. This is elaborated in the next section.

Methods

This section provides details of the teaching unit, the participating student teachers as well as the methods used for data collection and analysis.

The teaching unit

The teaching unit was designed to support student teachers in developing their understanding of corrosion in the nearby outdoor environment. It was developed based on ideas on teaching chemistry outdoors proposed by Höper and Köller (2018), and recommendations for outdoor learning in the Scandinavian tradition, such as students solving an authentic problem, and alternating between indoor and outdoor settings (Remmen and Frøyland, 2017).

The teaching unit is described in Table 1 and was implemented by two of the authors at their respective universities (hereinafter referred to as Universities A and B). It was part of an action research project focusing on the inclusion of outdoor environments in chemistry education. Before being presented with the authentic problem of this study, the student teachers were engaged to recall basic principles and concepts of redox chemistry from a previous science course by finding instances of redox reactions in the open-air campus (see Jegstad *et al.*, in review).

Corrosion was chosen as the authentic problem in order to apply and elaborate the basic knowledge about redox chemistry in a new context. The student teachers were presented the following task, which allowed them to choose the specific objects themselves, to examine why corrosion occurs, and how to prevent it:

The University is struggling with corrosion on metal surfaces. Pick a specific surface and give suggestions on how the maintenance department can solve this problem.

To solve the problem, the student teachers had to start by verifying the nature of the corroded metals by using modified colorimetric water-quality test kits outdoors (*e.g.*, VISOCOLOR ECO Iron 2; MQuant Zinc), as shown in Fig. 1. The kits are designed to measure concentrations of metal ions in water, and we added a step-by-step guide on the procedure to extract samples of metal ions from solid surfaces by using a cotton swab, moistened with diluted HCl. Tests were available to

Table 1 Overview of the teaching unit involving outdoor and indoor activities. Columns A and B denote the approximate times allocated for the student teachers to work on these activities in Universities A and B, respectively

		University	
Setting	Teaching sequence	A	B
Classroom	The teacher introduces the concept of corrosion and metal surfaces as an authentic problem on campus	10 min	10 min
Outdoor	Student teachers work in groups, using test-kits to detect metals in objects found around the university campus; the teacher gives individual advice during group work	30 min	40 min
Classroom	Student teachers continue group work, use test-results to solve the authentic problem and prepare a written proposal, which includes an explanation of the corrosion processes on submicro-level	40 min Letter	90 min Poster
Classroom	Student teachers present and discuss results of group work (letters/posters) in whole class; the teacher gives feedback	30 min	30 min

Fig. 1 A typical situation during the outdoor sequence. Group 3 found corrosion and used the modified test-kits directly outdoors to find out more about metals in the corroded construction. Here, by testing for iron and zinc-ions.

identify iron, copper, zinc, nickel, and aluminum; for detailed description of the test-methods, see Schwedt (2015). The handling of the samples was explained in the classroom, including advice to always use safety goggles and other precautions according to the step-by-step guides, which followed the test-kits. The student teachers were given time to get acquainted with the procedures and gather all the necessary equipment before conducting the analyses outdoors. They were allowed to use their smartphones for taking pictures to document the corrosion and test-results for their posters and letters.

In the end, after analyzing the corrosion incidents and proposing solutions, they presented their conclusions to their peers. This presentation gave the teacher a possibility to correct misconceptions and discuss missing content of the topic and the proposed solutions.

Data collection, selection, and participants

Video data from the student teachers' conversations and actions throughout the teaching unit were collected by chest-mounted video cameras on one person per group. The video cameras captured learning processes from the participants' perspective, which allowed researchers to conduct in-depth analyses (Frøyland *et al.*, 2015). Student teachers in six groups consented to the research project, but due to technical issues, videos from two groups were excluded from the analysis. Video data from the four remaining groups (two groups from each university for a total of 17 student teachers) yielded approximately 8 hours of video footage for the analysis.

All participants were enrolled in an integrated master's program in pre-service teacher education, preparing for a career teaching at the upper-primary and lower-secondary levels (grades 5–10, pupils aged 10–16 years). They were educated in a combination of two school subjects, most of them in science and mathematics, while two student teachers combined science with languages. This was the second science education course in the teacher education program, following a course of 30 ECTS (European Credit Transfer and Accumulation System) credits on a general introduction to science. In the first course, redox reactions were introduced briefly while the student teachers learned about chemical reactions in general.

Except for the two courses in the teacher education program, the student teachers had different backgrounds in chemistry. Most of the student teachers in Group 1 (University A) had had formal education in chemistry in the past. Henrik and Xander (the names used throughout the article are pseudonyms) had attended higher education science studies, which is not common for student teachers in the program. Karoline and Iris had had two years of chemistry from upper secondary school. Elijah was the only person in the group without science education after having completed the compulsory general science education at age 17 (grade 11). Of the student teachers in Group 2 (University A), Oscar, Rita, Andrea, and Erica had each had two years of a specialization in chemistry in upper secondary school, while Monica had had no science education after her compulsory education.

The student teachers in Groups 3 and 4 (University B) had less prior knowledge of chemistry. In Group 3, two student teachers had had compulsory general science education (Lisa and Eva), while a third, Jennifer, had specialized in biology in upper secondary school. The same was true of members of Group 4, in which William, Simon, and Roger had had compulsory general science education up to grade 11, whereas David had specialized in biology.

The student teachers had not been taught about corrosion and how it can be prevented during teacher education, but those with two years of chemistry from upper secondary school might have learned about it in school.

Table 2 Detailed description of the steps in the thematic analysis

Phase	Description of the process
1. Becoming familiar with the data	The first and second authors transcribed the videos from their own respective universities. They then read all transcripts and wrote down spontaneous ideas and thoughts that were discussed with the third author, who was from a third university
2. Generating initial codes	Both researchers coded individually and inductively for one hour of video each, and jointly created a codebook consisting of 42 codes. These were used to double-blind code shorter sequences to refine the codebook and understanding of each code, obtaining consistent intercoder agreement of more than 85% accordance (Creswell and Poth, 2016). After reaching this threshold, the first and second authors then coded the remaining transcripts by first coding two groups each, then double coding the other two, and finally discussing and resolving residual disagreements together
3. Searching for and reviewing categories	The codes were compared for similarities and differences, and were often double-checked with the original transcripts and grouped into preliminary themes, which were then regrouped several times after critically examining their details
4. Defining and naming themes	The four remaining themes dealt with different aspects of content knowledge and experimental competence, which were in line with the research questions
5. Producing the report	Excerpted examples were selected to help explain the main findings. The selection and final use of the excerpts and descriptions validated the core of each category. These were then discussed by all authors in the light of the theoretical perspectives

Data analysis

NVivo was used to transcribe the video footage verbatim, including comments on important nonverbal events in the videos, such as a group member scratching the surface of a rusty pipe. The authors then analyzed all four groups, as described in detail in Table 2. This analysis was based on the thematic analysis approach by Braun and Clarke (2006), a method for identifying, analyzing, describing and reporting themes within a dataset (Nowell *et al.*, 2017).

Results

As a result of the thematic analysis, four themes were defined in answer to the research questions. They are presented in Table 3, and are described together with the relevant excerpts to verify the trustworthiness of the results.

RQ1: Student teachers' use of knowledge in chemistry while solving a problem-based task on outdoor corrosion

Throughout the teaching unit, the student teachers' use of content knowledge in their dialogs was related to two themes: content knowledge related to solving the task, and other content knowledge.

Theme 1.1 Content knowledge related to solving the task

The groups began their task by choosing objects and testing for metals outdoors, as depicted in Table 4. Groups 1 and 2 used the test-kits to confirm their assumptions. Groups 3 and 4 tested their objects for a range of metals, with members of Group 4 returning twice, to do additional analyses.

Table 5 gives an overview of solutions to the corrosion problems discussed by the four groups. Some solutions, such as coating and galvanizing, were discussed by all groups, whereas other common solutions to corrosion problems, such as alloying, sacrificial anode, and an oxide layer, were discussed by two or three groups.

Table 4 Overview of the objects, analyses and their results (+ = positive; − = negative)

	Group 1	Group 2	Group 3	Group 4
	Corroded bike rack	Corroded pipe	Corroded pillar	Uncorroded door lock
Fe	+	+	+	−
Zn			+	+
Cu				+
Al			−	
Ni				+

Table 3 Overview of the results of the thematic analysis related to the research questions

Research question	Theme	Condensed description of allocated codes
1. Use of content knowledge	1.1. Content knowledge to solve the task	Containing dialogs, reasoning about the search for corrosion events, discussion of hypotheses and chemical reactions, and proposed solutions at the sub-micro, symbolic, and macro levels
	1.2. Other content knowledge	Dialogs and reasoning about other topics in chemistry, or actively linking the task to related topics in science
2. The student teachers' experimental competence	2.1. Practical skills	Practical enactment of the analyses, both dialogs and actions, connected with practical work as well as observed and perceived challenges
	2.2. Health and safety awareness	Safety aspects, discussions on health and safety regarding the practical activities and general aspects as well as the observed enactment of safety measures

Table 5 Overview of the solutions that the student teachers discussed

Solutions	Group 1	Group 2	Group 3	Group 4
Coating	✘	✘	✘	✘
Galvanizing	✘	✘	✘	✘
Alloying	✘	✘		✘
Sacrificial anode	✘		✘	✘
Oxide layer		✘		✘
Other solutions to corrosion problems	Group 1: Remove reactants, shock absorber, remove bicycle racks, use wood instead of iron Group 2: Better routines for maintenance, roof to protect the iron from water Different metals were proposed in between by some participants when discussing reactivity, for example ironically gold and platinum			

Despite reaching similar solutions, the student teachers had different strategies for discussing the problem.

Group 1, which contained members with the most formal education in chemistry, came up with several suggestions while outdoors. This was evident from the beginning of the outdoor task when Elijah, who was the only group member without formal education in chemistry, started a discussion on how coating and galvanization can prevent corrosion through preventing oxygen from reaching the metal:

Elijah: *So, how does one prevent corrosion? Like ... painting?*

Henrik: *Applying a coating. Coating or alloy.*

Xander: *What are you doing with your car if it gets rusty? You polish it and paint over to prevent oxygen from reaching it.*

Iris: *It must not be open.*

Elijah: *Because that's it; if oxygen cannot reach it, there won't be any corrosion?*

Xander: *Yes*

Elijah: *Aha. So easy.*

Iris: *So easy, but yet, so complicated ...*

Xander: *But then, the reason for using a zinc coating or galvanizing should be that the zinc should ... should ...*

Iris: *So, the zinc shall corrode first?*

Xander: *Yes.*

The group continued by selecting a rusty bike rack as their problem object. After performing the test, within seconds of interpreting the test kit, they moved to possible solutions and theoretical reasoning on how to solve the corrosion problem.

Iris: *This is what becomes our redox reaction.*

Henrik: *What is the name of the series with things that...*

Karoline: *Who is stealing ions from whom, or something like that?*

Iris: *The reactivity series?*

Elijah: *I see, like electronegativity?*

Iris: *No.*

Henrik: *[showing the group the reactivity series on his phone] We see iron there, which means that everything above iron will oxidize.*

As seen in the excerpt, they had discussions involving both the macro- and the submicro-levels directly outdoors without using other sources than the reactivity series, which was searched for online by a group member.

The other three groups worked differently from Group 1. They focused on conducting tests outdoors and discussed solutions mainly afterwards in the classroom.

In the classroom, they used the textbook as a source for their discussions, referring directly to the book when using content knowledge such as reduction potentials, as shown in the excerpt below. Group 3 chose a corroded pillar-construction:

Lisa: *Can we use copper to protect iron?*

Jennifer: *No, copper has a high ...*

Eva: *It says here: "Does not react with water."*

Jennifer: *If we protect something, we do have to choose something further down the list [Jennifer points to the half-reactions in the standard reduction potentials table].*

Lisa: *But now we have to protect iron.*

Jennifer: *Yes.*

Lisa: *So, we can't change it.*

Eva: *Potassium!?*

Lisa: *We only need ...*

Jennifer: *Yes, but potassium is way on the top of the list, it will lead to an explosion [giggling].*

Eva: *Magnesium [whole group giggling].*

Jennifer: *Can't we just use zinc, as it is the choice of the textbook?*

Using the potentials table, they discussed different solutions, based on the redox reactions at the submicro- and symbolic levels, which were depicted in their book. They arrived at the choice of zinc to protect iron, due to their test results and recommendations in the textbook. The choices considered in the dialog indicate that at least Eva and Jennifer use the table of reduction potentials correctly.

Group 4 chose a metal plate around a keyhole as object. It caught their attention despite not being corroded. At first, they were unsure of their test results, especially the high values for zinc that seemed to contradict non-existent corrosion. Back in the classroom, they tried to find an explanation for their observation by using the textbook and the Internet. Two group members chose to go out again for additional testing. David described their insights to the whole class in the following words:

Around [the keyhole], we got really positive results for zinc [...]; and then we investigated for all metals, and why did they not get rusty, and found that zinc corrodes and rusts, too, but it does so in another way than iron and copper do. Instead of it being brown or green or broken, there is a thin layer around it that prevents oxygen. So, the first time it comes in contact with oxygen, it reacts, and there appears a thin layer, an oxidation layer that prevents more oxygen from coming through. As long as you do not come and scrape away that layer, it is protected from further oxidation.

In the excerpt it becomes clear that they found a realistic explanation of protecting objects by means of passivation of zinc. The learning process for this group began with curiosity about the object, and questions to which they did not know the answers. The strategy of alternating repeatedly among the literature, discussions, and new analyses in the nearby outdoor environment allowed the group to go beyond the content of the textbook. They found answers to their questions by using internet resources and verified their new knowledge by using additional metal tests. In the end, they identified the door-lock as an alloy, containing copper, zinc and nickel.

Theme 1.2 Other content knowledge

All groups referred to other scientific content and experiences outdoors in addition to the issue of corrosion. Group 4, for example, discussed earlier teaching experiences, such as those with citric acid as an antioxidant in food preservation.

Group 2 used first-hand observations of this task to reflect on related content, like plastics as a source of pollution:

Oscar: *I just ... can plastic rust – no, not rust, but can it corrode?*

Rita: *Maybe not corrode, but it eventually wears off due to the wind and ... it gets smaller [unclear voice].*

Andrea: *But it's stupid to bring in plastic, I think, in relation to the environment. We do not want to put even more plastic in the environment, do we?*

Group 3 examined reactions other than redox reactions and conducted analyses related to these reactions as well. During their work outdoors, they noticed a white substance on a brick wall, and wondered if this might be an instance of corrosion. They hypothesized that it was limestone, and were encouraged by the educator to test for calcium carbonate by applying hydrochloric acid to it. After they had applied some droplets, the following dialog took place:

Jennifer: *It's fizzling [excited voice]. Yes. It fizzles a lot!*

Eva: *Jipiehh! [applying more HCl]*

Eva: *Yes. I think it is limestone.*

Jennifer: *Yes, so we've proven that it's limestone.*

Eva: *Where does the limestone come from?*

Teacher: *Yes, that's a good question.*

Lisa: *Acid rain?*

Jennifer followed up on this experiment and their observations afterwards in the classroom:

Eva: *What are you doing?*

Jennifer: *I'm trying to figure out that limestone thing.*

[Silence]

Jennifer: *Ahhhhh, [reads from the laptop] calcium carbonate is insoluble in water, it is common as white precipitate when carbonate-ions are added [...].*

[Silence]

Jennifer: *You can write that according to SNL [an online encyclopedia], calcium carbonate—calcium compounds are used in cement.*

[...]

Lisa: *Is that why it is calcium on the brick, because it was calcium in the cement around?*

Jennifer: *Yes.*

Even though precipitation was beyond the scope of the given task, they decided to add it to their presentation as a related problem of degradation to show to others. In these excerpts, we see that the student teachers continued reasoning about the phenomenon they had discovered outdoors by using Internet-related sources in the classroom and, hence, acquired new content knowledge.

RQ2: Student teachers' experimental competence while solving a problem-based task on outdoor corrosion

Two themes were identified in the analysis of the student teachers' actions and dialogs that were linked to experimental competence: practical skills, and an awareness of health and safety.

Theme 2.1 Practical skills

One part of the assignment was to identify the metals that had been used on campus, before discussing measures to protect them from further corrosion. These tests created different challenges, which were mostly solved by using the detailed step-by-step guides, by reasoning or sometimes asking the teacher.

One example, which caused confusion in all groups, was the concept of taking both a sample containing the ions as well as a negative control when analyzing for iron. Another example was related to the testing method in general. Because an undefined probe of a solid material instead of the commonly used water probe was used, the results of the tests had to be treated as qualitative rather than quantitative. The group members understood this aspect either on their own during the first waiting period or while reading the instructions again, reasoning with one another and asking the teacher for help.

Group 2 discussed the handling of the test kits in a representative way, as happened in all groups:

Andrea: *But why not wait for seven minutes? Don't we believe we got iron?*

Oscar: *Because it is about to measure. [pauses] Yes–what does it actually measure? It measures ...*

Andrea: *Iron ions. How many?*

Rita: *We can just let it go for seven minutes.*

Andrea: *The number of iron ions, wouldn't it?*

Oscar: *But we did not take a defined amount by brushing over. So, we can only interpret it as yes or no.*

In this excerpt, they were trying to understand the test procedure by using submicro-level reasoning to explain macroscopic observations. While Andrea and Rita still struggled to see the consequences, Oscar understood the reason for gathering qualitative results in the last sentence. The group continued by asking the teacher if Oscar's assumption was correct.

Theme 2.2 Health and safety awareness

All groups discussed health and safety issues while analyzing corroded metals outdoors. This was surprising, as they did not discuss this while preparing their investigation bags and reading the step-by-step-guides in the laboratory before leaving the classroom.

Group 4, for example, discussed it as follows:

David: *But this is hydrochloric acid, HCl.*

William: *[Pointing toward the instruction sheet] HCl, ffff, yes. How many moles?*

Roger: *0.1 mole.*

Simon: *Yes, how strong is that?*

David/Roger: *I don't remember.*

[...]

William: *But – caustic on ... skin?*

David: *[By looking at the label] Yes.*

William: *fhhhhhhh—gloves! We wear gloves, just in case. We don't know enough about the substance.*

[The group prepares the test in silence.]

William: *Not knowing is allowed, isn't it?*

As we can see, they followed the precautionary principle, and this was valid for Groups 2–4 in general, who followed the precautions without disagreements, wearing gloves and safety glasses.

Group 1 considered this more critically:

Xander: *We don't need safety goggles.*

Elijah: *Yes, you do!*

Iris: *No, the hydrochloric acid is just 0.1 moles.*

[...]

Elijah: *It is not for this, it's for that. That's the one, which is harmful (pointing toward the NaOH).*

Karoline: *No.*

Elijah: *Yes.*

Xander: *Because I used NaOH.*

[...]

Elijah: *Yes, that's the one that is harmful.*

Xander: *Not kidding.*

Elijah: *It is not hydrochloric acid.*

Xander: *This one [pointing toward the hydrochloric acid], I may drink without getting harmed much.*

Elijah: *[Laughing] I'm not sure I would have done that.*

Karoline: *Hydrochloric acid?*

Xander: *You have it in your stomach anyway, and it is much stronger than this one.*

They ended up wearing safety glasses but no gloves. Xander was not correct about the concentration of HCl in the stomach, and 0.1 M HCl causes eye irritation, indeed. However, the group discussion was right about the different harmfulness of NaOH and HCl. As a result of their discussion, their decision to wear safety goggles was appropriate and necessary.

Discussion

This study investigated how problem-based learning outdoors can facilitate the learning of chemistry in teacher education, using the everyday-phenomenon of corrosion as a problem-based example. The analysis of the video data shows how the student teachers used their previous knowledge about redox chemistry in a new context, while at the same time acquiring new knowledge about corrosion. The learning was facilitated by their use of the textbook, internet resources and discussions mainly in the classroom while preparing a poster or letter, but also outdoors (Group 1). Furthermore, the student teachers gained new experimental experience by using test-kits outdoors to confirm the nature of the corroded metals. In this section, the discussion focuses on three learning opportunities that can be deduced from the results: the unique opportunities in outdoor situations, the different approaches to the chosen problem enabled by the nearby outdoor environment, and health and safety awareness outdoors.

Multiple opportunities for learning chemistry

Corrosion events in the nearby outdoor environment enabled the student teachers to choose from among several objects. In our study, the student teachers had to choose an individual context and find out exactly why the object had corroded.

This freedom to choose different objects contributed to enhancing the student teachers' interest, in line with the findings of other projects (Fägerstam, 2014; Höper and Köller, 2018). Group 3, for example, inspected different objects before becoming excited about white depositions on bricks. Despite being informed that it was a side event, and not a redox reaction, Jennifer insisted on finding out more about this particular phenomenon. In line with experiential learning, this experience of exploring and solving the problem of the bricks not only improved their motivation, but also represents an ancillary way of understanding the process of corrosion by challenging previous knowledge (Kolb, 2014). This is supported by Beames and Ross (2010), who have argued that learning is most effective when the learners' questions arise from their experience, and not the prescription of the teacher.

Being able to investigate entire objects in their natural context thereby contributed to a better understanding of the place itself (Popov, 2015; Semken *et al.*, 2017). In this case, the area around the buildings, which has been used by the student teachers in their daily routines, was suddenly connected to a distinct chemical concept, thus adding a new layer of knowledge to the student teachers' knowledge of the place (Semken *et al.*, 2017). This learning was evident, for instance, in Group 1: Its members discussed general ways of protecting a piece of metal while on their way to the outdoor area. However, when engaging with the real object, more targeted solutions were discussed—for example, protecting the rusty bike rack by building a shelter. Here, the place contributed to a more realistic understanding of the phenomenon at hand as well as the theory behind it (*e.g.*, Waite and Pratt, 2017).

Another occasional feature in our results, which has been acknowledged as an integral part of place-based education (Semken *et al.*, 2017; Waite and Pratt, 2017), consisted of discussions on interdisciplinary topics. Group 2, for example, discussed the use of plastic coatings and concluded that they have a negative impact on the environment. This shows, as emphasized by Popov (2015) in his research on similar, physics-related experiential learning: the place affects the learner, but the learner might affect the place as well and therefore begins reflecting on decisions in light of their long-term effects, which is an important aspect of sustainability (Sandell and Öhman, 2010; Jegstad *et al.*, 2018). Through this, both the phenomenon in the place and the scientific content became more relevant (Mandler *et al.*, 2012; Stuckey *et al.*, 2013; Semken *et al.*, 2017).

The nearby outdoor environment allows different approaches to the chosen problem

The second opportunity that can be deduced from the results relates to the use of the immediate surroundings of the classroom or laboratory with regard to a seamless learning process. The student teachers approached the problem-based task in two fundamentally different ways depending on their background knowledge.

One approach was represented by Groups 2–4, who mainly focused on the experimental part outdoors, and did not discuss possible solutions before entering the classroom. Their reflective observations of the experience with the chosen problems seemed to create a need for knowledge among the student teachers in all three groups, before they could form their conclusion based on their experiences in line with work by Kolb (2014). This triggered the use of the textbook when trying to connect their observations to the theory afterwards in the classroom. It is here that the nearby environment becomes important for a continuing learning process, as it enables a quick switch to the classroom and secures the availability of the teacher (Beames and Ross, 2010; Fägerstam, 2014; Ayotte-Beaudet *et al.*, 2017).

While the student teachers in Group 2 mainly worked independently, both outdoors and inside, those in Group 3 asked repeatedly for help to understand why and how to use the test kits and interpret the results, behaviors indicating that these student teachers were novice learners with little background knowledge (Overton *et al.*, 2013). The university teacher thus became important with respect to providing an appropriate amount of scaffolding (Bruckermann *et al.*, 2017) to help them understand that the test results could not be treated quantitatively, which was worked out independently by the members of Group 2 as shown in the excerpts.

For Group 4, the proximity of the outdoor environment provided the opportunity for a ''second chance'' for linking theory to reality. By alternating between testing outdoors and reading the literature in the classroom, Group 4 found out why the metal plate had not corroded, and developed its understanding of the problem to a degree that would not have been possible if its members had been outside only once. This makes sense in the light of experiential learning theory, which views learning as a process that continues in circles (Kolb, 2014). As a result of their reflective observations of the first outdoor experience, the student teachers struggled to understand why the door lock did not corrode. The search for explanations led to repeating and expanding their test activities, twice, thereby creating new experiences on which they could reflect. Typically for Groups 2–4, they continued discussing solutions in the classroom, and not outdoors.

Group 1, consisting mostly of student teachers with robust formal background knowledge, chose a different approach. Its members proposed solutions immediately once outdoors. The bike rack triggered this group to link its previous theoretical knowledge directly to the phenomenon, searching purposefully and successfully for adequate solutions, a characteristic of expert learners in problem-based learning (Overton *et al.*, 2013). The student teachers discussed both the problem and the test kits at all levels of chemistry (*i.e.*, the submicro-, symbolic, and macro-levels) (Talanquer, 2011). This is noteworthy given recent studies in chemistry showing that even third-year college students partly struggle to translate between the different types of chemical representations (Gkitzia *et al.*, 2020). Discussing the macroscopic phenomenon directly in this known place was thus tantamount to creating a meaningful learning experience for this group (Scott *et al.*, 2011; Blatt and Patrick, 2014).

In summary, the different approaches employed by the groups of student teachers in this study indicate that the problem-based task provided opportunities for learning similar to those reported in studies on problem-based learning in the classroom (Kelly and Finlayson, 2007; Tarkin and Uzuntiryaki-Kondakci, 2017). At the same time, it offered variations by integrating nearby places (Beames and Ross, 2010). Hence, problem-based learning in outdoor environments can potentially supplement problem-based chemistry education.

The outdoor environment raises health and safety awareness

The final, unexpected, result was that the outdoor environment raised the student teachers' awareness of safety measures. While safety-related aspects were not mentioned by the groups in the classroom before they went out, the use of droplets of hydrochloric acid and sodium hydroxide outdoors triggered several discussions. These discussions took place in all groups, but Group 1 stood out with lengthy discussions on the rationale for using protective equipment. When referring to concentrations, substances, and their expected impacts on the body, they invoked all levels of chemistry (Talanquer, 2011), and were able to give a causal explanation for choosing adequate protection. By contrast, Group 4 struggled to understand the reasons for the procedures owing to a lack of basic knowledge, and their uncertainty led them to use protective gear ''just in case.'' As a general result, Groups 2–4 were occupied with the precautionary principle and used protective equipment during the experiments. This is comparable to Waite and Pratt's (2017, p. 16) conclusion that ''the apparent unpredictability of outdoor contexts'' would prepare learners to deal with uncertainty in different ways than in the classroom owing to unexpected experiences.

Even though health and safety aspects were not emphasized in our study, most student teachers became aware of the necessity of knowing of the relevant hazards and appropriate measures as they were about to handle the test kits, without the direct supervision of the teacher. This is interesting with regard to the literature. In regulations and recommendations for outdoor teaching, chemistry-related health and safety issues are scarcely considered, as seen, for example, in CLEAPSS (2006) ''Guidelines for activities in the school ground,'' which refers only to chemicals such as pesticides and fertilizers in the context of gardening. In their review of outdoor education in the nearby environment, Ayotte-Beaudet *et al.* (2017) did not find health and safety to be a concern for teachers, either. Meanwhile, in a review of the status of health and safety education in schools and universities, Fivizzani (2016) demanded that "the students must practice what they learn about safety in their lab courses." In the laboratory, learners expect the teacher to have prepared for adequate safety measures such that they would simply follow well-known advice. Apparently, they do not always do so, according to Schenk *et al.* (2018), who found that most accidents in schools involve the inappropriate handling of acids and bases despite the provision of safety measures.

Thus, the increased awareness towards health and safety, which we observed among the student teachers in the outdoor situation compared with that in the classroom indicates that experimental outdoor experiences might be an overlooked opportunity to complement the setting in the laboratory.

Conclusions

By using a teaching unit in the outdoor environment nearby the university classroom, this study examined learning processes among student teachers. In the discussion, we proposed three opportunities for learning basic chemistry that might be interesting in other contexts:

First, multiple learning opportunities arose due to the authentic phenomena outdoors. The diversity of corrosion-related events gave the student teachers the freedom to choose an object they were interested in, to analyze and develop purposeful solutions for it. Second, the nearby outdoor environment allowed adaptations to solve the given problem. Student teachers with advanced background knowledge successfully linked theory to the phenomena outdoors, while the other groups focused on working experimentally outdoors and continued theoretically indoors due to the proximity of the outdoor environment to the classroom. Third, the outdoor situation increased the student teachers' awareness of health and safety. Being forced to conduct experiments outside the laboratory, without direct supervision by a teacher, appeared to contribute to an increased awareness and implementation of safety routines.

This study focused on the learning process, the observed conversations and actions of the student teachers while they were outdoors. This means that the student teachers were participating in their role as learners, and not as future teachers. Insights from student teachers' reflections on how to integrate and develop chemistry-related outdoor activities have been discussed in detail by Remmen *et al.* (2020).

Implications for teacher education

The learning opportunities in this study directly address the accusation leveled against school chemistry as irrelevant to learners and point to the nearby environment as a way to overcome the challenges of integrating outdoor education into a crowded curriculum. Thus, an implication for chemistry education is that teachers should consider the outdoor environment as a setting for learning basic chemistry. Having experienced working outdoors may then serve as a prerequisite for student teachers for integrating such tasks into their own future teaching (*e.g.* Remmen *et al.*, 2020).

In this study, being able to choose between different corrosion incidents motivated the student teachers to work on their understanding of chemistry. Problem-based learning could take this interest further with varying degrees of freedom. Learners may be encouraged to find their own problems, or delve deeper into the consequences of corrosion, for example construction stability or contamination of drinking water, which again could be examined by the same test-kits. There are other contexts, as well, in which using problem-based learning outdoors might be important for student teachers' own learning of school-relevant environmental issues, for example measuring carbon-dioxide-concentrations.

Implications for teaching in school

The problem of corrosion is ubiquitous. The topic used in this study thus fits well with curriculum-based teaching of redox reactions across the world, especially in upper secondary classes. However, it would be necessary to adjust the problem-based task, classroom management, and health- and safety-related aspects according to the age of the learners. One should, for instance, limit the handling of test kits with hazardous chemicals (zinc and aluminum) to the teacher, while students can detect iron and copper ions, whose tests are based on harmless chemicals.

The problem-based learning approach may foster the linking of submicro-level chemistry content to macro-level everyday experiences. We propose that including outdoor problems near the classroom might be relevant to other contexts and age classes as well. These can be problems related to basic chemistry, for example which materials to choose in the schoolyard or playground. Integrating the local environment might even motivate students to further explore the environment around their homeplaces and learn about more complex environmental issues (Beames and Ross, 2010).

Implications for research

Further aspects of this problem-based approach could be studied in-depth, for example the detailed chemistry in the student teachers' discussions, letters and posters in comparison to their textbook and internet resources. Another aspect would be to investigate how student teachers who experienced outdoor education during their preparation implement outdoor chemistry in their own future teaching. A related study would be how teacher content knowledge in detail affects the ability to integrate outdoor phenomena. Future research should also focus directly on how outdoor chemistry can be included in secondary education and how it can be assessed.

Limitations

There were some limitations in this study. First, the use of video cameras for data collection led to some technical issues and, hence, data from some of the groups were lost. This limited the amount of data available and, hence, the amount of evidence related to the research questions. However, incomplete video data were omitted because they did not allow for a consistent thematic analysis required to answer the research questions.

Second, although flexibility can be a strength of thematic analysis, it can also lead to inconsistency and incoherence in the development of themes (Nowell *et al.*, 2017). This limitation was encountered by providing thick descriptions of the selected excerpts.

Finally, selecting excerpts does not provide evidence for generalizations, and they can serve only as illustrative examples of the themes and codes identified in our analysis. That said, the phases of thematic analysis in Table 2 were an iterative and reflective process over time that required several discussions among the researchers. Alternating between the data, preliminary codes, and themes, revising the themes and codes, developing rich descriptions of examples, and discussing them within the research group were all crucial strategies for establishing the trustworthiness of all qualitative research (Creswell and Poth, 2016).

Ethics statement

All participants in this study were anonymized. All consented to their participation in this research project. It was registered, evaluated for ethical compliance and data management, and approved by the national authority, the Norwegian Centre for Research Data (NSD).

Conflicts of interest

There are no conflicts of interest to declare.

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