"Ok, so what becomes water?"

Scaffolding students’ learning by using mediating artefacts in a chemistry classroom

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"Ok, so what becomes water?"

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This thesis took the joint effort of several supervisors, additional advisors, and supporters among family and friends. First, I wish to thank Hani Murad for introducing me to the topic of this thesis, and guiding me through the concepts of this thesis. Then, a thanks for Birger Møller Pedersen, for supporting my wish to write a thesis in fields that were new for both me and him. A special thanks to Suhas Govind Joshi and Jan Arild Dolonen for some informative talks during a stressful pinch.

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My family and friends, J, ever the pillar of support, believing in me when I faltered, helping me when I’d fall, thank you so much.
Learning about the periodic table of elements can be a challenge for second grade students. The amount of theoretical information, combined with abstract scientific concepts, makes it difficult for students’ meaning-making. Research done on the concept of scaffolding is usually concerned with subjects within language, culture, and occasionally scientific subjects. This study aims to evaluate existing research, gather data on the domain, and see what scaffolding elements can be added to a tool to support students’ meaning-making when learning about the periodic table of elements.

Interviews with teachers presented an objective, namely that students could make connections between small, abstract atoms, and how they exist and shape everything in the everyday world. Through observations and interviews with students, it was expressed that learning about the periodic table could be boring, that there was too much theory, and that the majority of said theory was not memorable.

Analysis of the test results showed that by having multiple representations, students could relate to the periodic table of elements, the elements themselves, and their properties, in different ways. By working in groups, and aiming to unlock achievements, they were driven towards a goal by prompting each other to meet their aim. Throughout the interactions, they would combine the everyday concepts from the multiple representations with scientific concepts from the tool.

The results indicate that while having different forms of scaffolding combined into one tool, one can see the positive scaffolding effects of said elements. The positive effects being able to relate representations of tiny, abstract atoms, to their effect on the real world based on the atom's properties. However, the combined scaffolding elements also bring their negative side effects (distraction, frustration and confusion) if the tool is not presented correctly, and the components of the tool are not explicit.
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Chapter 1

Introduction

Curiosity is a staple in scientific fields, whether it is in work or in educational environments such as schools and universities. For those who are new to how the world works and how *science* is connected to the natural world, there can be a lot to take in and a lot of questions to be asked. Thus it is vital to be able to give explanations and answers in a way that they can understand and learn from. Existing research and pedagogical theory explores the way tools can be used to *mediate* and *scaffold* learning (Vygotsky [1], Wertsch [2], Wood, Bruner & Ross [3]). There is also research done on how digital tools have an effect on learning, where the design of the tool in question, as well as the classroom session, can affect the students’ learning and meaning-making in different ways, which will be briefly presented in the section for establishing new propositions.

This thesis will be looking at the classroom setting when learning about the *periodic table of elements* in secondary school, and how changing the way the topic is presented and interacted with may change the way it is learned about. A high fidelity prototype will be designed for this situation, and be explored and developed through the thesis and tested for results. For this thesis I wish to investigate how it is possible to support learning processes in a secondary school classroom through approaches in the field of CSCL.
1.1 Motivation for this study

The motivation for this thesis is to create a tool that can support learning about the periodic table of elements for secondary school students. There are already tools and resources for learning about chemistry, but when it comes to learning about the periodic table of elements, the learning process is static. Therefore, the aim is to create a new experience when it comes to learning about the periodic table and the properties of elements.

In order to create such a tool, I will be studying existing experiments and research done in the field of CSCL, under the topic of scaffolding. Scaffolding is a term from the pedagogical research community, referring to tools and resources that support learning within the zone of proximal development. These terms will be further explained in the theoretical frameworks chapter. I created a prototype based on what students struggle with when learning about the periodic table of elements. Their struggles are tightly connected to how they are taught about the elements’ properties and chemical reactions. The way elements work is a basic staple in learning about natural sciences.

From my personal experience, I had trouble remembering the different groupings of elements and their corresponding effects and attributes. Students today may also have the same problem, whether it is because of limitations from the school or insufficient follow-up from teachers. It is then interesting to see how the development of a learning tool can help with their learning experience. By working with experiments and laboratories they can see how chemical substances react with each other, but those experiments do not show on the most basic level how it actually works. That part is often written in books or demonstrated by the teacher. What is interesting to research, then, is whether visualization of and interaction with the elements (without the risk of health effects or hazardous materials) may facilitate discussion and learning in the classroom. It may also facilitate inquiring about topics that would not be asked or considered during a traditional educational setting.
1.2 Establishing new propositions

In the field of CSCL it is encouraged to do research on specific areas to gain understanding on how cooperative learning takes place, and what aspects of the field can be tied to the research area (Lipponen [4]). Lipponen states that by making clear what theories and background the researcher bases their work on, it will help define their contribution in CSCL’s educational technology paradigm. The educational tools that have been created and researched upon have a varying focus on what aspect of education they are supporting. There are support systems and tools for helping academic processes (Furberg, Kluge, Ludvigsen [5], Slotta [6]), and all the way to tools and technologies with aspects of gamification involved to engage students and keep them in the scientific world a little longer (Kluge & Dolonen, Ainsworth & Habgood). There are also works that compare the pros and cons of both sides (Kluge & Dolonen, Jahreie et.al.).

What I wish to aim with my thesis, is to find a middle ground. Find a new way or students to interact with the periodic table of elements by combining the elements found in existing scaffolding research papers. On top of this, I want to explore how this interaction takes place when the students are grouped, in order for them to push each other into dialogue with the help of the prototype. The technology in this project may, simply by its introduction, facilitate inquiry and curiosity. For this thesis the technology created is a web-application called MyReactor (MinReaktor in Norwegian). It is an interactive prototype that displays information in various ways, described in further detail in later chapters. The prototype is then tested in classroom settings to see its effect in the classroom environment.

MyReactor is meant to work as tool that connects the abstract world of atoms and their properties, with real-life examples and visual representations. These representations can urge the students to ask new questions or interact with the periodic table in a way they haven’t before. Tied to this is Vygotsky’s Zone of Proximal Development, where the technology can work as a bridge between what the students know and have learned, and what more they can learn and understand with support. I aim for MyReactor to be a means of support.
1.3 Research question

The research for this thesis is focused more on learning theory and pedagogy than the actual development and design processes of creating a digital learning tool.

- **What does a learning tool about the periodic table of elements need in order to scaffold second grade students’ learning of elements and their properties?**

This question is very specifically tailored for the issues I met with when interviewing teachers and students about what is the goal with learning about the periodic table of elements. Also, from the students’ perspective, what is difficult. The question will focus on what a digital learning tool can have, where interacting with it helps the students learn about the periodic table in a new way. The application will reviewed against scaffolding concepts and other theoretical frameworks for evaluating learning tools and to what degree they support a student’s learning processes.

The **timeframe** of my analysis of how my prototype scaffolds learning will be limited to the classroom session where the students are performing the test. This is not a long-term study of how well the students remember what they have learned by using my prototype, but instead an analysis of how their **interactions** with the prototype change. Those interactions can say something about how their interactions with the **representation** of elements in the periodic table changes.

Before we can start answering the question, I will establish what aspects of the periodic table of elements I am focusing on. The scientific background chapter presents basic information about elements, groups, and reaction types, as well as their most common properties.

I will then present the theoretical frameworks this thesis will explore, and the scientific fields this thesis is relevant for. The theories have been selected based on what I considered appropriate for a classroom environment that was learning about the periodic table of elements. While this thesis may have elements that remind of interaction design, my main focus is on pedagogical theory and the concretisation of those theories.

The theories I will explore can be briefly described by an activity model where the subject is the student, the object is learning new concepts, and
the mediating artefact is a scaffolding tool. I will further explain what scaffolding means, as well as where and how it takes place when students learn new concepts. Examples of scaffolding will also be presented, as they were key to the inspiration for the design of my prototype.

My methodologies will be presented in the following chapter, describing the ways I have chosen to gather data. I have chosen to focus on a user centered design, where the end users are the ones who shape the contents of my prototype. Since the focus is on the users, methodologies like interviews, observations, and video recordings are chosen.

Existing resources will be analyzed based on the perspectives of the teachers and students used for data gathering for the prototype. Their impressions about both teaching- and learning about the periodic table of elements will set the structure for what I want or do not want to include in my own prototype.

The analysis of interviews, observations, existing research, and existing technologies will then be evaluated to create a purpose for my prototype. This purpose will then affect the actual creation process, and I will describe all the components of the prototype. I will then tie these components to the theoretical concepts from earlier.

The following chapter will then evaluate the test results. A description of the school and classroom sessions will be presented, and then the interactions observed as the students used the prototype. One of the most important tests will have a timeline of the students familiarizing themselves with the application, and then expressing their understanding by their following interactions.

These interactions will then be discussed in light of the research question. In the discussion chapter I will attempt to answer my research question, and go deeper into how the interactions can be results of the scaffolding my prototype is meant to give.

Finally I will present some concluding remarks about how my research can contribute to the scientific field of learning theory and CSCL. Here, I will also reflect on my own work.
Chapter 2

Background

The Norwegian Directorate of Education (UDIR in Norwegian) states that after having finished secondary school its students should know several aspects of the properties of elements \[7\]. The parts this thesis will be focusing on are the seven first points listed under "Suggestions for learning goals"("Forslag til læringsmål" in Norwegian):

"I can:

- Use the terms group, period, shell model, atomic number, proton and electron to place the constituents correctly in the periodic table
- Describe how the elements in the periodic table are divided into metals, semi-metals and non-metals
- Explain what is meant by main groups (basic families), give examples of some main groups and place them in the periodic table
- Use the basic name, symbol and location of the periodic table to write formula for simple chemical compounds and name them
- Describe what is needed for atoms to have charge and what we call such atoms
- Explain the difference between an element and a chemical compound"

Figure 2.1: Suggested learning goals for the chemistry classroom

The way the class can be structured to teach about these topics is also listed in UDIR’s pages. The class has a textbook which has general information
about the elements and their properties, and the majority of Norwegian schools also have access to computers and laptops that can be used in the classroom. The teacher is also a source of information who can present the topics, either through plain presentation or using images and PowerPoint presentations as a tool to make things more relatable and engaging for the students. With the internet there are several sources online that teach about elements and reactions through text, videos and podcasts, but it requires some element of critical thinking and understanding to navigate through the sea of information online. Considering the progress of mobile computers and technology, information is available at all times, anywhere, but the issue is finding it on a correct level and it being understandable for the target audience. The existing resources will be further presented in the following chapters.

The Directorate of Education also presents ways to evaluate the level of students’ understanding of the topic when giving them grades. The range goes from presenting basic facts taken from written literature to reflecting over scientific correlations \[8\]. The scientific background for the paper will be focusing on the properties of and chemical reactions between elements in the periodic table. This focus will mean that the suggested goals from UDIR may be fulfilled, as it is not possible to talk about reactions and grouping of families of elements without mentioning the suggested terms. Due to the complexity and magnitude of elements this thesis will be focusing on the 20 first in the periodic table. This set will include elements that are included in the four major groups, as well as elements that are reactive and recognizable in everyday life.

2.1 Properties of an element

The way the periodic table of elements is designed is based on the properties each element has. By grouping each element by how many electrons are in its outer shell and how many protons an atom’s core contains, the table is supposed to gives its viewer a way to understand how elements may interact with each other \[9\]. The properties of an element can mean a lot, considering what decides how an atom interacts with another depends on many things. For simplicity’s sake, and for this thesis, the properties of elements will be what decides the interaction between elements in relation to whether they are metallic, non-metallic, alkaline, halogen or noble.
2.1. Properties of an element

Figure 2.2: The full periodic table of elements with colored components. The colors signify which elements have similar properties.

This system can be hard to understand for the first time, and difficult to remember. Even with rules set up for amount of elements per shell, there are some atoms in the full periodic table that have special rules in regards to their outermost shells. This is why for first time learners, it can be easier to focus on the grouping of elements. My prototype will contain only the first 20 elements of the periodic table, which some call "The little periodic table"("Det lille periodesystemet" in Norwegian). The following are the groupings I will be focusing on:

- Metals: In 2.2 the divide between metals and non-metals is the diagonal separation from aluminum (Al, group 13) to oganesson (Og, group 18). The majority of elements in the periodic table happen to be metals. Their appearance tends to be shiny, and they are often solid in room temperature, with high melting points. The atoms in this group are structured, which also makes them great electroconductors. The divide between metals and non-metals has a small subgroup of metalloids, which have some properties from both metals and non-metals.

- Non-metals: Non-metals are defined as elements that do not have the properties of metals. This group is characterized by having the ability to gain electrons easily, with the exception of noble gases. They are also a group that contains atoms that are in different states. Where
metals are generally solid in room temperature, non-metals can be solid, liquid or gas. They are otherwise poor heat and electricity conductors.

- **Alkaline metals**: The atoms in this group can be seen in 2.2 group number 1. This group is the first and colored red. The outermost shell of the atoms in this group contains only one electron. This causes the atom to be very reactive, as it wishes to get rid of its electron. They are quick to react with non-metals, and especially atoms from the halogen group. In my prototype, only lithium, sodium and potassium will be included. Hydrogen is in group 1, but is considered a non-metal, as it does not behave as an alkaline metal under natural circumstances.

- **Halogens**: The atoms in the halogen group can be seen in 2.2 group number 17. In their outermost shell, the atoms in this group have 7 electrons, and need one more for a complete shell. Halogens are so reactive that they do not occur as free elements in nature, and are usually bonded with metals to create salts. This is a group of non-metals, and my prototype will contain fluorine and chlorine.

- **Noble gases**: The noble gases are the last group in the periodic table, in 2.2 they are group 18 and colored light blue. These atoms have a full outer shell, and are the least reactive elements in the periodic table. My prototype will contain helium, neon and argon.

2.2 **Reactions between elements**

One of the main reasons why atoms react with each other is related to the octet rule; a chemical rule of thumb that atoms want their outermost shell to have eight electrons, thereby filling that shell completely. For elements that do not have a full outer shell, they achieve this by forming bonds with other atoms that need the same thing. Reactions between elements can happen through three bonding types:

- **Covalent bonds**: This type of bond is when atoms share a pair of electrons. This type of bond happens between atoms in the non-metal group. The paired electrons make it so each atom end up with a full outer shell.
2.2. Reactions between elements

Figure 2.3: A visualization of a methane molecule, consisting of one carbon atom and four hydrogen atoms in a covalent bond.

- Ionic bonds: Ionic bonds occur between a metal and a non-metal. These bonds are created from the charge an atom gets when it either "gives" or "receives" an electron. The "giving" atom gets a positive charge, and the receiving gets a negative charge. This polarity attracts the atoms, which now have full outer shells, to each other.

Figure 2.4: A visualization of a salt molecule, consisting of one sodium atom and one chlorine atom in an ionic bond.

- Metallic bonds: Metallic bonds occur between metal atoms. The property of this bond is that when metals bond with each other, they share electrons in a "sea", where the electrons are free to float between
the shells of the different atoms. This is a simplified explanation of metallic bonds, but it is this type of bond that gives metals their properties, especially in regards to the conductivity of heat and electricity, and the fact that metals are malleable.

Figure 2.5: A visualization of a metallic bond, showing a lattice of positively charged atom cores and the sea of electrons in between them.

School classrooms usually have big posters of the periodic table of elements that are either colorized to show groups, or colorized to show metals/non-metals. These posters are supposed to serve as a supporting tool for students to understand the properties of atoms, but can be detached from the experimentation when the students actually use elements during their experiments. A poster of the periodic table of elements is a mediating tool, which will be explained in the theoretical section of the thesis, but perhaps the poster itself needs a tool to support its presentation.
Chapter 3
Theoretical frameworks and perspective

This chapter presents which theoretical frameworks the thesis will be based on. The most prominent theories and approaches being the zone of proximal development, scaffolding and computer supported collaborative learning.

Much of what drives the thesis will be based on Piagetian and Vygotskian theory around the sociocultural perspective. This perspective focuses on the social context of learning and how tools and signs mediate action and learning. What Vygotsky focused on was that the development of a child is co-constructed between the learner and tutor. This approach of thinking focuses on the learning process as a social activity, since there needs to be interaction between the teacher/tutor and an active learner. The potential the learner has that can be reached though external help is what Vygotsky called the Zone of Proximal Development (Vygotsky [10], Verenikina [11]).

In practice, the process of scaffolding describes measures that can be taken to support the learner as they are performing a task (Wood, Bruner & Ross [3]). Scaffolding can occur in the form of both signs and tools, and mediates the action of the learner (Vygotsky [1], Wertsch [2]). In the context of this thesis, MyReactor will be designed as a scaffolding tool following different previous research done in the CSCL field. What will be observed is to what degree MyReactor mediates the students’ actions.

3.1 Activity Theory

In order to understand scaffolding, we will look at the activity model presented by Engeström, where between the subject and object, there is
3.1. Activity Theory

a mediating artefact. In the case of the subject being a student, the object will be the periodic table of elements, and the outcome is to be learning about the periodic table and elements’ properties; the supporting tool will be the mediating artefact.

Traditionally, activity-models are meant to represent short-lived interactions between subject and object [12]. The figure shows more an overarching activity of “learning new, scientific concepts”. This is simply to illustrate the role my prototype will play. In addition, the rest of the activity model shows the student’s relation to the rest of the classroom. The classroom rules, the classroom itself, and the delegation of roles will become more prominent during the discussion chapter, where we can analyze what roles the different users take when interacting with the prototype. Another noteworthy aspect of the mediating tools/signs is that it does not necessarily mean only the prototype. Where the tool is the prototype, the signs are the discussions that take place while using my prototype, an activity in itself. The role of scientific discussion to obtain understanding will also be further analyzed as I test the prototype.
3.2 Learning concepts

There are two terms for concepts used widely in educational research and CSCL, namely everyday concepts and scientific concepts. These terms were introduced early on by Vygotsky as he also set the grounds for the development of higher psychological processes. In his book, *Mind in Society*, he explores the terms as what is learned in everyday life versus what is learned in an academic setting. Everyday concepts are learned throughout one’s life in everyday settings.

Scientific concepts, however, are learned in school, or other academic settings. Unlike everyday concepts, scientific concepts are systematic, based on models and procedures that can explain them. If one learns scientific concepts, they are key to scientific fields and processes. In these fields, one learns more about scientific practices and can further one’s learning [1].

3.3 Scaffolding

Scaffolding is a more practical approach to what the The Zone of Proximal/Potential Development presents. ZPD is described by Vygotsky as the area between what a learner or child can learn and accomplish on their own, and what they can learn and accomplish by the guidance from an expert or tutor [10]. This tutor can be a teacher or parent, but also a peer that understands the domain better. Since the interaction between tutor and learner is to be two-sided, the guidance can be described as a collaboration between these two parts. This requires the learner to be involved in active learning, meaning not just passively listening, but participating in actions or usage of tools that uses the information given to them by the tutor.

The role of the tutor has further been explored by Wood, Bruner & Ross, where they define tutoring as an adult or expert helping another who is not an expert to solve a problem. In *The Role of Tutoring in Problem Solving*, they observe children being asked to solve a puzzle, with the presence and help from a tutor. They describe how the tutor adjusts their methods based on what child she interacts with, adjusting her tutoring to suit the child’s age, interest and previous knowledge [3]. As the student learns more and more how to solve the problem, the tutor can take away certain support structures for the student’s individual learning. The point of scaffolding is to not be constant, that elements of support are lessened as the student learns the problem and the usage of tools and language to solve the problem.
The following subsections contain concrete examples of scaffolding which I will be using throughout my thesis.

### 3.3.1 Everyday- vs. scientific concepts

In *Algebra Learning through Digital Gaming in School*, Kluge and Dolonen explore how two different applications scaffold algebra learning \[13\]. The class is split into two groups, where each group of students are to use their respective applications. The first, *Dragonbox*, is defined as a serious game. The point of the game is to balance equations, and mathematical symbols are represented through game-ified imagery, shaped as boxes. The function is to drag these boxes around and drop them in appropriate sections of the equations to solve the equation, and the result is shown to the students at the end of a task. As it is a game, it introduces a new way of learning the topic of algebra to the students.

*Kikora* on the other hand, is classified as a digital learning tool. Here, the main goal is also to solve algebraic functions, but the structure of the tool closely resembles what students are shown in their books. The students are given immediate feedback, and there are hints if the students get stuck while solving a problem. In this study, tests of the students algebra skills were taken before and after working with the different applications. In general, the students who had used Kikora performed best. This was mainly related to the fact that while the students who used *Dragonbox* used everyday terms to solve the equations, the other students would be using scientific terms. This allowed them to identify the problems given to them in their tests and solve it based on their previous experience with the digital learning tool.

This example shows the importance of introducing and continuously making one familiar with scientific concepts, instead of just everyday concepts.

### 3.3.2 Prompting

Another act of scaffolding is prompting, *the act of suggestion and prompts to show the learner a new perspective* or nudge them along the way. These prompts, however, may induce a "copy-and-paste" behavior, instead of prompting reflection. This copy-and-paste behavior is also seen in the study by Kluge and Dolonen, where students would resort to dragging and dropping random boxes in order to solve the puzzle, instead of thinking through what they needed to solve the equation. Furberg uses Viten.no as an example, a website for learning about the natural sciences. Here,
the prompts show up as “notes”, containing open-ended questions for the students to make them try to reflect upon the information they are given.

Furberg distinguishes content versus process oriented prompts. Content oriented prompts, as the term implies, are hints or feedback for the user in relation the content that they create. For example, the application (OBS forgot its name) is meant for writing essays, and will inform the user if they have not included aspects of an essay in their writing. Process oriented prompts are hints or feedback that guides the user through the usage of the scaffolding tool. These prompts can be indicators for where to click, or where to look for information, and so on. If a user ends up stuck or feeling "finished" with their work, prompts are reminders, for the student in case they have not reached the potential content or ideal usage.

3.3.3 Multiple representations

The last example of scaffolding is using multiple representations, or Multiple External Representations (MER). Using multiple representations for users to understand a concept on a deeper level is the third function of how to use MERs in one’s design (Ainsworth [14]). This can be considered one of the more simple forms of scaffolding, where more than one representation is used in order for the user to make relations between them, and allow for easier meaning-making. By giving a description of something in text, and providing a picture, the user can relate their ideas and impressions from the text with the image. MER can involve an array of representations, from numbers, tables, images, animations, text, and more.

From Ainsworth’s article, I intend to focus on this quote:

"In addition, to maximise opportunities for learners to build cognitive links over representations, then representations should be co-present."

How this will be implemented in my prototype will be further discussed in the MyReactor chapter. The difficulties of including "too many" representations will also be discussed, as this is presented as a problem by Ainsworth in relation to the third function of MER in an application.
3.4 CSCL

Computer-supported Collaborative Learning is a pedagogical approach to the interactions between students and technological learning tools. CSCL is in many ways connected to Vygotsky’s Zone of Proximal Development, and by extension the sociocultural perspective. With the understanding that interactions with others is a way of knowledge building, the cooperative work aspect of CSCL focuses exactly on that; how knowledge is shared, distributed and internalized, as well as being supported with a tool. CSCL is an approach that comes partly from Computer Supported Cooperative Work, a field of study focusing on work settings and the cooperation between coworkers and their interactions with a shared technological tool.

In the CSCL research field, two approaches have been defined: Systemic and Dialogic research (Arnseth & Ludvigsen [15]). With a systemic approach, the focus lies in how the technology affects the students’ understanding or problem-solving abilities. This is done through looking at the relation between social interactions and the different types of support for it, as well as the outcome of these interactions. Models can be created that link these points together in order to come with suggestions for positive learning outcomes. These models can then be created or determined through statistical analysis. Through the dialogic approach, the focus lies much more in social practices. That dialogue, discourse and knowledge is dependent on the context, setting and previous interaction.

"The meanings and functions of one variable cannot be treated as distinct and separable from the others. On the contrary the different elements mutually shape one another, and their meanings and functions are results of local negotiation and sense making" - Arnseth & Ludvigsen

The role of technology in a dialogic approach lies in providing a context for these social interactions to take place, for dialogue to be initiated. However, as Arnseth and Ludvigsen mention, if an ordinary classroom is not used to exploratory talk, it can be difficult to only use the technology as a facilitator for discussion and inquiry. The technology and/or the classroom environment will then have to be designed to prompt dialogue. For this thesis, the dialogic approach will mostly be in focus when it comes to designing and analysing the prototype.

Stahl, Kochmann and Suthers (2006) and Lipponen both seem to agree that researching CSCL in a manner of ways is appropriate, as there are so many
unique factors in different learning and knowledge-building environments \[16\]. With the focus on a scientific field, viewing the learning process with a sociocultural perspective will be interesting. In language learning and social studies classes, class discussions, discussion between students, and group assignments are a key aspect of the class. In sciences, there is less of a focus on how the classroom can be seen as a social environment in which dialogue and discourse between learners plays a central role. In the context of a chemistry classroom, there is the exception of experimenting in groups or having experiment demonstrations for the class, but other than that teachers might not consider dialogue-based collaborative activity as key for learning certain aspects in chemistry.
Chapter 4

Research methodology and methods

The creation of my prototype will be based on the feedback I get from interviews with students and teachers. As there are different classes and schools involved for the project, the prototype will be developed in between tests. The development will then be based on the feedback from its users. The users are key to the development of the prototype and the analysis of the results. Therefore, the methodology used in this thesis will be User Centered Design.

The effect and value of User Centered Design has been studied and evaluated through surveys and reviews (Mao et. al. [17]). Vredenberg, Isensee, and Righi, whose book describes the process of UCD and the way to integrate it into a project [18], focus more on using UCD to design systems in or for organizations/business. Nevertheless, the basic principles have made way for designers and researchers to mold the scope of said principles based on their target group (Bannon & Marti [19]).

1. User focus
2. Active user involvement
3. Evolutionary systems development—the systems development should be both iterative and incremental
4. Simple design representations
5. Prototyping
6. Evaluate use in context
7. Explicit and conscious design activities
8. A professional attitude (ISO 13407 1999)
9. Usability champion—usability experts should be involved early and continuously throughout the development lifecycle
10. Holistic design—all aspects that influence the future use situation should be developed in parallel
11. Processes customization—the UCSD process must be specified, adapted and/or implemented locally in each organisation.
12. A user-centred attitude should always be established.

- Gulliksen et. al. [20]

The effect and value of User Centered Design has been studied and evaluated through surveys and reviews [17]. The surveys often reveal that not all principles or methods within UCD are used due to either cost or other limitations. For this thesis, there are also limitations to be considered, mainly the availability of grade school students for usability testing (point 6), and time for designing low-fidelity prototypes (point 4). Point 7 to 11 have also been assigned a lower priority due to the limitation of the thesis.

4.1 Research methods

There are already a few methods central in UCD, such as doing ethnographies, interviews and usability testing. Due to both the limitations on access to the end users and their environment, the ethnography section was changed more into a case study of multiple cases. On top of this, Document analysis was briefly used to help me understand the field of the periodic table of elements, as well as understand the level of the language and knowledge that is presented to grade school students. Therefore, the data collection contains several methods for understanding the environment and problem area. By triangulating different methods, eventual gaps in the data can be filled or clarified.

The data gathering process was divided into three steps. Step 1 was for ideation and pilot prototyping, serving as a general guideline for problem areas in a classroom learning about the periodic table of elements. Step 2 was for further development of the prototype, understanding of classroom settings in a secondary school, and primary testing of the prototype. Step 1 and 2 were mainly used for chapter 5, when designing the prototype. Step
4.1. Research methods

3 was for beta testing of the prototype with a fully realized educational purpose. Measures were taken for step 3 to include pedagogical frameworks, such as facilitation for inquiry based learning beside just the usage of the prototype.

The two schools used for data gathering were located in different parts of Oslo, Norway, with different classroom structures. In this thesis, they are called School A and School B. School A’s classroom sessions about natural sciences have been observed to see the learning environment, and to learn the strategies used to teach about the periodic table. I have interviewed the teachers with regards to their experience with teaching about the topic in both School A and School B, and conducted a group interview with a few students to get their view on the topic and the classroom setting as well. The periodic table of elements is a topic newly presented to students during their eight year at school. The different steps of the data gathering process would help with mapping out problem areas and the general attitude towards learning about this topic. I will be following the guidelines for performing qualitative data gathering and referencing to Doing Ethnographies by Crang and Cook [21].

4.1.1 Observation

For the purpose of this study, observation was first used to get an understanding of the user domain and also to map out initial problem areas when learning about the elements. When observing the classroom setting, Cohen, Manion & Morrison [22] puts it into perspective:

"...[Observation] can also focus on events as they happen in a classroom, for example, the amount of teacher and student talk, the amount of off-task conversation and the amount of group collaborative work."

And so both passive and active observation was used during all sessions when I was introduced to a new classroom. When coming up with ideas for the prototype, passive observation during the pre-design data collection was enough. The participatory observation was in the form of acting as the teacher to the students when I would test MyReactor. In Doing Ethnographies, Crang and Cook present the importance of roles and relationships that form when a researcher enters places and communities [21]. There is a risk of changed behaviour, both on the students’ side and the teachers, to have a researcher present in their classroom. Whether or not
the students will listen to my guidance as a teacher can also be a conflicting matter, as it is not the norm, and they are not used to my presence in a regular classroom session. Another aspect of participatory observation is my own language usage and how it differs from the classroom or the students, as the classroom setting is unfamiliar territory for the researcher as well. How the researcher will then blend in has an effect on the data gathered.

4.1.2 Interviewing

Interviews with teachers give good, in depth information about how the learning structure exists within the classroom before my work is introduced. It will also give me contextual information about the status of the school and the environment in general [21]. Maybe they have both heard of and tried to implement inquiry learning in their classrooms. In order to make sure that my work is not a critique to the already existing methods the teachers use, I have also gotten their opinion on the prototype in order for it to match their learning goals, and for them to also be affiliated with what is made and used.

Group interviews with students are fruitful in gaining knowledge from the learner’s perspective. The challenge was to present myself as a third party who would not judge their experiences and opinions about the topic and learning environment to get honest answers. Their answers can give great insight of the classroom environment, the dynamics between students when learning, and the opinions on the different teaching techniques used to teach about the elements.

In regards to making arrangements for the interviewing process, interview guides were created with questions targeting the teachers and the students separately. These interview guides were followed, but loosely. The interviews were mostly conducted in a semi-structured manner, and if new topics or questions would pop up, those would be asked as well. Consent forms were made and signed by the teacher, but the consent forms made for the students were vouched for through the teachers instead of their parents. See the appendices for full documentation of the interviewing setup process. When doing group interviews with the students, I attempted to have a balance of genders. I also attempted to scout the students who were either most active, or less active, in the classrooms, to get feedback from different points of view. The choices for this would sometimes be limited as I would only pick those students who willingly wanted to participate in a recorded interview. As can be seen in the appendices explaining the interview setups, as well as the transcripts in, the interviews would
start with casual pleasantries, the introduction of the themes we would
go through, and confirmation of audio recording. In the first transcript,
however, audio recording was started after those first few steps.

4.1.3 Media

Since mediating artifacts is another central topic in this thesis, getting
pictures and documentation of what was available in the classrooms was
important. The classrooms studied had posters the students had made in
relation to whatever topic they were learning about, as well as posters or
images taken from the topic field itself. Particularly for this thesis, I was
looking for whether classrooms had posters of the periodic table of elements
hanging on the wall, or other representations of the elements available in
the classroom.

The usage of media tools like recording devices and cameras aid in all
previously mentioned methods. In a classroom, there are too many elements
and details that can slip past the notes and memory of the researcher. By
transcribing media, a process in which one must pay a lot of attention to
the contents of the media, the researcher can be made aware of these details
that were perhaps not noted down during an observation or interview.

Media also allows the researcher to take freedom to engage in and follow
up interactions instead of being tied to write down notes and talk at the
same time. Most of the previously mentioned methods used were for
gaining an understanding of the environment the students are learning
in; their procedures, their opinions and their resources. Video recording
is particularly important for analyzing the characteristics students would
display when interacting with MyReactor. Transcribing video material
means being able to catch utterances and physical movements related to
interaction with the prototype. Furthermore, transcribing recorded data is
used during interaction analysis as well, since it allows for observing the
development of interactions over time (Mercer [23], Furberg & Ludvigsen
[24], Dolonen & Kluge [13]).

The tools used for recording was a personal iPhone 5S and a hand held
camera on a tripod for video recording. Reference pictures of classrooms
and books were taken without the presence of students or teachers, and
during the video recording the faces of the students cannot be seen. The
camera was left on the tripod and unattended until the end of the data
gathering session.
4.1.4 Surveys
Although my research is mostly based on qualitative data, some quantitative research methods were used to easier see patterns and make connections. For the beta tests with a more finished prototype, surveys were used to get feedback on the classroom experience. Questions ranged from how they felt about using MyReactor as well as how the experience was like working with it as a group. The students’ individual replies will help with understanding who got something out of the prototype and the exercise. These surveys would then also be good to compare with other data, to see if the students did what they claimed in the survey.

4.1.5 Document Analysis
While document analysis is a method mainly used in connection with the grounded theory methodology (Bowen [25]), it was used as a part of my process for understanding the classroom environments. This method was a very small part of my data gathering, yet I would like to mention it in order to specify my usage of document analysis in this study. Informal document analysis was used in the sense that I reviewed and evaluated secondary school learning requirements and sections from the books used in the schools. The learning requirements came from UDIR’s pages, as stated previously. The school books were used to gauge what I could potentially expect from the students I would do usability testing on. Bowen also mentions the review of ads, posters, etc, which was used as I was interested in what visual documents the students in a classroom had access to, such as a poster of the periodic table. If so, the look of the poster could help me shape the design of the scaffolding tool.

4.2 Ethics and security
Working with a school and with children means the data collection methods for the project need to be reported to the Norwegian Centre for Research Data (NSD). An application was sent with information of what types of data I will be storing, as well as interview guides and consent forms. If the project is a candidate for an article for publication, every subject involved in the project must be anonymous and protected. Precautions for this have been taken, as the transcripts of recordings contain no sensitive information, or have been made anonymous. The students and teachers will also at all times know when they are being recorded or observed, and informed of the purpose of the study.
Chapter 5

Existing resources

In this chapter I will review some existing tools and resources that are either used for learning about chemistry and the periodic table of elements, or has the potential to. Whether or not the resources have the potential to be used as learning tools, will be measured by looking at how they can fulfill the learning goals suggested by UDIR\textsuperscript{21}. For specifically the field of the periodic table there are quite a few existing resources meant for supporting education. They have varying levels of interactivity and visualization. These existing tools had a big role for conceptualizing and designing my own prototype, so their key aspects will be presented.

5.1 goREACT

The most suitable and relevant for this project is the web-app called goREACT, created by several parties for the Museum of Science and Industry in Chicago \cite{26}. The app demonstrates what different elements can become once they react with each other. It also gives information about each element and displays hints for which elements the user can put together for a reaction. If used in tandem with teaching about the periodic table in general, it can be a powerful scaffolding tool for creating relations between the abstract periodic table and things that the students have or experience in their regular life. It shows pictures of what kind of items that contain the element, and also shows pictures of what becomes of the elements when they react with each other.

The app lets the user switch what mode the periodic table is shown in. In its standard mode it shows the elements as the corresponding letter name with an atomic number. Based on how experienced the user or student
is with different aspects of the periodic table, they may choose to switch the view of the periodic table for the same experience, but with a different perspective. The different periodic table versions are:

- Standard mode with the atomic mass of each elements added. All of the atoms have this mode.

- Only the ionic charge of each element. Atoms with atomic numbers 1-83, 57, 92 and 94 have this mode.

- The letter name of each elements with a Lewis dot structure [27]. See 5.2 on which atoms are presented with this structure.

Other than those options, the app gives hints to the user for what atoms they can put together to form reactions. These prompts can can engage students in participating further if they get stuck. The hints in goREACT can be seen as process oriented prompts, but students may still fall into the trap of dragging and dropping in the suggested atoms without thinking about what they may gain from the reaction. goREACT allows for exploration and playing with the atoms.

![Figure 5.1: Thought bubble prompting the user to start interacting with goReact.](image)

Fig 5.1 shows the first prompt the user gets when visiting the application. A bubble shows up on the screen giving a hint to what the user can add
into the reaction area, introducing the user to what they can do with the application. The hint comes either in the form of suggesting an atom, or suggesting a chemical compound.

![Element Highlighted](image)

**Figure 5.2:** An element is highlighted by being outlined by arrows.

The bubble then disappears, and if an atom was suggested, it will be highlighted further with arrows around the box (fig 5.2). If clicked, the application will display a small rectangle with a *fun fact* about the atom at the top of the screen. I will refer to this rectangle as the *info box*. The text in the info box is accompanied with an image relating to where the element can be found in everyday life. In fig 5.2, the atom clicked is aluminum. The descriptive text contains that it is found in "...everything from airplanes to aluminum foil", and the image is of a clump of said foil. The text in the info box can vary, and sometimes contain suggestions for experiments the user can do to see a compound’s properties.
Figure 5.3: An image representing the reaction created by the user.

The user can then drag that element into the small square at the bottom of the screen. As the user drags the element, it turns into a small, round "orb", with a specific color. When the correct atoms are dragged and placed into the reaction area, an image shows up with a short descriptive text on what the user has "created" (fig 5.3). This image takes most of the screen space, and the descriptive text is usually one sentence at the bottom of the screen.
Figure 5.4: Yellow lines are animated to "emit" from the compound created.

When the user closes the image, or the image disappears itself, an animation is shown in the small rectangle where the atoms are. The animation is strings of yellow, squiggly lines "flying" from the compound, representing energy being emitted from the compound being created (fig 5.4).

The pros and cons of goReact, as well as the other resources stated in this chapter, will be analyzed further. The scaffolding properties of goReact will also be further discussed in the Design choices chapter.

5.2 Periodesystemet.no

Periodesystemet.no is a web application created and updated by the University of Oslo. It features a full periodic table of elements, where each element is interactive. When clicked, the page redirects to highlight the element and provides links with information about different aspects of the element. This application also contains multiple representations of the periodic table, including differently color coded maps, a word cloud representing the elements’ abundance, and much more.

The language is not an issue, as all the pages are in Norwegian. The students also have some control and interaction with the website, clicking on links or hovering over elements gives further information. Each element also
5.2. Periodesystemet.no

has several representations, shown in the form of images and text. The complexity of the language used in the website is scientific, and more geared towards advanced students. However, it is written simply enough, and categorised in ways that can make it easier for students in the second grade to follow along.

![Periodic Table](image)

**Figure 5.5:** The main page of Periodesystemet.no.

When the user first enters Periodesystemet.no, they see the full periodic table of the elements, along with some textual prompts. The first prompt says "Choose an element!", and the second, right above the periodic table, informs the user of which color filters the periodic table is being shown in. In 5.5, the periodic table of elements is shown with the filter of metallic properties, where the dark blue color represent elements that are metals, and the light blue represents non-metals. The green coloration represents metalloids, but for simplicity, they can be considered a part of the non-metals.
Figure 5.6: Periodesystemet.no showing the different filters available

It is possible to change the color theme of the periodic table by applying filters. These change the periodic table’s colors, and information displayed on each atom. This is similar to the functionality in goReact\[5.1\] although Periodesystemet.no seems to have more filters.
**Figure 5.7:** Clicking on an element shows some information about the atom. In this image one can see a prompt as well.

When an element is clicked, the element’s square in the table is highlighted, and a brief description of the element is shown above the periodic table. On the top right corner, a small "Did you know" box occasionally pops up. These contain short facts in the form of an open question, where the user can also click a link to give them more information.
Figure 5.8: What is shown when more information about an atom is clicked. To the left, there are categories of information about silver. This page also contains a little prompt.

The information page of the element, in this case silver, contains further information about the element. Its scientific name, along with its common name, as well as images of the different forms silver can take. The page is sectioned into categories, based on where the element can be found. On this page, there is also information boxes with "Did you know?" questions.
5.3 Games and media

The university has a couple of games related to learning about the periodic table of elements, namely Periodic Puzzle and Chain. In Periodic Puzzle, the point is to place the elements back into the periodic table in their respective spaces. This requires that the student has an understanding of how the atomic value in each element works and why elements are placed in the periodic table the way they are. The game has a scaffolding element of letting the user choose how much help they want in order to complete the puzzle. The application is for use on mobile devices, and works on smaller screens, but works best on larger ones, such as an iPad [28].

In Chain, the user is presented with different molecular models and is supposed to select the correct amount of atoms involved in the model. It is timed, and the user can lose points if they choose a wrong option. The application comes with a separate instructions page. While this game has aspects of fun involved, and can be used as a new experience with chemistry and bonds, it might be hard to add to a collaborative environment. The timed aspect of the game allows for very little discussion and reflection, as the game relies more on the recognition of different molecular shapes and models.

Games can be used in a classroom setting to test out the students previous knowledge(Young et.al. [29]), but need to have some element of reflection involved. If the user is not prompted to reflect upon their choices, it is very easy for the user to resort to mindlessly clicking and simply achieving a score instead of understanding what they are actually doing (Dolonen & Kluge [13], Furberg [30]).
Chapter 6

Pre-design data collection from the School

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>School A</td>
<td>The first school, where observations, interviews and testing took place.</td>
</tr>
<tr>
<td>Teacher A</td>
<td>The first teacher I came in contact with, responsible for class 1. Observed his class, had informal interviews.</td>
</tr>
<tr>
<td>Teacher B</td>
<td>The second teacher, responsible for class 2. Observed her class twice, had formal interview.</td>
</tr>
<tr>
<td>Class A.1</td>
<td>A class of 8th graders, just learning about the periodic table of elements, only observed.</td>
</tr>
<tr>
<td>Class A.2</td>
<td>A class of 9th graders, learning more about the elements and their reactions, observed and interviewed.</td>
</tr>
</tbody>
</table>

Figure 6.1: A table of the different classes and teachers I gathered data from for my design process.

Before starting to design my prototype, I did some preliminary data gathering to map out problem areas and commonly used teaching methods in secondary school classrooms. These preliminary observations and interviews took place in the first school, School A. During both data gathering sessions, the students were learning about the periodic table of elements. The following sections will have the results of my data gathering structured into tables. They contain the teacher’s perspectives on teaching
about the periodic table of elements, and their thoughts on what is difficult for the students.

The second section describes the students’ perspective and their impression about learning about the periodic table. This was particularly important for the user-centered focus of my design process. Following the students is my own observations and impressions of a classroom session.

6.1 Teachers’ perspective

The interviews with the teachers from school A gave insight on their perspectives when it came to teaching about the periodic table of elements. Teacher A was more informally spoken with in regards to his teaching about the periodic table of elements. His focal point was to let students understand the connection between atoms and everyday objects. He meant that it was a difficult and abstract concept for the students to understand. Since he was responsible for Class A.1, he commented that "At the age they are in, they simply need to cram this information in. They have to take [our/the books’] word for it, as there is little else they can do to truly understand it". Since Class A.1 were eight-graders being taught about atoms and the periodic table of elements, it would be difficult for them to come with reflections and start discussions with their classmates about the topic.

Teacher B’s focal point when teaching about the periodic table of elements was the big picture. Somewhat connected to Teacher A’s focal point. She wanted the students to see the connections between the atoms, their properties, and their real life applications. She did, however, note that the students could show a little more curiosity, to not accept what they were told immediately. The students were more engaged in doing practical experiments, but needing to take time to learn theory before they practice it. She mentions later that class A.2 are curious, but are more alert and present in the classroom sessions when the topic mentions things they are familiar with. These topics include the human body, or other everyday topics and terms. Teacher B’s ultimate wish was that the students explore the theory as much as they showed interest in the practical experiments.

6.1.1 Resources

The school book was central for both teachers, as it contains tasks, experiments and information fit for the context of the classroom. The book is written with a language targeted towards secondary school students.
The experiments are chosen based on how they tie in with examples and prompts in the information chapters of the book. The teachers would engage students when teaching about the periodic table of elements with the following resources when teaching:

- The school books, NOVA 8 and 9 or Tellus, their most reliable resource
- Experiments, either set up by the teacher, or from their books.
- Periodesystemet.no
- Educational videos
- Molecular building blocks, but more reserved for 10. graders when learning about organic chemistry.
- Posters of the periodic table
- Presentations, extra paper handouts, images used during lectures.

The teachers use different representations in order for the students to learn how the periodic table of elements is structured. However, it is still hard for the students to understand the connection between the properties of elements and how they are set up in the periodic table.

The last commentary from the teachers was regarding time and exploration. Teacher B commented specifically that she wished she had more time for following up the students learning. And in regards to exploration, that the students could find joy in exploring the periodic table.

6.2 Students’ perspective

The students of class A.2 were interviewed, a group interview of two girls and two boys. When asked what they thought about learning about the natural sciences in general, the first reply was that it was boring. It then changed to the topic being exciting, but that there was quite a lot of cramming involved. They enjoyed the experiments, but not writing and that there was so much to learn. One student pointed out that he felt like it would not be of use. The students were excited about the current project they were working on; writing about an element of their choosing. Another thing they enjoyed, were the experiments.

When asked what they remembered learning, the answers varied. One student mostly remembered hydrogen, as it was the element they were
writing about. Another understood how groups and periods were connected, another didn’t. They also commented that sometimes it would be too much information. Too many drawings by the teacher, and too much to go through in one session. This would make it hard for some of them to concentrate or be engaged in the classroom session.

The students commented that learning by talking with their peers, or getting difficult things explained by their peers, was what helped most. Their peers used a more simple language, on the same level as themselves. When asked about their opinion group work, their impressions were divided. They would enjoy group work if they were evaluated individually. The students were also concerned about the group’s level, as in, how much each group member could contribute. If there was one hard worker in the group, most of the work would end up being their responsibility. Having a group where each member could take responsibility for their own learning would be ideal, but this posed another problem for the students.

From the interviews, I also gathered that group work could be tricky for the students. Group work creates a choice between societal norms and the personal goals for the students. This means, the issue of choosing a group in order to have a good group dynamic clashes with feeling like one has to group up with friends. If they choose friends, they can keep up the societal norms of being loyal to their friends, but then that can disrupt their work ethic and progress. If they choose the best "group" structure, they prioritize their own educational development. However, if the teacher randomly chooses a group, they end up constructing groups by delegating the work to the group members.

6.2.1 Resources

Via observations, I gathered a list of resources of what the students would use when they were left for individual work. This list contains what the students used, whether prompted by their teacher or searching on their own.

- Laptops, used by class A.1
- Stationary computers, used by class A.2
- Store Norske Leksikon, used by both class A.1 and A.2
- Wikipedia, used by both classes
- Google search, used by both classes
6.3. Researcher’s perspective

This section presents my own observations of classroom sessions in both class A.1 and A.2. My aim was to gather impressions of how the classroom session is structured, and how the students act during a regular session.

6.3.1 Class A.1

The first observation was in Class A.1, and was already set up before the students were to arrive. The students had a divided class, Class A.1.1 had 8 students, Class A.1.2 had 13. As the class started the teacher first asked if anyone remembered anything from their previous classes in relation to the periodic table. They had two weeks to learn about the elements and how they react with each other and this was their second week. With the first half of the class, the teacher asks them questions in a more casual manner:

“What decides what is groups, and what is periods?”
“What do the elements in a group have in common?”
“What is the wildest dream for all atoms?”

The teacher had the objectives for the day’s class displayed on a projector, and the task for the class was written on the blackboard:
Goals:

- I can explain how the periodic table of elements is built by periods and groups.
- I know what the octet-rule is
- I recognize the characteristics of alkaline metals, halogens and noble gases.

Plan for the class:

Expert groups (for the three groups) On Wednesday you share your knowledge

Figure 6.2: Instructions for class A.1 given by the teacher

After a brief recap of what they had learned prior to the autumn holidays, the teacher then divided the students into three expert groups. Each group was to focus on one main group/basic family. The students were to first read the book, then look for more information online, using laptops. When the students got to the part of finding their own information, they all went to Google, and searched for terms they had read about in the book. This lead to the majority of students visiting Det Store Norske Leksikon, which contains adult language and even more complex expressions.

Despite being grouped together, and needing to work together for their project, there was little talking and discussion going on. Each student had their own books, their own laptops, and worked individually. The teacher would walk around and ask questions in an attempt to start some discourse, and to explain some harder concepts for the students.

6.3.2 Class A.2

Like class A.1, the teacher wrote the objectives for the class up on the blackboard:

"Today we continue with bonds and the periodic table of elements"

In class A.2, The students were more inquisitive, and when the teacher demonstrated the structure of the periodic table, the students would ask
questions. The teacher would join them in wondering about interesting aspects about the elements, such as:

"Why is it called a blyant(pencil) when there is no bly(lead) in it?"

After answering some questions, using the periodic table of elements poster on the wall, she told the students to work individually for a while. The students were seated as groups, however, and the teacher encouraged them to explain things for each other. One of the students started explaining ionic bonds to a fellow student, but was interrupted after a while when the teacher needed to move on with the classroom session.

Their second classroom session, where they were to make a poster about an element, they had computers and a list of resources they could use to find information. The task was presented as "Creating a poster of an element that contains the following...":

- Create a shell model
- Which element family/group the element belongs to
- The element’s properties
- What is it used for
- In which ordinary chemical bonds does it exist
- Fun facts or other interesting things

The students could pick which atom they wanted to make a poster on, and were immediately interested in finding the coolest atom, or at least the most interesting ones. The way they measured said interest, would be based on where the element could be found that they found interesting. The closer relation an element had to everyday concepts they were familiar with, the more popular it was. For example, oxygen was immediately claimed.

From the observations in the classroom sessions, I gathered that interactivity with the topic, in the form of experiments, for example, were what stuck with the students best. Those interactions engaged them, and were memorable. Another observation, was that the contents of each existing resource was not always made with second grade students in mind. Whether it was irrelevant to what they were learning about, or out of scope,
the content could end up confusing the students even more. The language being in Norwegian was important too, as that is the language they would be tested on, and the language which would be used in the classroom sessions. Finally, being able to relate elements with everyday concepts would make them memorable, so it was important to have a resource that had multiple representations.
Chapter 7
Design Choices

For this chapter I will be accumulating the perspectives of the teacher, the students, and my own analysis of both the classroom sessions and existing tools. The goal is to guide my design of my prototype so it can fulfill these accumulated needs.

7.1 Summarizing the perspectives

First and foremost, the teacher’s perspective presented two issues:

- *Making connections* between atoms in the periodic table of elements and their relation to the world
- *Exploring* the theory behind the periodic table of elements and the properties of elements

The points in [7.1] are mainly taken from Teacher B, as my focus group ended up being 9th grade students. Both the teacher’s opinions on these matters have been structured into the table in fig [7.1]. This table, along with the other perspective tables, will be used to shape the purpose of my prototype, and how I judge existing prototypes. If the table contains N/A, it means that no specific statement was given regarding the topic.
## 7.1. Summarizing the perspectives

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Making connections</th>
<th>Exploration</th>
<th>Curiosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Might be difficult at the beginner level, as atoms and the periodic table of elements is very abstract</td>
<td>N/A</td>
<td>Accepting what they are given, not much room for reflection</td>
</tr>
<tr>
<td>B</td>
<td>Important for the students to understand the big picture, how the elements are all around us, and their properties affect the real world</td>
<td>Not just explore the practical experiments, but also the theory behind the reactions.</td>
<td>Questioning what they do, and the information they are given</td>
</tr>
</tbody>
</table>

**Figure 7.1:** Mapping the teacher’s perspectives

The students presented new issues, related to their personal experiences with learning about the periodic table of elements, combined with their everyday experiences in the classroom. Their main concerns about learning in the natural sciences subject are stated in fig. 7.1:

- **Level of entertainment:** students commented that compared to other subjects, learning about the sciences can be boring. This makes it hard for them to like the subject, often related to the other points in this list.

- **Type of content:** whether the students are working on written assignments or practical experiments. Their interest varies based on the type of content, and also what they can relate to. Whether what they learn can be used in the future is important for some of them as well.

- **Amount of content:** when there is too much information being given to them in very little time, without them being able to follow the information at their own pace, this makes learning about the topic difficult, as they can lose the thread.
• *Level of complexity;* Some subjects are easier and more fun than others, because it’s easier to relate to them. There are more everyday concepts attached to the scientific ones.

• *Level of language;* having something difficult explained to them by a peer with their own language and expressions is easier than the language that teachers use.
### Figure 7.2: Students’ opinions on learning about the periodic table

<table>
<thead>
<tr>
<th>Student</th>
<th>LoE</th>
<th>TOC</th>
<th>AoC</th>
<th>LoC</th>
<th>LoL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.G1</td>
<td>Natural sciences, compared to other subjects, is boring</td>
<td>Not too much to learn, but cannot be applied to the real world</td>
<td>Level of complexity is fine, but it’s not interesting enough</td>
<td>Despite the topics being complex, he could have understood, but it’s not interesting enough</td>
<td>Learns better from friends</td>
</tr>
<tr>
<td>A.G2</td>
<td>Not that boring, but it is boring to have a teacher that gets mad</td>
<td>Practical experiments are fun</td>
<td>Atoms in general are difficult, but also atom’s shells</td>
<td>N/A</td>
<td>Learns better from friends</td>
</tr>
<tr>
<td>A.J1</td>
<td>Actually boring</td>
<td>N/A</td>
<td>A lot of content, difficult to keep up if you miss something.</td>
<td>Ions are difficult</td>
<td>Learns best by talking with peers/friends, and having them explain difficult topics in a lower-level language</td>
</tr>
<tr>
<td>A.J2</td>
<td>Exciting when they do practical experiments</td>
<td>There is a lot to learn</td>
<td>N/A</td>
<td>Ions are difficult</td>
<td>Learns better from friends</td>
</tr>
</tbody>
</table>
7.2 Forming a Purpose

Each perspective and problem area can be related to the three examples of scaffolding presented in the theory chapter 3.3. **Making connections**, from the teacher table 7.1 and **Type of content** from the student table 7.2, can be related to **Multiple representations** 3.3.3. By showing the students different forms the element can take, can make it easier for them to relate atoms and its properties to everyday objects.

**Level of complexity** and **Level of language** is already tied into making sure there is a balance between usage of everyday concepts and scientific concepts 3.3.1. From their interviews, it seemed that the students were more comfortable having scientific concepts explained in relation to everyday concepts, instead of explaining them with even further scientific concepts. The latter would lead to them feeling overwhelmed. When A.J1 from 7.2 was asked what helped her to learn the most, she commented:

"I think fellow students [help me the most, though it] depends on which fellow student you ask? But i think it works best, because they can explain in a way that they know you will understand. Since they are the same age, [they] don’t explain it so much more difficult- or too simple."

**Exploration/curiosity** can be tied with prompts, as hints and suggestions can lead students to exploring the application more 3.3.2. Finally, **Level of entertainment** is a slight mix between all three scaffolding elements. This is where the *interactivity* comes in. From Kluge and Dolonen’s research on combining algebra with gaming, the students showed much more interest in maths. Dragonbox represented maths in a way that made it more interactive and fun, and this lead to the students being engaged with it longer.

My design choices will be based on the practical feedback given by the teachers, students, and my own observations. Their feedback, however, is yet again traced back to concepts that implement scaffolding:

- Combining scientific and everyday concepts
- Making sure they are prompted to engage the student in continuing their exploration and interaction
- Adding multiple representations
7.3 Evaluating the technology

The existing resources I have presented, namely goReact and Periode-systemet.no, each have their ways of implementing the three scaffolding examples from 3.3. In order for my prototype to differ from the existing technologies and resources listed, I needed to map out what worked and did not work with the existing resources. In order to do this, I will compare the existing resources to the purposes listed in 7.1.

In the beginning, I was not sure whether I would develop a web application or a tangible tool for the students. When I saw that the students had access to laptops and computers 6.2.1 I decided to make a web application. This was both for the accessibility of the learning tool for different schools, but also what was the most familiar thing for me to create, considering my programming background.

In fig 7.3, the different colors are representative to what degree the different resources meet expectations based on my purpose from 7.1. A white background means not relevant or interesting for my use. A light green background represents components that I wish to include, but that are not optimal in relation to the purposes proposed. The strong green color is both what I want to include, and that works well in the existing resource as it is.
### 7.3. Evaluating the Technology

<table>
<thead>
<tr>
<th>Tool</th>
<th>Interactivity</th>
<th>Contents</th>
<th>Language</th>
<th>Representations</th>
<th>Prompts</th>
</tr>
</thead>
<tbody>
<tr>
<td>goReact</td>
<td>Clickable, draggable elements with a reaction zone for creating reactions</td>
<td>Little textual information and context</td>
<td>English, everyday language</td>
<td>Images, text, animation, filters</td>
<td>Arrows suggesting atoms and reactions, suggestion-cloud</td>
</tr>
<tr>
<td>Periode-systemet.no</td>
<td>Clickable elements</td>
<td>Plenty of content about the elements</td>
<td>Norwegian, slightly difficult language</td>
<td>Images, text, filters, categories</td>
<td>&quot;Did you know?&quot;-text snippets</td>
</tr>
<tr>
<td>Store Norske Leksikon</td>
<td>None</td>
<td>Complex levels of content</td>
<td>Norwegian, a difficult vocabulary, many scientific concepts</td>
<td>Text, tables, images</td>
<td>None</td>
</tr>
<tr>
<td>Nova (Book)</td>
<td>None</td>
<td>Appropriate content written for student-level comprehension</td>
<td>Norwegian, mix of everyday-and scientific concepts</td>
<td>Images, text</td>
<td>&quot;Did you know?&quot;-text snippets</td>
</tr>
<tr>
<td>Class sessions</td>
<td>Interactivity with teacher and whatever tools they are using in the classroom</td>
<td>Appropriate content written for student-level comprehension</td>
<td>Norwegian, mix of everyday-and scientific concepts</td>
<td>Videos, experiments, models, Teacher pictures, text</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 7.3:* Table showing the main attributes of each resource
Chapter 8
Designing MyReactor

The aim of MyReactor was essentially to bridge a gap between a gaming application and a learning tool. As explained in the design choices chapter, there was also a gap between cramming the properties of an element, and actually understanding how it all fit together. I interpreted the quote from one of the teachers (see 6.1) as: students struggle to understand the abstract concepts related to atoms, as atoms are not visible to the naked eye, and the experiments done in relation to learning about the periodic table cannot allow for the manipulation of atoms themselves. I wanted to design an application where they could manipulate a representation of the elements and atoms, and allow them to see patterns while manipulating the elements.

8.1 Design components

The majority of the design components for MyReactor were taken from the existing goREACT application. goREACT has a fundamentally close functionality to what this application is supposed to achieve, with the exception of the language used, and not enough explanatory text, as well as no structure for showing an end goal. MyReactor contains elements, meant to be dragged and dropped into a reaction zone, where upon clicking checking their reaction, they may unlock achievements. The drag-and-drop nature of MyReactor has mainly come from Kluge and Dolonen’s study, described in 3.3.1 where the game DragonBox had a similar function.
8.2 Elements

Each block of "elements" is a square with the chemical symbol written on them. Each element's background color is referenced from *The Periodic Table: A Visual Guide to the Elements* [31], as well as images of the periodic table shown on 2.2.

(a) An oxygen atom, colored light green (b) Sodium with dark red for alkaline-metals

(c) Neon with a purple color representing noble gases. (d) Fluoride with a yellow color for halogens.

**Figure 8.1:** Different colors of atom blocks

8.3 The Reaction Zone

The reaction zone has two main modes, an *interaction mode*, and an *information mode*. As the name indicates, interaction mode means that the reaction zone can be interacted with, while in information mode, the user is displayed information. The reaction zone cannot be in both modes at once.
8.3. The Reaction Zone

8.3.1 Interaction mode

When the reaction zone is in interaction mode, it is not displaying information, and atoms can be added to the zone. It starts out empty with the description "Drag and drop elements into the reaction zone!", as shown on Figure 8.2.

![Figure 8.2: An empty reaction zone](image)

When elements are added to the zone, buttons appear to allow the user to either check reaction or empty the zone. Due to the limitations of the prototype, only three elements are allowed at a time in the reaction zone. This was also a choice made in order to limit the focus on simple, inorganic compounds. The aim of the prototype was to allow visualization and familiarization with the basics of reactions and properties of atoms.

![Figure 8.3: Addition of atoms into the reaction zone shows buttons](image)

8.3.2 Information mode

When the reaction zone is in information mode, it displays information with text and images to the user. Based on what type of information the prototype is showing, the layout of the reaction zone changes.
8.3. The Reaction Zone

**Figure 8.4:** The reaction zone showing information about an atom

In 8.4, the information shown is when the user clicks on an element. This was mainly referenced from how the interactive periodic table of elements from the Department of Chemistry works. To the left, there is an image of where this element can be found in the real world. In the middle, there is a description of the element, including whether or not it is metallic, and which group it belongs to. To the left, there is an animation of the atom, represented through Bohr’s model.

**Figure 8.5:** The reaction zone shows that the user made carbon dioxide.

In 8.5, the information layout shows when a successful reaction is made. The image of the reaction is shown to the left, the type of reaction or
8.3. The Reaction Zone

grouping is shown in the middle, as well as the atoms that made it, and the description of the reaction

(a) The reaction zone showing info about a reaction type, in this case ionic bonds.

(b) The reaction zone showing info about a grouping.

Figure 8.6: What happens when the user clicks on an achievement

Lastly, in 8.6, the reaction zone the last type of information view, consisting of an image or animation to the left, and a description to the right. This view is related to unlocking achievements, and the descriptions contain open-ended questions to prompt reflection between students. One of these questions, as shown in 8.6b, asks "Think about what you typically imagine when someone says the word "metal". What words do you think of?". 
8.4 Achievements

Figure 8.7: Response given to user when they have an incomplete reaction.

Another Prompt is shown in the reaction zone when the user has not added enough atoms in the reaction zone for a reaction to occur, shown in 8.7.

8.4 Achievements

Figure 8.8: The symbol for a locked achievement

Achievements represent the different reaction types and groupings that the students are meant to achieve. These are related to the goals presented in 2.1 and are obtained by knowing how to group together atoms. There are 8 achievements in total, and upon unlocking them, the user receives information about the achievement. The information comes in the form of an image or animation, accompanied with a block of text, usually ending with an open-ended question. This functionality was inspired from goReact5.1 where the user gets an image of what they have created when they add atoms together. The difference being, containing more information about what kind of reaction the user makes, as well as an
animation of the actual atoms added to differ my prototype from the existing Periosdesystemet.no

8.4.1 Reaction types

\begin{figure}[h]
\includegraphics[width=\textwidth]{reaction_types.png}
\caption{The achievements for reaction types}
\end{figure}

(a) Ionic bonds \quad (b) Metallic bonds \quad (c) Covalent bonds

Fig. 8.9 shows the icons representing the achievements for unlocking the different reaction types. In fig 8.9a the imagery is supposed to represent the opposite charges an atom gets when it gives and receives an electron, prompting an ionic bond. The three orbs in fig 8.9b are supposed to represent clumps of gold (an element and a metal), silver (also an element and a metal) and bronze (an alloy). These three colors are supposed to represent commonly seen metals, with a shine to represent the sheen metals commonly have as a visual property. This sheen is also drawn in a different way in fig 8.10d.
8.4.2 Element Groups

(a) The block representing ionic bonds
(b) The block representing metallic bonds
(c) The block representing covalent bonds
(d) The block representing metals
(e) The block representing non-metals

Figure 8.10: The achievements for element groups

The element groups achievements represent the groups described in 2.1. Fig 8.10a represents the alkaline group, characterized by their one electron in their outermost shell. This leads to them being electropositive, wishing to get rid of their electron for a full shell. Hence the +1 in the center of the atom.

Fig 8.10b on the other hand, contains seven electrons in its outermost shell, and is drawn as such. Halogens are extremely electronegative, hence the -1 in the center. Finally, noble gases have a full outermost shell, and is drawn as such. The zero in the center represents that noble gases have no electronegativity. They do not want to give or receive any electrons, hence their non-reactive property.
8.5 Programming language and frameworks

Since MyReactor is a web application, the most suited language for an interactive single-page website is Javascript. ReactJS [32] was the library I chose, mainly for its convenient setup and easy integration with web-server services like Heroku [33].

```javascript
class Element extends React.Component{
  constructor(props){
    super(props);
    this.state = {
      name: props.eleName,
      image: props.eleImage,
      desc: props.eleDesc,
      ex: props.example,
      atom: props.atom,
      group: props.groups,
      metal: props.metal,
      showInfo: false,
      clickCount: 0
    };
  }
}
```

Figure 8.11: Code snippet from the Element component

The element component shown in Figure 8.11 contains the variables that will later determine what kind of information will be shown in the reaction zone. These variables also determine what kind of reactions or groupings the element is involved in.
checkBinding(){
    let tmp = this.props.reactants.map(e => {return e.name});
    let reactions = this.state.reactions.map(r => {return r.elements});
    let names = this.state.reactions.map(r => {return r.name});
    let image = this.state.reactions.map(r => {return r.img});
    for(let i=0; i<reactions.length; i++){
        let found = this.compareSets(tmp, reactions[i]);
        if(found){
            return [names[i], i, image[i]];
        }
    }
    return null;
}

compareSets(a1, a2) {
    if (a1.length !== a2.length) {
        return false;
    } else {
        let match = 0;
        let tmp = a2.slice();
        for(let i =0; i<a1.length; i++){
            for( let j=0; j<tmp.length; j++){
                if(a1[i] === tmp[j]) {
                    tmp.splice(j,1);
                    match += 1;
                    break;
                }
            }
        }
        return (match === a1.length);
    }
}

Figure 8.12: Code snippets from the Reactor component

The above snippet shows one of the methods used for finding the correct reaction based on which atoms are added into the reaction zone. As the reactions container is an array, the algorithm in compareSets() iterates through each value in the array and checks if there is a total overlap between the elements added in the reaction zone and the elements required for a specific reaction. This ensures that no matter what order the users add the atoms into the reaction zone, it will still display the correct reaction.

React is mostly a tool meant for front-end, creating dynamic visualizations on the web page itself. Normally it needs external components for database
support and back-end programming. Due to time constraints, only React was used to create a simple prototype in order to have some functionality for learning purposes.

The final prototype can be found on github at:
https://github.com/mahasty-assi/MinReaktor.

The final version of the prototype can be visited at:
https://minreaktor.herokuapp.com/
8.6 Scaffolding elements

The components of MyReactor have all been carefully selected based on the design choices made from the previous chapter. The components are also based on the scaffolding elements from 3.3.

8.6.1 Multiple representations

The multiple representations of an atom in MyReactor are:

- ...showing it as an animated model
- ...showing where it can exist in an image
- ...describing its attributes with words
- ...presenting it as an avatar of the atomic symbol

A missing representation would be each element in its "original" form. This could have even further shown the user the properties of each atom. If all the metals were shown to be metallic, answering the metal bond prompt question may have been easier.

The representations of achievements are a little more connected to the actual atom-avatar, but also colors. The representations are:

- ...showing an image representing the group OR showing an animation of the reaction type
- ...describing the achievement with text
- ...an illustration as an avatar for the achievement

The image used for the group achievements are simply the avatars of the atoms belonging to that specific group. If a user unlocks one group, and sees that there are atoms not in that grouping, then they might come to the conclusion that atoms not in that group, exist in another group instead.

Since the avatars for the atoms are color-coded, the user can also co-relate the color of the atom-blocks/avatars, with the color of the achievement avatar. The choice to make the background and art elements of alkaline metals, halogens, and noble gases the same color as the atom blocks the group consists of, I am hoping it is a connection that is noticed.
8.6.2 Prompts

When the students open the application, they are met with:

"Click on an element to see information about it" (see fig 8.4)
"Drag and drop elements into the reaction zone!" (8.2)

These are *process* oriented prompts, telling the user *how* to navigate the application. In my application, these are the only prompts I would describe as process-oriented. The rest of the prompts in MyReactor are *content oriented*. Placing the words "Groups" and "Reaction types" over the two types of achievements gives a hint as to *what can be achieved* in MyReactor. This gives a suggestion for what the user is supposed to *discover*.

If the user attempts to create a reaction or grouping that either does not exist, or is not implemented into the application, the user will receive a message:

"Are you missing any atoms?" (see fig 8.7)

This is *intended* to make the user think about whether or not the reaction they are making needs another atom, or more of the same atom. A lot of reactions, like $H_2O$, need two hydrogen atoms.

The last *types* of content-oriented prompts are the questions added into achievements’ information boxes. These questions are mostly open-ended, so the users can take time to reflect on the achievement they just unlocked.

An example for one of these questions for the group achievement is:

"Think about what you usually imagine when someone says "metal". What words do you think of?"

This question is meant to make the users think of words like *shiny* or *heavy*, words associated with the properties of metals.

An example for what kind of questions are asked for reaction type achievements is:

"Do you see a pattern for which types of atoms that most often form ionic bonds?"

This kind of question is more for the user to be able to consciously make more ionic bonds. If they can find a pattern for how ionic bonds are (in
a very basic way) created, they can understand the connection between elements’ electrons and their reaction types.

8.6.3 Everyday- and scientific concepts/language

The everyday concepts present in MyReactor come in the form of:

- ...images of objects that contain the element
- ...description of atoms including references to familiar items/concepts

Adding images of items that contain the atom is a representation of the atom in a way that allows the user to recognize it. That spark of recognition can set in motion meaning-making processes as the student related the element to a specific item. This was seen especially during the observation of class A.1, where the student asked the teacher that:

"If fluorine is poisonous, how can we have it in toothpaste?"

They relate fluorine, an element, to toothpaste. The compound Fluoride is what is actually in toothpaste, but the student asking this question already has them curious about what scientific concepts exists in their everyday world.

By mixing familiar elements with unfamiliar imagery, I hope to achieve the same effect for the students testing out MyReactor.
Chapter 9
Evaluation of Testing

In this chapter I will go through the setup and results of the testing of MyReactor. MyReactor was tested three times:

- Preliminary testing to gather first impressions and check feedback on basic functionality
- Main test for preparing a classroom session where MyReactor is properly used
- Final test containing a slightly different setup than the Main test

The preliminary test was used to fine tune some functionalities, to make sure that the application was easier to use for the students. The main test had a structured classroom session and some extra elements added to help them understand their task. The final test was to see how I could structure a classroom session so that the students could focus on nothing but the process and contents of MyReactor, instead of struggling with things covered in the main test.
9.1 Pilot test: Class A.2

Class A.2 was the class with the students whom I had observed the most. The group I interviewed also came from this class. While their experiences and perspectives contributed to the design of the prototype, they did not get to test the fully functional prototype, only its early iteration. This iteration lacked interactive achievements, and did not have that many bonds registered. Due to last minute changes before the test, some existing, correct information was also changed to be incorrect.

9.1.1 Task setup

As this was my first test, I did not have any specific setup planned. I drew the different MyReactor components on the blackboard as guidelines for what could be interacted with. After introducing the goal of my prototype, I asked the students to go to the website and simply explore.

9.1.2 Interactions

The classroom session was recorded, but the video was too far away from any one group. Due to the noise, their conversations were not easily transcribed, if at all. However, there were some interactions that could be followed. For the sake of simplicity, I have given the students simple names for this transcript, as there is not much of it.
Hunting for achievements)

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>07:00</td>
<td>AS.1</td>
<td>&quot;aaaaagh!&quot; ((while he is looking at the screen))</td>
</tr>
<tr>
<td>07:10</td>
<td>AS.1</td>
<td>“C O 2! Take two oxygen”</td>
</tr>
<tr>
<td>07:14</td>
<td>AS.2</td>
<td>((mumbling)) “O.. two!”</td>
</tr>
<tr>
<td>07:17</td>
<td>AS.1</td>
<td>((dissapointed tone))“Noooo, it wasn’t an achievement?”</td>
</tr>
</tbody>
</table>

Figure 9.2: Student dissapointed at not unlocking an achievement

The interaction in fig 9.2 is at the very beginning on the session, where AS.1 realizes that in order to get carbon dioxide, one needs two oxygen atoms. He then ushers AS.2, who controls the screen, to drag one carbon and two oxygen atoms down. AS.1 is, however, disappointed that they did not unlock an achievement. This classroom session did not have any specific end goal or task given to them, nor were they presented with any context of how they were supposed to use MyReactor. Therefore, to find meaning, the achievements became the sole tasks.

Later in the session, AS.2 exclaims:

“Yes! we got all the achievements! Yeah!”

This indicates that despite the unclear instructions and lacking functionality, there was still a thrill of being able to unlock all the achievements.

9.1.3 Group movements

An interesting phenomenon was that whenever a group was concentrating on making something in MyReactor, or reading something, they would all huddle in. They would focus on whatever they were reading or viewing on the screen, until a result was given, in which case the group would open up again, and they would sit back. This was observed with both group 2, 3 and 4.
9.1.4 Post-test evaluation

As the prototype was not finished yet when I tested it with class A.2, there was a lot missing that the students asked about. The functional issues made it harder for them to focus on creating reactions and groupings, as they would not be able to achieve some reactions even though it was suggested by the teacher. Some complaints both during the testing were that:

- They would forget how to close the information view from 8.3.2
- They could not see what the achievements represented, as each achievement was just an icon
- They did not see the point of using the application for an end goal, since no tasks were given to them

9.2 Main test: Class B.1

The main test took place in School B. This school had a system for grouping up students throughout their school years, for learning how to take responsibility in groups, and to get accustomed to group dynamics. Their work could be individual or collaborative, but the groups themselves had a structure where the group leader would make sure everyone pulled their weight, and would represent the group. The group leaders would be switched so every member of the group had been leader at least once. Once or twice a year, the group members would change as well.

The students in this classroom had been split to different classroom sessions, so I only had half the class. They were already split into groups. See 9.3 for the classroom structure and camera setup in B.1. The dark "heads" in 9.3 were the students who were interviewed.
Since their school was under renovations, this was not their original classroom. This classroom did not have any periodic table of element-posters, but plenty of history-related posters. The classroom also had a cellphone box, where the students would put their phones before the classroom session started.

9.2.1 Task setup

Following my experiences with class A.2, I tried setting up tasks for the students this time. These tasks were questions I formulated with UDIR's goals for the second grade(2.1) in mind. There were three questions the students were supposed to focus on during this session:

1. In what ways can elements be grouped?
2. How does the structure of elements determine their properties?
3. What properties lead to different reaction types?
The goal was to use MyReactor in order to be able to answer these questions, but also use the questions as a guide for how to use MyReactor. Each question is related to ways one can unlock the different achievement types. By thinking about how one can group elements, the students can unlock alkaline metals, halogens and noble gases. The question also works for metallic- and non-metallic bonds. Question 2 is a mid-way question in order to be able to answer question 3. By figuring out how elements’ properties work, that it is related to how many electrons there are in their outermost shells, it can help students remember the different reaction types.

Idea papers

In preparation for beta testing I intended to use a concept I called idea papers (Norwegian: idéark). These papers were meant to be a tool for a scientific thinking process as they were using the prototype. The papers were split into four sections, each section meant to be a step towards hypothesis creation and testing. The purpose of this was to see if the students were able to follow a scientific process of research when using MyReactor. Having them write it on paper would mean having a written reference to whether or not they understood the concept, and in which case what they would try and find out.
The students were encouraged to use the idea papers. There they could write down what they were wondering about, what they would do to answer their question, and what kind of outcome they thought their actions would have. The last section was set for reflection, if the students got the desired results and their thoughts on it.

As shown on Figure 9.4, the students did not manage to fill out the idea papers fully, and while some understood the concept of writing down their ideas, and the answers as they tried to solve their problems, it became more of a distraction than an asset.

The teacher was encouraged to participate by reminding the students of previous learning material that might help them answer some of the questions. At the end of the lesson, they were collectively quizzed by me with a simple test of drawing an "anonymous" atom on the whiteboard and asking what the students could tell me about it. At the end of the test, the majority of the students filled in the surveys regarding this experience.
9.2.2 Interactions

Most of the interactions shown here was from group 1, a group of three girls. Their table setup can be seen in fig 9.3. S1.1 was in control of the computer, and had the most knowledge about the periodic table among them. The following sections how the development of interactions as all three students understood the usage of MyReactor. Group 1’s interactions start with S1.1 tentatively trying out its functionality, and there is little chatter or speaking out loud as she does this. The other two members are unsure of what they are supposed to do, and it takes a few minutes for them to get comfortable with MyReactor.

Asking questions

As S1.1 is experimenting, student S1.2 is very inquisitive. One particular interaction between her and S1.1 goes as follows:

“Can- Is it possible to make gold?” - S1.2
“No, because gold it its own- eh... that’s why alchemists and such can’t make gold, because it is its own element.” -S1.1

This is a familiar setup as they continue to explore MyReactor. Student S1.2 will ask questions using everyday language, using phrases like "gold, water, air", and wondering how it is possible to make everyday things. Occasionally, if S1.1 knows that it is not possible, she will say so, but otherwise, she will attempt to try out what is being suggested. An example of this interaction is shown as the classroom session progresses.

9.2.3 Ideas based on scientific concepts

S1.1 starts talking a little while experimenting with the prototype. The first achievement they unlock is by combining one hydrogen and two oxygen. As she looks at the non-metal group, she exclaims:

"These here are non-metals, so what isn’t there [is] metals...like aluminium and magnesium?” -S1.1

When she groups those two atoms together, she gets an incomplete reaction-message. Her not getting a confirmation was due to the structure of my prototype and that I did not present its limitations during the classroom session.
She performs the same pattern when unlocking salt, and when prompted with the question "Do you see a pattern for which types of atoms usually form ionic bonds?", she immediately goes to the alkaline metals and starts mumbling.

Most of S1.1’s ideas are stumped by the limitations of my prototype. When she clicks on the different atoms of MyReactor, and sees that some of them are grouped as metals, she attempts to put them together. However, since she only groups two atoms max, the system does not register it as a grouping.

**Ideas based on everyday concepts**

S1.2 complains in the beginning of not understanding what they are supposed to do. As she sees S1.1 interacting with the prototype, she begins suggesting reactions. These suggestions are referred to based on things she experiences in real life, or recognizes from the images presented in the atom descriptions:

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:12</td>
<td>S1.2</td>
<td>“okey, what becomes like water”</td>
</tr>
<tr>
<td>12:20</td>
<td>S1.1</td>
<td>((mouses over to the achievement “non-metals” and clicks it)) “water became this”</td>
</tr>
<tr>
<td>12:21</td>
<td>S1.2</td>
<td>“what becomes air then?”</td>
</tr>
<tr>
<td>12:25</td>
<td>S1.1</td>
<td>“We can take…” ((drags two of oxygen over to the reaction zone and checks the reaction))</td>
</tr>
<tr>
<td>12:31</td>
<td>S1.1</td>
<td>“Oxygen gas!” ((achievement of covalent bonds appears, S1.1 starts reading the description out loud))</td>
</tr>
<tr>
<td>12:44</td>
<td>S1.1</td>
<td>((clicks on the covalent bond achievement and starts reading that description))</td>
</tr>
</tbody>
</table>

**Figure 9.5:** Transcript snippet of S1.2 giving reaction suggestions

S1.2 refers to bonds as actual things she recognizes, such as water, air, and gold. The interaction in [9.5] is interesting, as some misinformation is shared. When S1.2 asks "what becomes water?", S1.1 referred to the non-metals achievement. This was gained from S1.1 adding two oxygen atoms to the reaction zone instead of two hydrogen.
S1.2’s reactions correspond with what representation she relates to the most: the images shown in the information box in each atom.

<table>
<thead>
<tr>
<th>Time</th>
<th>S1.2</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>23:05</td>
<td>S1.2</td>
<td>((points at the screen)) “Which one of them had the white pencil again?” ((S1 opens up the information window for Si))</td>
</tr>
<tr>
<td>23:11</td>
<td>S1.2</td>
<td>“That one! So with Si and C” ((S1 closes the page as she hovers over Carbon))</td>
</tr>
<tr>
<td>23:14</td>
<td>S1.1</td>
<td>“That C?”</td>
</tr>
<tr>
<td>23:15</td>
<td>S1.2</td>
<td>“That one yeah, that, also that: one that was with the pencil”</td>
</tr>
<tr>
<td>23:20</td>
<td>S1.1</td>
<td>“Silicon and carbon?”</td>
</tr>
<tr>
<td>23:21</td>
<td>S1.2</td>
<td>“Try!”((They try and get an incomplete bond, this is a lack of my prototype, as SiC(Silicon carbide) is a legitimate reaction))</td>
</tr>
<tr>
<td>23:25</td>
<td>S1.1</td>
<td>“Ah, no”</td>
</tr>
<tr>
<td>23:26</td>
<td>S1.2</td>
<td>“I thought I had a hint!” ((A little laughter from S1))</td>
</tr>
</tbody>
</table>

**Figure 9.6:** Transcript snippet Group 1 experimenting with different compounds

**Externalization of thought process**

S1.1 is the most talkative in the group. For the most part in the beginning of the classroom session, as they are familiarizing themselves with the prototype and the learning goals, she talks out loud about what she is thinking as she experiments. In the following example, I have just told them that some of the description boxes of the elements contain *hints* to compounds they can make.
<table>
<thead>
<tr>
<th>Time</th>
<th>User</th>
<th>Memo</th>
</tr>
</thead>
<tbody>
<tr>
<td>25:01</td>
<td>S1.2</td>
<td>“We have to find the hint in some of them”</td>
</tr>
<tr>
<td>25:03</td>
<td>S1.1</td>
<td>“But if you can see, this one has one”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((pointing at the animated model of K))</td>
</tr>
<tr>
<td>25:07</td>
<td>S1.1</td>
<td>“I think it will bond with Fluorine”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((Clicks at F))</td>
</tr>
<tr>
<td>25:11</td>
<td>S1.1</td>
<td>“It’s missing one”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((points at the missing atom in the model))</td>
</tr>
<tr>
<td>25:15</td>
<td>S1.1</td>
<td>“((reading from the text)) [Fluorine is one of the most]...reactive and dangerous elements in the periodic table”</td>
</tr>
<tr>
<td>25:20</td>
<td>S1.3</td>
<td>“Huh?”</td>
</tr>
<tr>
<td>25:25</td>
<td>S1.1</td>
<td>“[It is what] we put in our mouth”</td>
</tr>
<tr>
<td>25:26</td>
<td>S1.2</td>
<td>“Holy shit!”</td>
</tr>
<tr>
<td>25:27</td>
<td>S1.1</td>
<td>((while pointing at the text)) “Deadly to breathe in! And streams of fluoride can light fire to almost anything. It’s in toothpaste.”</td>
</tr>
<tr>
<td>25:32</td>
<td>S1.2</td>
<td>“Oh: so we have to take [the same as?] Fluorine atom...”</td>
</tr>
<tr>
<td>25:37</td>
<td>S1.1</td>
<td>“Fluoride”</td>
</tr>
<tr>
<td>25:38</td>
<td>S1.3</td>
<td>“Fluoride?”</td>
</tr>
<tr>
<td>25:42</td>
<td>S1.1</td>
<td>“Sodium Fluoride!”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((pointing at the word on the screen))</td>
</tr>
<tr>
<td>25:47</td>
<td>S1.2</td>
<td>“We have to take Na and F!”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((pointing at the elements on screen)) “Sodium and Fluorine!”</td>
</tr>
<tr>
<td>25:56</td>
<td>S1.1</td>
<td>(( drags F and Na into the reaction zone and checks it, they get a result with an image, but the reaction type (ionic bond) is something they have unlocked before))</td>
</tr>
<tr>
<td>26:03</td>
<td>S1.2</td>
<td>“Is it a picture??”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((referring to achievements))</td>
</tr>
<tr>
<td>26:04</td>
<td>S1.3</td>
<td>“Nah, it’s not one of those pictures”</td>
</tr>
</tbody>
</table>

**Figure 9.7:** Transcript snippet Group 1 discovering hints and S1.1 reflecting

The snippet in fig 9.7 shows a gradual change in priorities. While S1.1 is still reading the information out loud, and conveying it to the other group members, S1.2 is getting interested in unlocking achievements. S1.2 is, however, starting to use the scientific names for each atom, instead of only...
referring to them via the pictures she relates them to. This can just be an effect of parroting S1.1, since she names them almost every time, but using a scientific language starts happening to S1.3, too.

**Relating atoms to everyday objects**

In an instance where S1.1 clicks at Boron, S1.2 recognizes lens water. As S1.1 reads that borax is used to make slime, S1.2 exclaims "Boron? Doesn’t one use lens water to make slime?", to which S1.1 responds:

"There is probably boron in the lens water" -S1.1

This is one of several familiar interactions where they relate a fairly short interaction, but happens as S1.1 is clicking through each elements. As she clicks, the images pop up, and S1.2 exclaims what she recognizes from the images. S1.1 does, however, not linger enough for S1.2 to make other comments.

**Using scientific language**

![Figure 9.8: S1.3 (upper left) touching the screen, pointing at atoms for S1.1 (bottom) to try adding together](image)

S1.3 is very quiet in the beginning, but starts giving more suggestions after a while. She mostly starts by pointing towards the screen instead of verbally...
suggesting atoms at first. In fig 9.8, her hand is to the left, suggesting an atom for S1.1 to try. Snippet 9.9 shows a moment where she goes from non-verbally referring to atoms to suggesting them by name.

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>29:35</td>
<td>S1.1</td>
<td>“Noble gases... Noble gases don’t bond together”</td>
</tr>
<tr>
<td>29:42</td>
<td>S1.3</td>
<td>((Points at the screen, with her middle and index finger tapping at Be and Mg respectively)) “Try those”</td>
</tr>
<tr>
<td>29:44</td>
<td>S1.1</td>
<td>“Beryllium and Magnesium?”</td>
</tr>
<tr>
<td>29:54</td>
<td>S1.1</td>
<td>Drags Mg, Be into the reaction zone. They get the “incomplete” message.</td>
</tr>
<tr>
<td>30:02</td>
<td>S1.1</td>
<td>“Let me think a bit...”</td>
</tr>
<tr>
<td>30:06</td>
<td>S1.2</td>
<td>“Beryllium and Blo:- Boron:”</td>
</tr>
<tr>
<td>30:10</td>
<td>S1.1</td>
<td>“It has three in its outermost shell?”</td>
</tr>
<tr>
<td>30:11</td>
<td>S1.2</td>
<td>“It lacks oxygen”</td>
</tr>
<tr>
<td>30:13</td>
<td>S1.1</td>
<td>“It has three in its outermost shell ((points at animated image, closes B and opens up Be)), that one has: two in the outermost shell”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>((Video part two, continues where previous section left off))</td>
</tr>
<tr>
<td>00:04</td>
<td>S1.1</td>
<td>“So that one((points with the mouse to Be)) has two in the outermost shell, and that one ((points to B)) has three in the outermost shell [and they get] five if they share”</td>
</tr>
<tr>
<td>00:14</td>
<td>S1.3</td>
<td>((while pointing at the atoms in the screen)) “What about Calcium and Boron?”</td>
</tr>
<tr>
<td>00:17</td>
<td>S1.1</td>
<td>“That one only has one in its outermost shell ((Quickly opens up the image to check/show)), and that one has: three in its outermost shell”</td>
</tr>
</tbody>
</table>

**Figure 9.9:** Transcript snippet Group 1 all talking among themselves

We also see how S1.1 tries to explain how electrons have an effect on what reacts with what. She uses the prototype to confirm what she is saying, checking the atom model to make sure that Boron indeed has three electrons in its outermost shell. In the same snippet we hear S1.2 using element names.
instead of pointing or mentioning pictures.

**Using other resources**

Unprompted, student S1.2 starts using the book, looking for examples of bonds that can be made in my prototype. They want to unlock all the achievements but seem stuck. In fig. 9.10 we can see S1.2 growing somewhat exasperated that her suggestions from the book are not corresponding with MyReactor.

<table>
<thead>
<tr>
<th>Time</th>
<th>User</th>
<th>Action/Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>05:06</td>
<td>S1.2</td>
<td>“((unintelligible)) Na? Sodium?”</td>
</tr>
<tr>
<td>05:08</td>
<td>S1.1</td>
<td>Drags Na over to the reaction zone</td>
</tr>
<tr>
<td>05:09</td>
<td>S1.2</td>
<td>“and then you try O”</td>
</tr>
<tr>
<td>05:10</td>
<td>S1.1</td>
<td>Adds Oxygen</td>
</tr>
<tr>
<td>05:12</td>
<td>S1.2</td>
<td>“And then you try H”</td>
</tr>
<tr>
<td>05:13</td>
<td>S1.1</td>
<td>Fumbles around with the mouse pointer, “H”</td>
</tr>
<tr>
<td>05:15</td>
<td>S1.1</td>
<td>“Hydrogen?” She adds Hydrogen and checks the reaction, gets “are you missing something”</td>
</tr>
<tr>
<td>05:21</td>
<td>S1.2</td>
<td>“It’s in the book!” ((sounds of pages of the book being flipped))</td>
</tr>
<tr>
<td>05:40</td>
<td>S1.1</td>
<td>Tries making NaOH again, but gets the same failed message. She then clicks on Na, K and Li respectively.</td>
</tr>
<tr>
<td>05:50</td>
<td>S1.1</td>
<td>Drags Li, Na and K into the reaction zone, and gets the achievement for alkaline metals.</td>
</tr>
<tr>
<td>05:55</td>
<td>S1.1</td>
<td>“Yes!”</td>
</tr>
<tr>
<td>06:23</td>
<td>S1.2</td>
<td>“Two Ns”</td>
</tr>
<tr>
<td>06:30</td>
<td>S1.1</td>
<td>Adds two Ns into the reaction zone and checks, gets “missing” message</td>
</tr>
<tr>
<td>06:33</td>
<td>S1.2</td>
<td>“But it says ((unintelligible))! says right there!” ((Sounding exasperated/frustrated, referring to the book?))</td>
</tr>
</tbody>
</table>

**Figure 9.10:** Transcript snippet S1.2 suggesting compounds from the book to S1.1

The usage of the book being something the students thought of themselves shows a hint of recognition. That this periodic table is the same that they
have been reading about in their book. Surely, it means that what is in the book should be shown in the application as well. Sadly, due to the limitations of MyReactor, this connection isn’t fully made.

S1.2 is immediately distracted, however, due to the group earning another achievement.

Different perspectives

Within the classroom session, there was one group of two students, group 4. Here, only one of the students was actively engaged with MyReactor, and when stuck, asked Group 3 for help. She wondered how they had gotten "The yellow one", the halogens achievement. When I came over to help, she said she did not understand how to unlock said achievement. We then started to talk about what halogens are, and how they are the ones missing one atom in their outermost shell.

Immediately after realizing that, she started thinking out loud how the atoms in the halogen groups had to have so-so many electrons in total. Since each outermost shell had 8 electrons, except for the innermost shell, she started looking for how the numbers added up, and which atoms could belong to the halogen group. She clicked on the different elements looking at the number in the center, to see if they corresponded with how many electrons in total a halogen would have. This was different from some of the other groups, who would instead look at the electron animation.

9.2.4 Post-test evaluation

At the end of the classroom session, a small test was held to check if the different groups had understood the basic characteristics of atoms. A "blank" atom was drawn on the whiteboard with a random number of electrons.

When asked what they could tell me without knowing which atom this was, at least one from each group raised their hand to answer. They started with what kind of group it was in based on the amount of electrons. Based on that, they also answered what group of atoms it would be most compatible with, and what kind of reaction this atom and a potential atom from that group would have.

Another observation was that group 3 were accompanied by a teacher for a long time, and they were the most vocal. They had four members, and from the video recording, one could hear snippets of their inquiries. Their
teacher would *remind* them of things they had learned earlier, to jog their memory. This assistance lead to interesting questions being asked, and since these discussions took place, their idea papers also looked similar. All the ideas they wanted to explore, or questions they had, were the same across the group.

The experiences I gathered from this session were:

- That the language used to ask the questions was difficult
- That the goal for using MyReactor was still unclear
- That having to click on the animations to play them, in the reaction achievements, made it so the students did not realise they *were* animations.
  
  That the students did not understand the point of idea papers. They were already busy discussing their ideas and testing them out without seeing the need to write their process down first.

### 9.3 Final test: Class A.3

Class A.3 had also recently finished their mock exams when this test took place. The teacher in this classroom was the same teacher from class A.1, and participated by observing and helping where he was needed. A video recording is not available for this session, but participatory observation was used here as well, and notes were taken before and after the session. For this class, I gave a live demonstration on how to use MyReactor.

Because of some permission issues, this classroom session was not filmed, and there are no transcripts of interactions between students. However, there were some notable observations.

#### 9.3.1 Task setup

The tasks for this class were altered a bit based on the feedback from the students in B.1. The wording in the sentences was simplified, but meant to convey the same questions:

- In what ways can we **group** elements?
- Why is the **amount** of electrons in the outermost shell important?
- In what ways can atoms **react** with each other?
I did not bring the papers into this test, as they were a distraction and confusion element for the students in class B.1. I also made it so that the animations would play automatically once an achievement was opened. This way, the students could immediately see the interactions between atoms during a reaction.

9.3.2 Observations

These observations were from my own notes right after testing with this classroom. They were a full classroom, 23 students grouped into fours, interacting with MyReactor on one laptop per group. After the live demonstration on how to use the application, I showed them the questions and wanted them to answer them by using MyReactor.

Limitations of MyReactor

Almost immediately after the students started experimenting, one of the students in the class asked out loud why they could not add more than three elements into the reaction zone, as they wanted to make an organic compound. I explained that the prototype focuses on inorganic chemistry. This was later mentioned as something that could be added to the prototype, as it was a bigger focus down the line for the students in higher level classes.

Recognition of colors

One of the most notable interactions was when one of the groups had one member who seemed to be disinterested. She wondered if the app would be any "good for those who did not have interest or knowledge about the periodic table of elements on beforehand". As I wanted to ask further, one of the students remarked that the periodic table in MyReactor had atoms sectioned into different colors. Another then tried to remember how the periodic table was sectioned off in regards to horizontal and vertical lines. He was gesturing towards the screen, drawing horizontal and vertical lines with his finger. At this point another exclaims to check the poster on the wall, and they turn their attention to it.
They comment on how similar the color setup is, and are a little stuck. In order to help, I mention that the *lines* are called groups and periods. They start remembering how to group atoms. One student remembers alkaline metals and asks

"Alkaline [metals] are basic, right?"

This was not information I immediately had an answer to, but they fell into experimenting with grouping the atoms together.

Around this time the girl from this group was looking at the poster as well at the smaller periodic table in MyReactor. She mentions that the colors are different, referring to the turquoise section in the middle of the full

**Figure 9.11:** The full periodic table of the elements on the classroom wall
periodic table of elements. I explain that the version in the prototype is a smaller periodic table with elements with up to 20 protons in their core. She then replies, "Oh, so they’re bigger," while looking at the turquoise elements in the poster.

9.3.3 Post-test evaluation

This was the first school where almost all groups were finished with unlocking the achievements, and answering the questions on the blackboard before the session was over. I tested them the same way as I had done with B.1.

Since this are from my notes, the interaction snippets will be presented as the students responded to my questions. I drew one atom with seven electrons, and asked if they could tell me something about it.

"It belongs to the group with one missing electron" - From group 2
"Does anyone remember what that [group] was called?" - Me
"Halogens" - From group (4?) "Can you tell me if the halogens could react with any other group?" - Me "Alkaline metals" - From ?? "And what kind of reaction would this be?" - Me "A covalent bond...?" - From group 3 "Well, alkaline metals are known for having one electron in their outer shell that they want to get rid of" - Me "Oh then it will probably be ionic then" - From the same girl in group 3

This was a way for me to test the questions I had asked them to answer in an indirect way. After the test, they gave feedback to MyReactor, where their responses were:

- That it would be easier if they did not need to clear the reaction zone each time they wanted to make a new connection
- That it was too bad there was only room for three atoms per reaction
Chapter 10

Analysis and discussion

10.1 Answering the research question

What does a learning tool about the periodic table of elements need in order to scaffold second grade students’ learning of elements and their properties?

This research question cannot be answered in a definitive way without setting limits to the aim with scaffolding. As mentioned from the beginning, the scaffolding concepts implemented in MyReactor are not meant for long-term learning. This study was meant for the development of ideas and connecting the functionality of the prototype with scientific concepts associated with the periodic table of elements. This was within the time limit of a classroom session.

The theory this thesis has been relying on has been research of existing scaffolding tools. Specifically the usage of scientific and everyday concepts, the usage of prompts in digital learning tools, and the aspect of representing something in different ways to create connections between old knowledge and new. I attempted to see how I could combine these three concepts within one application. By doing this, I could then see whether my combination of these concepts could help students learn about the periodic table of elements in a new way.

The combination of these three concepts has worked different ways based on how they have been presented to the students. Multiple representations has made it so students relate to the periodic table based on what they are familiar with and focus on. Prompts allow the students to think out loud about their ideas, and drives them to test their ideas with MyReactor.
Scientific concepts mixed with images of everyday items make atoms and elements more relatable for some students. How these three concepts achieve these effects will be further discussed. But while the three concepts combined scaffold some aspects of learning and meaning-making, they also bring along their side effects.

As most digital learning tools, MyReactor in itself cannot be used by to students in an optimal way without guidance from a teacher or expert. The components containing scaffolding elements allow students to make connections between scientific and everyday concepts, but in some ways it also confuses them. Either by the language used, due to institutional differences [15], by conflicting prompts [30], by overexposure to representations [14] or by the limitations of my prototype.
10.2 Effect of scientific concepts

The interaction between using everyday- and scientific concepts was more clearly seen during the test in class B.1. When viewing the dynamic between S1.1 and her two other group members, it is shown to be them asking questions or loudly suggesting things, and her answering their inquiries. While this may seem like a one-sided interaction, the fact that S1.2 and S1.3 ask her questions leads her to exploring her own thoughts and the prototype. She explains to them in a much more everyday language, and often uses "this" and "that", pointing instead of saying the names of elements out loud. She would, however, be the most consistent in also using scientific language. When one of her other team members would point at something, or use letter sounds instead of the element name, she would repeat the element they pointed at with the name. An example of this behavior is seen in 9.6 and 9.2.3.

Another exchange between everyday and scientific concepts is when S1.2 suggests things to S1.1. S1.1 tries them out, exclaiming the scientific concept for what S1.2 suggested. This is easily seen when S1.2 suggests making air, and S1.1 adds oxygen atoms together, creating oxygen gas 9.5. While air in itself contains many different elements, what is most memorable is that we breathe oxygen, therefore at least, it should be related to air in some way. The students are able to experiment with their ideas like this, essentially translating everyday words into scientific concepts.

This usage of concepts can also backfire, if the students end up developing ideas that they cannot make sense of. At some point, since the application did not give the same results back to the students 9.10, it lead to frustration and confusion, especially for S1.2. While their experimentation led to S1.1 understanding the pattern, and unlocking the last achievement, this was not shared between all group members.

10.3 Effect of prompts

The textual prompts in the form of questions seemed to have little effect. While S1.1 would read them out loud, the questions would not be discussed in the group. The achievements being unlocked however, prompted them to continue. They had a goal to reach, but they needed to think through what they were missing, and how they could unlock the remaining achievements.

MyReactor’s prompts would occasionally be picked up by S1.1, and that would lead her to think about how atoms are grouped, or what creates
10.4. Effect of multiple representations

The effect of having multiple representations in the prototype is mainly shown in snippet 9.6 and basically every time S1.2 relates to everyday objects when referring to atoms. She refers to atoms as what they exist in, what they help create. Later, she is the one who seeks out bonds in the school book. She seems to understand that the representations in my prototype are the same as the representation in the book, and that the book and MyReactor might be pointing to the same thing.

In school A, class A.3, a student realizes the colors of the periodic table in MyReactor matched the colors on the full periodic table on their classroom wall (see 9.3.2). This led to the group remembering that the colors could signify what group each atom was in. Allowing for these different representations in a prototype means that students who internalize information in a particular way have a chance of recognizing their ideas in the prototype.

That exact type of internalization and externalization of information is shown in B.1’s group 4. In 9.2.3, the student trying to find out which atoms belong in the halogen group uses math, looking at numbers, as opposed to the electrons in the atom animation.
10.5 Negative effects

Bu combining these three scaffolding concepts, they bring along the issues that is presented in existing technology. Kluge and Dolonen discuss during their research with algebra being implemented in games, that the students using *Dragonbox* could start behaving in a drag-and-drop behavior \[13\]. This behavior is also seen in Furberg’s research with prompting \[30\]. This behavior was also seen in MyReactor. At some point, when the students in group 1 did know know how to proceed, they would try adding random atoms without thinking it through. This behavior was more normal for them at the beginning, before they familiarized themselves with the *functionality* and limitations of MyReactor.

The achievements in MyReactor was also an interesting phenomenon. For class A.2, achievements were nothing but imagery. Despite this, the students were actively trying to unlock achievements. They also did not understand the achievements they got, even though they were actively trying to unlock them in \[9.1.2\]. Simply because of their existence, the achievements gave the students a drive to *complete* a function of MyReactor. Because no explanation was given, some groups would end up resulting in drag-and-drop behavior.

The setup of tasks was also a challenge. Class B.1 had trouble understanding the questions/tasks I had set up for their classroom session, because of too many scientific concepts. The level of my own language was unfamiliar, and to some degree directly translated from English. It is not enough to translate my web application to a language on the students’ level. I needed to adjust my own language as well.

Group 1, whom I recorded, did manage to unlock all the achievements in the end. This was mainly S1.1’s doing, and she did not explain or share with the other group members what she had understood to unlock the other achievements. When they had finished unlocking all achievements, S1.2 asked:

"Now what? do we just continue?" - S1.2

At some point, their focus had gone from the questions asked on their blackboard, to just unlocking the achievements in the prototype. This could have been avoided if I had worked more closely with the teachers, and had them plan a session for the students. They are after all more familiar with what level of scientific concepts to use.
Lastly, the side effect of multiple representations was the risk of only using the familiar representations of elements and the periodic table. While it was positive that the students could relate atoms to everyday objects and familiar items, there would also be the risk that they would always refer to the periodic table components as "the yellow one" or just by pointing. Ainsworth does warn that when MERs are used to combine several representations into one, there can be a risk of overexposure. However, since the representations for each atom were co-present, the risk was lessened.

10.6 Summary

All three scaffolding elements work with each other and result in the users subconsciously performing group work. While my prototype has prompts, both content oriented and process oriented, they are not as constant as the suggestions coming from peers who also have a goal they are working towards. The types of suggestions that goReact give, by pointing out which elements to add to their reaction zone, is now replaced by peers. The difference is how they use the language. If one of them uses an everyday expression, and another uses its equivalent scientific expression, they can make relations between both expressions, and use them in other contexts.

The fact that the students can relate atoms to everyday concepts, or even items, fulfills a part of the wish the teachers described during pre-design data gathering: "...that the chemical bonds we most hear about, water, carbon dixoide, and what other chemical reactions are happening around us on the daily. [...] To understand how something can become something else, basically."

This cannot happen without actually showing the students how atoms can take different shapes, and letting them make connections between what they are shown in real life and science. Each student is different, they will relate to different things. Whether it is color patterns, numbers, animations, or text; having an application that contains all these elements allows students to continue making connections in a way that is familiar to them.
Chapter 11

Conclusion

"The most well-designed Web based environment does not come with a one-size-fits all-design." - Furberg [30]

I asked my research question with the intent of finding a combination of scaffolding elements that could support students learning of the periodic table. By finding out what they needed to learn and how they were already learning, I could connect their existing methods with learning theory and pedagogy. By finding out what they struggled with, and what was memorable for them, I managed to find a purpose for the tool of this thesis, MyReactor. After creating MyReactor based on the student’s struggles, and the teacher’s intentions, it was tested. MyReactor was created to be a mediating artifact, a means to understand abstract concepts and inorganic chemistry. The prototype is meant to let the students interact with the representation of something abstract. The images presented for each atom were used to supplement a connection between the familiar and unfamiliar.

The tests revealed that by interacting with my prototype, and particularly being set in a group, the students would engage in discussion and inquiry. They would ask questions of what was possible, both within the limits of my prototype, but also questions related to the real world. By introducing MyReactor to the students, and having them interact with the tool and with each other, discussions and questions took place. These questions were initiated by the existence of the tool and their classroom session, where they interacted with something that was previously static.

The existing research that I based my thesis on focused mainly on reviewing existing tools and evaluating the students interactions with those tools. My research takes their evaluation, and uses it to create something new, combining the different scaffolding elements of each scaffolding example.
My research is one example of how these scaffolding examples can be combined, and some of the effects this combination can have on students’ learning over a classroom session.

My own work with gathering data and testing has in itself been a journey. Each iteration of testing with the classroom taught me something new, and in hindsight, I wished I had collaborated further with the teachers. Their knowledge on the classroom dynamics, and classroom setups, would have been helpful in creation tasks for the students that fit their level. By having a familiar face introduce a familiar routine, it could have allowed them to focus more on the tasks of interacting with the MyReactor instead of wondering about the purpose of the testing.

My own role in the classroom setting could also have been improved. A part of scaffolding students’ learning through dialogue is the way one asks questions. In particular, how teacher roles can adjust the way they answer students’ questions to allow students come to conclusions themselves. This gives room for more reflection.

My tests show students developing an understanding of the usage of MyReactor, and with it, a transition between using everyday concepts to scientific concepts. However, as the tests lasted for 30 minutes, it does not show whether my prototype has helped scaffold their learning about the periodic table of elements in the long run. MyReactor is a tool that bridges the gap between the unknown with the known by using multiple representations. It allows for further interaction by adding interactivity with something considered boring, and mostly represented as an image in a book or a poster. This allows for a new experience with the periodic table of elements for the students, and gives room for new questions and new ways of thinking based on their previous ideas.

MyReactor is not a complete tool, nor is it perfect, but by allowing these new experiences for the students, allows them in turn to think of the periodic table in new ways.
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Data gathering setup
Intervjuguide/temaliste for intervju; lærer

Dette dokumentet inneholder sentrale spørsmål og tema for forskningsprosjektet til Mahasty Assi ved Institutt for Informatikk, Universitetet i Oslo.

Spørsmålene er rettet mot naturfagslærere i ungdomsskolen fra 8.-10. trinn. Spørsmålene er på ingen måte en kritikk til oppsett av læringsomgivelsene eller faglig stoff, men heller for å oppnå forståelse av hvordan læring blir utført i klasserommet.

Personlig erfaring:
- Hvor lenge har du vært lærer ved denne skolen?
- Samarbeider du med de andre (naturfags)lærerne når du setter opp opplegg for klassen?
- Hvordan opplever du elevenes instilling til å lære om naturfag?

Faglig erfaring:
- Udir beskriver et generelt læringsmål i naturfag/periodesystemet for ungdomsskolen at elever skal kunne “vurdere egenskaper til grunnstoffer og forbindelser ved bruk av periodesystemet.” I relasjon til dette, hva fokuserer du på for å lære bort om periodesystemet og grunnstoffer?
- Endrer du på opplegget basert på elevenes mottagelse eller endringer i teknologi?
- Hvilken instilling har elever som oftest når de kommer til dette temaet? (typ, merker du at de reagerer annerledes når de skal lære om periodesystemet og grunnstoffer? er det vanskeligere for dem å forstå dette i forhold til andre temaer i naturfag?)

Klasseromsomgivelse:
- Jobber barna ofte i grupper? (generelt)
- Hvordan oppfører de seg når de jobber i grupper
- Er det de samme som svarer på spørsmål i timene/ er mest aktive?
- Bruker dere datamaskin ofte i klasserommet? / Hvilke ressurser har elevene i tillegg til naturfagsboka?
Intervjuguide/temaliste for gruppeintervju; elever

Dette dokumentet inneholder sentrale spørsmål og tema for forskningsprosjektet til Mahasty Assi ved Institutt for Informatikk, Universitetet i Oslo.

Spørsmålene er rettet mot elever i naturfagsklasserommet i ungdomsskolen fra 8.-10. trinn.

Spørsmålene er satt opp med en antakelse at de allerede har (noe) erfaring med grunnstoffene og periodesystemet.

**Generelle spørsmål:**
- Hva synes dere om naturfag?
- Hva synes dere om periodesystemet/grunnstoffer?
- Husker dere hva dere har lært i klassen om periodesystemet/grunnstoffer?
- Hva var det som var vanskelig med å forstå og huske om periodesystemet/grunnstoffer? (eks. grupper, perioder, “skall”, reaksjoner, protoner/elektroner)
- Hva bruke dere for å lære om periodesystemet/grunnstoffer?
- Hva synes dere var nyttig?

**Gruppearbeid:**
- Pleier dere å jobbe i grupper? (både i naturfagsklasserommet og generelt)
- Liker dere gruppearbeid? Snakker dere sammen i gruppa?
- Føler dere dere lærer bedre av gruppearbeid?
- Hvis dere måtte jobbe i grupper, ville dere heller jobbe med venner eller andre i klassen?
  - ...Hva med å jobbe med hele klassen?

**Verktøy:**
- Bruker dere datamaskin (ofte) i klasserommet?
- Bruker dere andre verktøy?
- Liker dere å bruke andre verktøy enn boka og tavla?
  - ... Hvorfor/hvorfor ikke?
Oppsummering av testing med MinReaktor

Dette arket vil nå spørre deg et par spørsmål om opplevelsen du hadde med applikasjonen MinReaktor og gruppearbeid i klasserommet.

Gruppe: ___________

**MinReaktor**

1. Hva syntes du om MinReaktor som et læringsverktøy?

2. Fikk du prøvd ting med MinReaktor som du ellers ikke hadde undersøkt på egen hånd?

   1. Hvis ja: beskriv noe du fikk prøvd:


4. Hvor viktig var det for deg å få achievements på starten av timen? Kryss av

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<th>Ikke så viktig</th>
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5. Hvor viktig var det for deg å få achievements på slutten av timen?

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<th>Veldig viktig</th>
<th>Litt viktig</th>
<th>Ikke relevant</th>
<th>Ikke så viktig</th>
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6. Ville du ha brukt MinReaktor igjen?

7. Hadde du anbefalt MinReaktor til noen andre?
**Gruppearbeid**

1. Hvordan følte du om å gjøre denne testen med en gruppe?

2. Fikk gruppen undersøkt alle idéene dere ville?

3. Kom du på noen nye ideer mens dere testet ut MinReaktor?

4. I hvilken grad fikk du bidratt i gruppen? Kryss av

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<tr>
<th>Bidro mest</th>
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<th>Bidro minst</th>
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5. Brukte du noen ord eller uttrykk som du ellers ikke hadde brukt hvis du ikke hadde jobbet med en gruppe?

   1. Hvis ja: Kan du huske hvilke(t)?

Og da var spørsmålene fullført 😊

---

Takk for deltakelsen!
Consent forms

The following PDFs are the anonymized, signed consent forms for interviewing from both teachers. Their order is the form for the teacher in class A.2 first, then the form for the teacher in class B.1.
Samtykkeskjema for lærers deltakelse i forskningsprosjekt


Prosjektet går ut på å legge opp for samarbeidslæring med teknologi innenfor tema "periodesystemer". Forsknings spørsmålet omhandler hvordan/hvorvidt teknologien kan eller kan ikke hjelpe elever i et klasserom å jobbe og lære sammen ved å stille spørsmål og utforske periodesystemet.

For læreren i klasserommet betyr det at de blir observert av studenten, og at de deltar på et intervju der det er mulighet for å ta opp samtalen. I senere stader av prosjektet vil det bli utført noe testing, der studenten ønsker å ta bilder av klasserommet som bruker en prototype av teknologien skapt for å støtte læring av periodesystemet.


Med dette skjemaet vil lærer samtykke til:

- Deltakelse i undersøkelse i forskningsprosjektet (bli observert, bli intervjuet)
- Det kan tas opptak av intervjuet
- Det kan tas bilder av vedkommende så lenge personlige trekk er anonymisert
- Det kan publiseres bilder i offentlige dokumenter eller tryksaker
- Deltakelse er frivillig og man kan trekke seg fra undersøkelsen så lenge man sier i fra til forskeren/studenten

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Samtykkeskjema for lærers deltakelse i forskningsprosjekt


Prosjektet går ut på å legge opp for samarbeidslæring med teknologi innenfor tema "periodesystemet". Forsknings spørsmålet omhandler hvordan/hvorvidt teknologien kan eller kan ikke hjelpe elever i et klassemøte å jobbe og lære sammen ved å stille spørsmål og utforske periodesystemet.

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- Det kan publiseres bilder i offentlige dokumenter eller trykksaker
- Deltakelse er frivillig og man kan trekke seg fra undersøkelsen så lenge man sier i fra til forskeren/studenten

For spørsmål, kontakt Mahasty Assi, mahastya@ifi.uio.no, +47 950 15 511 eller veileder Hani Murad, haniirm@ifi.uio.no, +47 901 50 029

24/5-18
(Dato og signatur)