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Students' understanding of the cell and cellular structures

Abstract

This study aimed to investigate Norwegian eighth-grade students' preconceptions of cells, the development of their understanding of cellular structure and function during cell biology instruction, and their understanding of the cell as a system. We conducted pre- and posttests including drawings, images and statements with 28 students. Our findings indicate that most students had a simplified view of cells prior to instruction but developed significant knowledge about cellular structures and different types of cells during instruction. However, several misconceptions arose, and some students seemed to alter their correct preconceptions. This suggests that teachers need to address misconceptions during instruction and support integration of students' previous and new knowledge. Additionally, we suggest that focusing on numerous structures and cells from different organisms confuses students and complicates the process of achieving a systemic view of the cell.

INTRODUCTION

Biology is defined as the science of life and living organisms. The cell is the smallest unit of life, and knowledge of cell structure and function is fundamental in the field of biology. All living organisms are built from one or more cells, and basic knowledge about the cell is vital for understanding different aspects of life, ranging from health and nutrition to mechanisms of evolution and biodiversity.

Cell biology is often taught and learned using highly detailed narratives, reducing the cell to the compartmentalized structures within it. In addition, whereas instruction often focuses on the basic structural differences between animal, plant and bacterial cells, connections between cell structure and function are rarely made. This leads to situations where students memorize organelles and structures without being able to see the cell as an interconnected system (Cohen, 2015).

In Norway, students are introduced to cell biology in lower secondary school, meaning that they have very limited instruction related to cells before the age of 13. Depending on interest and previous teaching, students will have varying conceptions of cells when they are introduced to cell biology in school. The data in this project were collected in 2018 when the learning objective was as follows: "*Describe the structure of animal and plant cells and explain the main features of photosynthesis and cell respiration*" (Utdanningsdirektoratet, 2006). The learning objective in the Norwegian science curriculum (renewed in 2020) for grades 8-10 (Utdanningsdirektoratet, 2020) in cell biology is as follows: *"Compare cells from different organisms and describe how structures and function are connected"*. The data and conclusions in this paper are therefore still highly relevant.

The teacher decides how to break down the learning objective for the students; however, this is often based on how the text book covers the topic (Hodgson, Rønning, & Tomlinson, 2012). This might lead to a rote understanding of cells without linking cellular structures to the functions of a multicellular organism.

Student conceptions of cell biology

As with all scientific instruction, students begin their study of biology with a diverse set of ideas about biological phenomena and processes. The work of Rosalind Driver and her colleagues (Driver & Easly, 1978) established research in this field, revealing students' preconceptions and alternative conceptions of different scientific concepts. These ideas may originate from students' previous education but also from their own everyday experiences, as children intuitively seek to understand and explain their surroundings. When students receive instruction on biological phenomena such as cells and photosynthesis, their previous ideas about these concepts may remain unchanged, or they may create alterative conceptions for themselves in order to explain personal experiences or ideas. These alternative conceptions or misconceptions are not restricted to younger students but also arise among biology majors (Coley & Tanner, 2015). In fact, teachers may have some of the same misconceptions as their students (Wandersee, Mintzes & Novak, 1994; Köse, 2008; Sanders, 1993). Biological concepts such as cells are complex systems that are difficult to visualize, and processes such as photosynthesis involve concepts related to both chemistry and physics, making them even more difficult to understand (Koba & Tweed, 2009). However, students do form ideas about cells from previous instruction and/or personal intuitive thinking. During instruction, these ideas might be challenging to change and thus act as obstacles to integrate new knowledge into previous knowledge (Driver & Easley, 1978; Wandersee, Mintzes & Novak, 1994).

Several studies have been performed to identify students' ideas about cells and cellular processes at different educational levels. For lower secondary school students, the living cell is abstract, and cells are often presented as "*building blocks*" of an organism, leading to the idea that cells are physical units inside the body rather than interconnected units making up the whole body (Dreyfus & Jungwirth, 1988, 1989). On a more structural level, confusion about the difference between cells and atoms or molecules has also been observed in several studies (Driver, Squires, Rushworth, & Wood-Robinson, 2014; Sewell, 2002). In both lower and upper secondary school, students might hold an animistic and anthropomorphic view of cells (Dreyfus & Jungwirth, 1988, 1989), for instance that cells "*know what they need*", "*require food*" or "*want to discard waste*". Assuming that plants "eat" sunlight, water and carbon dioxide to produce oxygen and glucose may prevent students from understanding that plants have the ability to produce their own energy source, and that they produce food for all species (Driver et al., 2014; Brown & Schwartz, 2009). In general, it is challenging for upper secondary school students to link subcellular processes to the functioning of an organism and life in general (Flores, Tovar, & Gallegos, 2003).

Students struggle to understand that different cells in an organism have different structures and functions even though they contain identical genetic material (Lewis, Leach, & Wood-Robinson, 2000). In fact, students often find it hard to gain a comprehensive understanding of genetics and alternative conceptions of DNA, genes and chromosomes are common (Lewis & Wood-Robinson., 2000; Shaw, Van Horne, Zhang, & Boughman, 2008) regardless of age (Saka, Cerrah, Akdeniz, & Ayas, 2006).

The lack of integrating genetics and cellular structure to cellular function and life processes may complicate students' understanding of processes like cell division, reproduction, respiration, photosynthesis, genetic regulation and subcellular organization when they reach higher educational levels (Flores et al., 2003).

Scientific knowledge is constructed through processes of communicating and negotiating individual and personal ideas. The sociocultural aspects of scientific knowledge are transferable to student learning in science (Driver et al., 2014; Leach & Scott, 2003). If students' personal experiences and explanations of biological phenomena observed in their everyday life are to be replaced with scientifically correct explanations, students need to be aware of the nature of science and how scientists communicate to establish scientific knowledge and of how models and other representations are used to explain and communicate these ideas (Driver et al., 2014). Teachers need to address students' scientific knowledge and ideas in the classroom and help them adjust their own personal ideas in response to those presented by the teacher. This process is enhanced by discussion with other students and with the teacher (Hatano & Inagaki, 2003; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

Drawings as a method of student assessment

In this study, we used drawings to assess students' knowledge of cells and cellular components. Drawings are quite simple to prepare and perform, and many students find it easier to draw than to express themselves verbally or in writing. Additionally, drawings may reveal the mental models students have of a particular scientific concept or phenomenon (Prain & Tytler, 2012; Thomas & Silk, 1990). Students who are less capable of expressing their knowledge verbally may do so through their drawings (Köse, 2008; Rennie & Jarvis, 1995; Thomas & Silk, 1990), which also may be a useful starting point for discussions. Several studies in scientific educational research have used drawings to access student thinking and misconceptions (Dikmenli, 2009; Köse, 2008; Langheinrich & Bogner, 2015; Saka et al., 2006). To analyse student drawings of cells before and after instruction, we used a modified version of the framework for drawing analysis developed by Köse (2008) and Dikmenli (2009) to assess student drawings of photosynthesis and mitosis respectively.

The teaching module "*The Cell as a System*"

In this study, we aimed to investigate students' conceptions of cell types, cellular function and cellular structures prior to and after instruction in cell biology. The instruction was given through the teaching module "*The Cell as a System*", developed by the Norwegian Centre for Science Education (NCSE) at the University of Oslo. NCSE developed teaching modules aiming to integrate inquiry-based science and literacy through the Budding Science and Literacy project (Ødegaard, Frøyland, & Mork, 2009; Ødegaard, Haug, Mork, & Sørvik, 2016). The teaching module "*The Cell as a System*" was developed for lower secondary school students aged 13-16 years. It consists of six sessions, each of which has different aims and elements of writing, reading, doing and talking. Its main purpose is to give students the opportunity to act as researchers in a project and to practice scientific argumentation to develop their knowledge of cells. The project scenario is that researchers have discovered a fossil inside a meteorite, and the research question is whether there could be traces of life in space. In their attempts to answer this question, the students need to reach evidence-based conclusions through discussion and negotiation. In this way, they learn about cellular structures, how cells work as a system and how different parts of the cell affect and regulate other cellular structures. Moreover, they learn how to use models to understand and simplify the microscopic world of the cell. The aims and content of the sessions are summarized in appendix 1.

The existing research on conceptions of cell biology among students has mainly investigated students' conceptual understanding of cells *after* instruction. However, less is known about students' preconceptions of cell biology and how teachers address these ideas during instruction. Our research therefore aimed to bring out information about students' knowledge of cells prior to instruction to fill a gap in biology education in lower secondary school. To this end, our research questions were the following:

1. What type of preconceptions do Norwegian eighth graders have about cells?
2. To what extent do students develop their conceptions about cells and cellular structures and function after instruction?

RESEARCH METHODS

Study context

We followed a teacher and his eighth-grade students (N=28). The teacher, henceforth denoted as the in-service teacher, was mentoring two student teachers, henceforth denoted as pre-service teachers. The pre-service teachers conducted all instruction in the classroom. The pre-service science teachers were sixth-semester student teachers in the biology-chemistry study programme at a Norwegian University. The content of the teaching module was the students' first real introduction to cells except for some previous instruction on mitosis and meiosis from earlier in the semester.

Data collection and study design

The data were collected during a period of four weeks from March to April 2018. Figure 1 shows a timetable for the data collection. All sessions lasted for 60 minutes; due to limited time, the teachers decided not to present session 3. All sessions were observed by one of the researchers. An overview of the data sources and how the data was used to answer the research questions is shown in table 1.

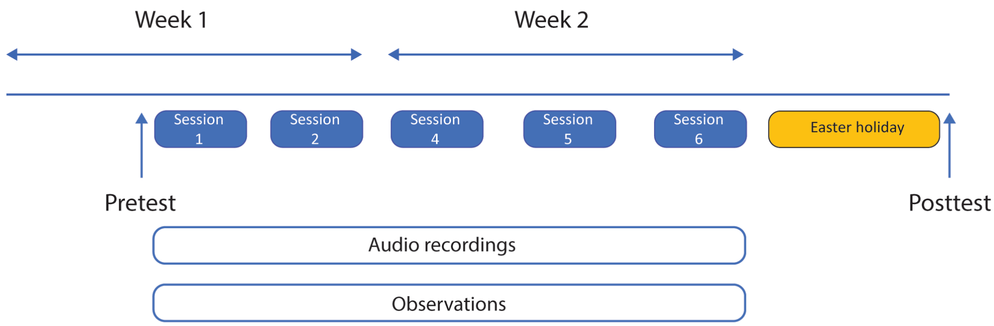

Figure 1. Time-table for the data collection. The pretest was conducted before instruction. Then five of six sessions were completed prior to Easter holiday. The posttest was conducted just after Easter.

The study was conducted using a single group pretest-posttest experimental design (T_1-X-T_2) (Bell, 2010). The pre- and posttests were administered to the students to evaluate the relationship between an intervention (the independent variable X being the teaching module) and the development of students' conceptions (the dependent variable T) from time point 1 (T_1) to time point 2 (T_2). We designed both the pretest and the posttest partly based on the content of the teaching module and partly based on ideas related to the American Association for the Advancement of Science (AAAS) project 2061. The AAAS project was used as a framework for questions in the test (AAAS, 2019). The framework is supplied in appendix 2. The content of the pre- and posttest is listed in table 1, and the complete test is supplied in appendix 3.

A validation of both the pre- and posttest was performed with a group of students from a separate class with another teacher. These students were asked to identify unclear and incomprehensible elements in the test, and one statement in the concept test was changed after validation. The results from the validation are not included in the data material.

Twenty-six students completed the pretest, whereas 28 students completed the posttest three weeks after instruction. The pre- and posttests were performed anonymously and could not be connected afterwards. The students knew that the pretest would not be part of their science assessment. In addition, to prevent students from preparing for the posttest, no information about the test was given beforehand. This could not therefore have affected the results in the posttest.

Table 1. Overview of research questions and the data connected to each question.

Research Question	Informants	Data Source	Aims of the test/purpose of data collection
What types of preconceptions do Norwegian eighth graders have about cells?	26 students	Data from pretest: Draw and label a cell and its structures Define 10 images as cell-containing or not, shown in appendix 3 Indicate whether 13 statements are true or false, listed in appendix 3 Answer an open-ended question ("*Explain how cells produce energy for survival*")	Investigate student knowledge of cells and cellular structures prior to instruction Identify student knowledge of cell-containing objects, and if they consider dead objects to contain cells Show student knowledge related to structure and function of the cell. The statements address differences and similarities between cells from different organisms. Show student knowledge of cell respiration and the function of mitochondria.
To what extent do the students develop their conception of cells and cellular structures and function after instruction?	28 students	Data from posttest: Draw and label a cell and its structures Define 10 images as cell-containing or not (identical to pretest) Indicate whether 13 statements are true or false (identical to pretest) Answer an open-ended question (identical to pretest)	To evaluate whether the students are able to describe cellular structures and functions and different types of cells. To show student knowledge related to structure and function of the cell. The statements address differences and similarities between cells from different organisms along with some ideas related to cells as a system and part of an organism. To reveal student knowledge of cell respiration and the function of mitochondria related to the cell as a system.

Data analysis of drawings

All the drawings were independently analysed by the two researchers. In addition, a biology lecturer was asked for an independent opinion on the analysis. Students' whole cell drawings were subjected to analysis using a framework developed for analysis of student drawings of photosynthesis (Köse,

2008) and modified for cell division drawings (Dikmenli, 2009). Drawings were categorized from level one ("*No drawing*") to level five ("*Comprehensive drawings*"), as described in table 2.

Table 2. The whole cell drawing analysis framework containing five different levels. (Dikmenli, 2009; Köse, 2008).

Level	Code	Description
1	No drawing	No drawing at all or a clear interference between the concepts of "cell" and "atom".
2	Non-representational drawings	Includes unidentifiable drawings that do not resembles cells. Also some identifiable elements of the cell structure, but no or wrong key concepts.
3	Simplified drawings and misconceptions	These types of drawings showed some degree of understanding on cell structure, but also showed a very simplified view on cells like only drawing the cell nucleus and cell membrane. The drawings also demonstrated some misconceptions and/or showing unidentifiable structures. A few key concepts were used.
4	Partial drawings with no misconceptions	The drawings in this category demonstrate partial understanding of the concepts. Include elements of the cell structure related to the key concepts like genetic material, cell nucleus, cell membrane, cell wall and mitochondria.
5	Comprehensive representation drawings	Drawings in this category are the most competent and realistic diagrams of cell structure. These drawings show a sound understanding of the cell structure, and contain both all key elements and additional cell structures. The students are able to name the type of cell in their drawings.

Limitations of the study

It is important to consider the fact that the pre-service teachers performed all teaching during the five sessions of the teaching module. This was not intentional, but it may have affected the results of the study.

The pre-service teachers used most of the learning materials (PowerPoint presentations, photos and figures) provided in the teaching module, but they did not use all concept sheets provided; nor did they put up a wall poster of any of the key concepts as recommended. During instruction, the pre-service teachers sometimes added elements, such as advanced images of the cell to help students visualize its complexity. Additionally, the pre-service teachers had minimal focus on the students' preconceptions about cells.

The mentoring in-service teacher evaluated each teaching session together with the pre-service teachers; however, a more experienced teacher might have affected student learning outcomes and been more aware of student misconceptions. In addition, when the pre- and posttests were given to the students, we did not ask them to identify themselves, making it impossible to pair students' pre- and posttest responses. Following the progress of each student from before to after instruction might have provided valuable information about student learning and possible misconceptions.

RESULTS

In the following, we present our findings according to the sequence of the different elements of the pre- and posttest, comparing results from both tests.

Student drawings

In both the pre- and posttests, students were asked to draw a cell and name its different parts, and the drawings were analysed using a five-level framework (table 2). Figure 2 shows examples of pretest and posttest drawings and the outcome of the drawing analysis. Most drawings (16 from the pretest and 14 from the posttest) represented level three of the framework, *Simplified drawings and misconceptions*, although the posttest drawings were more detailed with a higher number of named structures. Except for one drawing at level four, all pretest drawings were level three or lower, *Simplified drawings and misconceptions*, *Non-representational* or *No drawing*. Five students showed detailed knowledge of cellular structures in the pretest, indicating emerging knowledge of cellular structures. However, all comprehensive drawings showed misconceptions and were analysed as level three drawings. In general, all posttest drawings were more detailed compared to the pretest, and the drawings were often larger, filling the entire sheet of paper.

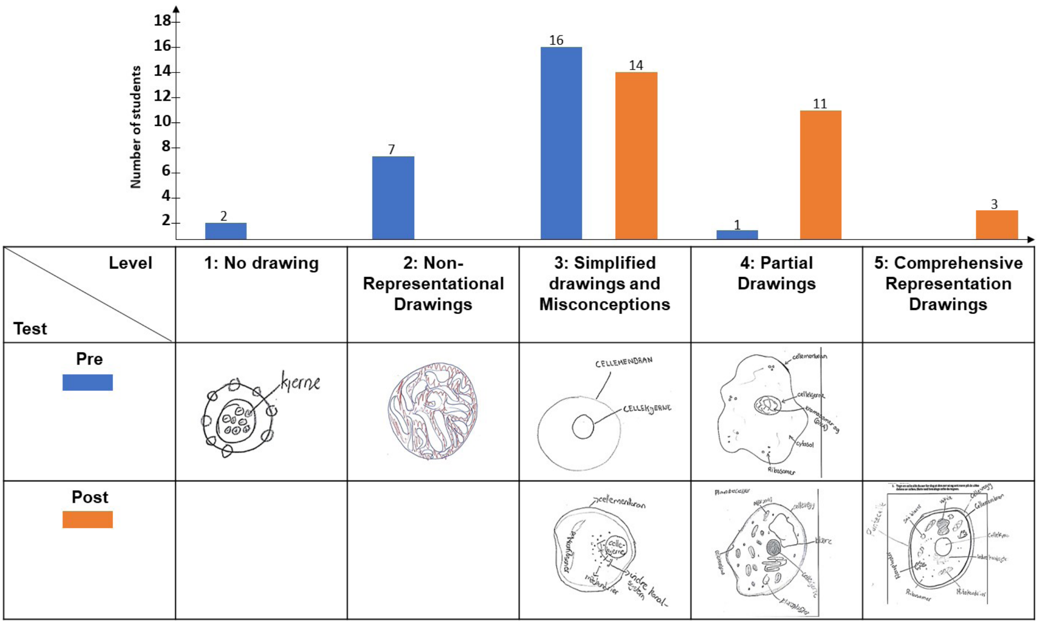

Figure 2. Analysis of the whole cell drawings where number of drawings in different levels are shown for the pretest (blue) and posttest (orange). Examples of drawings analysed and coded to different levels are shown.

The students had previously received instruction on mitosis and meiosis, possibly giving some of them basic ideas of cellular structures and the genetic material of cells. Nine of the pretest drawings included the concepts of DNA and genetic material, either inside the nucleus or in the cytosol. The rest of the posttest drawings (19 out of 28) showed either an empty nucleus or a nucleus with unnamed content. The students were asked to name the structures of the cell, and there was a considerable increase in the number of labeled structures in the posttest (figure 3). The majority of the level three posttest drawings, *Simplified drawings and misconceptions*, demonstrated student misconceptions (all misconceptions are summarized in table 3).

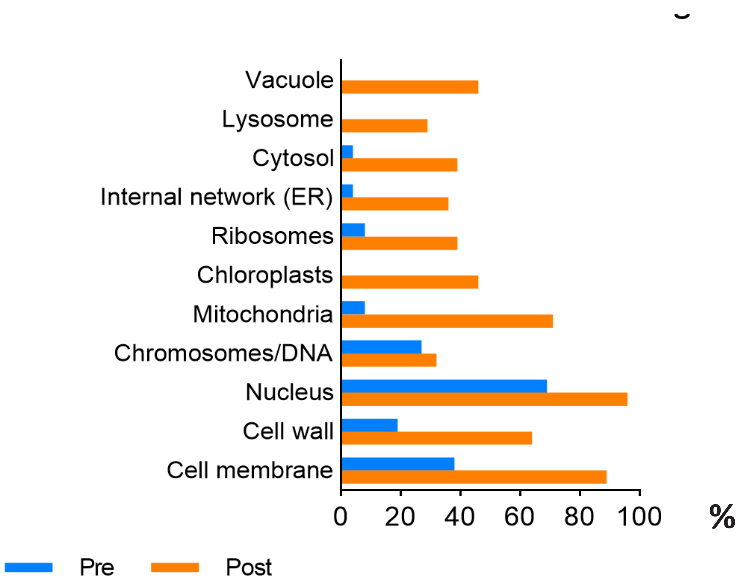

Figure 3. The percentage of students naming a particular structure when drawing cells. The figure shows both pre- and posttest results.

Students were confused about the structures "cell membrane" and "cell wall", about which cells contain a cell wall, and about how the cell wall is organized compared to the cell membrane. There were also examples of misplaced structures, such as chloroplasts in an animal cell and chromosomes in the cytosol, and DNA and chromosomes drawn as different structures (figure 4).

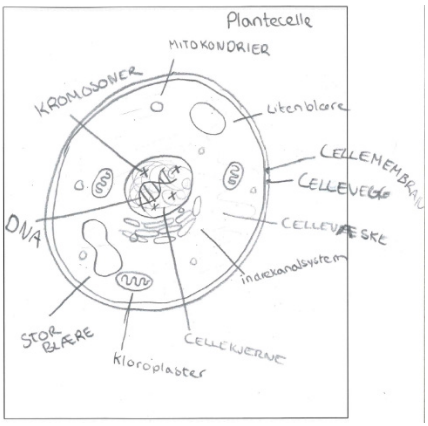

Figure 4. Example of posttest drawing with misconceptions. Plant cell with DNA and chromosomes drawn as separate objects.

Students' conceptions of cell-containing objects

The first session of the teaching module considers aspects of life and aims to make students understand what defines a living organism and that living objects are made of cells. During instruction, the students were asked to sort images of different objects into the categories "dead" or "alive". In the pre- and posttests, the students were challenged to use their previous knowledge to decide which objects are made of cells, sorting images of objects similar to those used in the teaching module. Most students showed a basic understanding of cell-containing objects in the pretest. However, images of a dead leaf and wood seemed to be more challenging to categorize, with around 75% of the students giving the incorrect answer (figure 5). Compared to the pretest, more students were able to choose the right answer for most objects in the posttest, except the dead leaf. Even though more students chose the correct answer for wood, the number was still low compared to the rest of the images, indicating that the students struggled to identify this object as cell-containing.

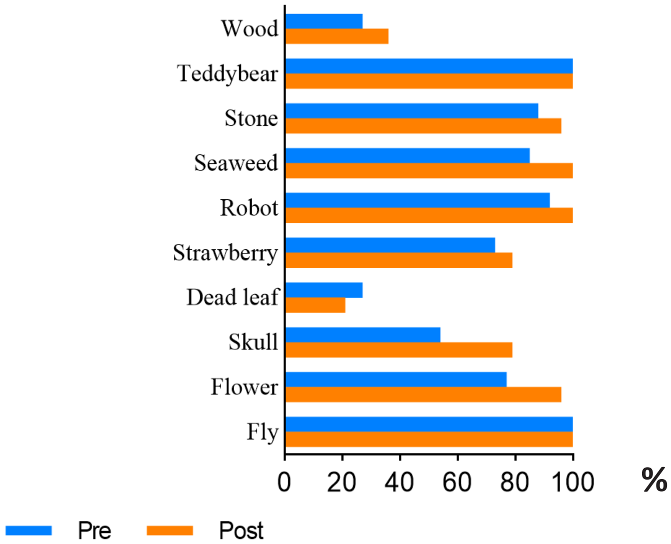

Figure 5. Percentage of students choosing the correct answer (n=26 in pre and n=28 in post) when asked about cell-containing objects. Blue bars from the pretest, orange bars from the posttest.

During instruction the students discussed whether the leaf was dead or alive. Most students agreed that it was not alive. After some discussion, they agreed that the dead leaf *had* been alive, but they never discussed whether it still contained cells.

Students' conception of cellular structures and function

We presented 13 statements (related to different traits of cells presented in appendix 3), asking students to decide whether the statements were true or false. Their answers are presented in figure 6. For 8 out of 13 statements, the percentage of correct answers increased after instruction, but for 5 statements the number of correct answers decreased, including for the statement "*All cells have genetic material*". Prior to instruction, only 3 out of 26 students (11%) were able to correctly identify the statement "*Only some cells have a cell wall*" as false, but in the posttest more than 80% of the students picked the right answer. On the other hand, almost 100% of the students were aware that most cells divide prior to instruction, a figure that showed a slight decrease after instruction (86%).

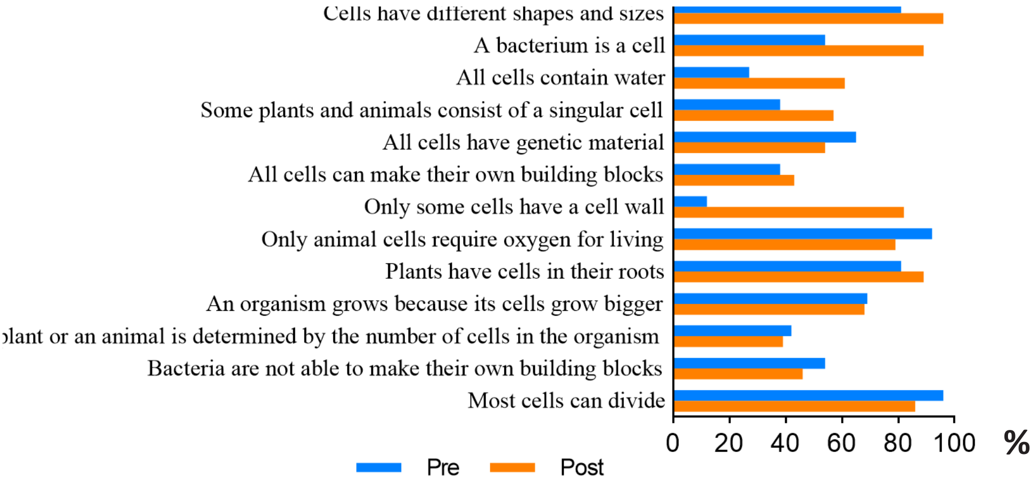

Figure 6. Percentage of correct answers to the thirteen statements of the pre- and post-test.

In the posttest, less than 50% of the students chose the correct response for three of the statements: "*All cells can make their own building blocks*", "*The size of a plant or an animal is determined by the number of cells*" and "*Bacteria are not able to make their own building blocks*".

When asked in the pretest to "*Explain how cells produce energy to survive*", 11 out of 26 students answered "*I don't know*" or did not answer the question. Five students included "*oxygen*" in their answer, and three students answered "*from oxygen*" (table 3). Two students wrote that "*cells are in the blood and get their energy from oxygen in the blood*", indicating that they believe that cells are inside the organism and not the building blocks of the organism and also the blood. After instruction, only two students gave the scientific explanation in the posttest referring explicitly to the concept of "*cell respiration*". Four students were able to make a link between mitochondria and energy production, showing an emerging knowledge of cell respiration without an explicit connection. Moreover, several alternative conceptions were identified, including confusing photosynthesis with cell respiration and relating mitochondria to photosynthesis. Eight of the students linked energy production to photosynthesis, and four wrote that food and drinks are energy sources.

Table 3. Summary of preconceptions from pretest drawings and the open-ended question regarding cell energy production.

Topic	Preconceptions pretest
Cell wall vs cell membrane	-Some students name the cell wall or cell membrane, none includes both structures
Genetic material	-Chromosomes drawn in cytosol -Chromosomes correctly placed in nucleus
Cellular concepts	-Cell drawn as atom-like structure -Cell-like but simplified structure -Cells are in the blood

Cellular structures identified	Ribosomes, mitochondria, cell wall, cell membrane, nucleus, DNA, chromosomes.
Cell energy production	-Cells get their energy from blood -By eating minerals, protein and water -By dividing and reproducing -From the organism they live inside

In summary, the students' conceptions of cells clearly developed during instruction in cell biology. Their previous knowledge of cells varied, and it is obvious that the extent of their knowledge after instruction did as well, as demonstrated by the variation in their drawings in terms of details and labeling. Also, some of the concepts were challenging for the students to understand both before and after instruction. Table 3 summarizes preconceptions identified in the pretest drawings and answers to the open-ended question, demonstrating that the students have some ideas about the cell, but are confused about several concept. Additionally, we identified several misconceptions related to cellular structure and function in the posttest, listed in table 4.

Table 4. Summary of misconceptions identified in the posttest. Findings are from the drawings and from the answers to the open-ended question.

Topic	Misconception posttest
Cell wall vs cell membrane	- Cell membrane lacking from plant cell - Only cell membrane in plant cell - Cell wall in animal cell - Cell membrane and cell wall switched place in plant cell
Genetic material	- Chromosomes drawn in cytosol - DNA and chromosomes as separate structures
Confusion about concepts	- "Krisomer" for chromosomes, mitosis for mitochondria, RNA for ER
Confusion about structures	- Mitochondria lacking from plant cell - Chloroplasts drawn in fungi cells - Vacuole drawn in animal cell*
Confusion about cell energy production	- Photosynthesis confused with cell respiration - Mitochondria connected to photosynthesis - Energy are produced from mitosis - Energy source confused with energy production

* Vacuoles might exist in animal cells; however, these students learned that vacuoles are observed in fungi and plant cells exclusively.

DISCUSSION

The study reported in this paper was performed with eighth-grade students at a Norwegian lower secondary school situated in the western part of Oslo. More research is necessary to draw any general conclusion about the development of Norwegian students' conceptual understanding of cell biology; however, in this section, we discuss our analysis in the context of current research and present implications based on our study.

Students' conceptions of the cell and cellular structures

Drawings have been used by many researchers to assess students' understanding of scientific concepts (Köse, 2008). Drawings are easy to prepare for the researcher and easy to conduct in the classroom, and they make it possible for teachers to assess student knowledge and conceptualization (Prain & Tytler, 2012). In addition, most students are familiar with drawings in the science classroom. Our analysis of whole cell drawings reveals that all students had more knowledge about the cell and its structures after instruction, as would be expected.

Students went from drawing generic cells (if any) containing mostly the cell membrane and nucleus to drawing differentiated plant, animal or fungi cells with several structures, showing that their conception of different cell types had indeed developed. Two students drew atom-like structures in the pretest, confirming previous findings by Sewell (2002) that students might have difficulties understanding the difference between cells and atoms. A few students drew detailed cells in the pretest, indicating emerging knowledge of cellular structures. Previously the students had been taught about mitosis and meiosis, possibly leading to some basic ideas of cellular structures and the genetic material of cells. Some of the pretest drawings included the concepts of DNA, chromosomes and/or genetic material, either placed inside the nucleus or in the cytosol. In the posttest drawings, these same concepts seemed to be challenging for some students, as a larger share of the posttest drawings had either an empty nucleus or unnamed content. Additionally, there were a few cases of chromosomes and DNA being drawn separately as different structures and also placed outside the nucleus.

Even though the genetic material of the cells is emphasized as one of the key concepts in the teaching module, many students seemed to be uncertain about this concept. After instruction, there was an increase in the number of students who chose the wrong answer to the statement "All cells have genetic material". This means that some of the students who answered correctly in the pretest gave the wrong answer in the posttest, suggesting that learning more structures makes some students less able to reconstruct their previous knowledge when learning new concepts. At the end of the teaching module, the students constructed an edible model of a cell. These models, similar to the drawings, showed variations in nucleus content, but all students were able to identify the nucleus as containing genetic material when presenting the models in the classroom (Author 2 & Author 1, 2019). Working with this edible model may have increased students' ability to draw a more detailed cell model in the posttest. However, our results show that the students seem to be confused about the concepts of genetic material, DNA and chromosomes. Most of them linked genetic material and DNA, but the concept of "chromosomes" was confusing to several students, who either placed them outside of the nucleus or inside the nucleus but in addition to DNA. Alternative ideas about DNA, genes and chromosomes are common (Lewis & Wood-Robinson, 2000; Shaw et al., 2008) and exist regardless of age (Saka et al., 2006). The pre-service teachers did not address these misconceptions, and there was no discussion about the content of the nucleus and the genetic material besides the conception of the nucleus as the control center of the cells. Additionally, using three different concepts, "*genetic material*", "*DNA*" and "*chromosomes*", may have confused the students, which suggests that the concepts introduced should be limited to only a few essential concepts. In this case, the pre-service teachers might have missed the opportunity to activate previous knowledge of chromosomes students may have gained during instruction on cell division.

In the posttest, the students were not asked specifically to label the content of the nucleus but only to label the structures, and this simple fact may be the reason that many students did not do so. On the other hand, asking the students to label the nucleus and its content would not necessarily show what they learned about the nucleus and genetic material through instruction. This suggests that a drawing test alone is not enough to make any conclusions as to whether students deepen their knowledge of cells. Adding a set of key concepts for the students to link to their drawings may support and activate their knowledge, and possibly show their understanding of the cell as a system.

Additional misconceptions were identified from the drawings, such as confusion about the cell membrane versus the cell wall, about which cells contain a cell wall or not, and how the cell wall is organized compared to the cell membrane. These are well-known confusions among students who have been trained in cell biology (Zamora & Guerra, 1993), and this was supported by our findings from the cell model study (Lunde & Gregers, 2019). The fact that the students learned about many different types of cells might have contributed to this confusion. The students remembered that different cell types have different characteristics but were not sure about which cells have a cell wall or whether these cells also need a cell membrane. They seemed to be aware that not all cells have a cell wall, but it might not be clear to them what the functions of the cell wall versus the cell membrane are due to the many details related to the four different cell types.

The drawings revealed confusion between chloroplasts and mitochondria, a misconception also reported by Keles and Keferi (2010). In general, as will be discussed further, students seem to struggle to get an overview of how the structures of each cell type are related to the function of that cell.

Students' conceptions of cell-containing objects

We found that most students had a generic understanding of what is alive and what is not and recognized that living objects contain cells. For example, all students knew that flies contain cells and that teddy bears do not. On the other hand, fewer students knew that flowers and strawberries contain cells with less than 80% of the students answering correctly (i.e. contain cells). In addition, the images of the dead leaf and wood all had lower scores. This is in line with several previous studies showing that students consider living objects as things that move and grow (Driver et al., 2014). In the posttest, there was an increase in correct answers connected to most images, except for the dead leaf. During the first session of the teaching module there was a discussion in the classroom of whether a dead leaf (among other objects) was alive. The students agreed that a dead leaf "*had been alive*", similar to wood. Only a small fraction of students indicated that wood contain cells in both the pre-and posttest. The fact that students do not consider dead objects to be cell-containing indicates that their conception of cells is related to objects that *are alive*. This is in accordance with Driver and colleagues (Driver et al., 2014). The fact that the students classified a flower as cell-containing in the posttest, in contrast to the pretest, suggests that the students have increased their conception about plants as living beings.

During session one of the teaching module, the students and pre-service teachers agreed upon some conditions defining a living object: gas exchange, movement and responsiveness to surroundings, reproduction and growth, and, later on, construction from cells. When students were confused about whether dead objects contain cells, they might have thought that these conditions excluded them from containing cells. The students may have struggled to transfer and adjust the new knowledge about cells and living objects in relation to their previous knowledge, and classroom discussions around objects and cells might have helped them adjust their conceptions.

Students' conceptions of the cell as a system

The teaching module has a focus on the systemic view of the cell, and we find it relevant to discuss some aspects related to student's conceptions of the cell as a system. Four of the 13 statements (numbers 6, 8, 12 and 13) from the pre- and posttest may reveal students' ideas about how cells function as a part of an organism. For some of these statements, the number of correct answers decreased after instruction, and even when the number increased, some statements seemed to be confusing for many students, such as "*All cells can make their own building blocks*" (the increase in the posttest was modest, 42% correct answer versus 38% in the pretest). Additionally, less than 40% of the students believe that bacteria are able to make building blocks, even though nearly 90% agree that a bacterium is a cell. It is not clear why the number of students picking the correct answers to these statements is relatively low, but one suggestion might be that they are unfamiliar with the word "*building blocks*" in this setting. During instruction, it was mentioned several times that organisms are built of one or more cells but not that cells make building blocks, which suggests that the idea of the cell as a system is not clear to the students.

The statement "*An organism grows bigger because its cells grow bigger*" can be related to the following statement: "*The size of a plant or an animal is determined by the number of cells in the organism*". Almost 70% of the students agreed that cells do not grow bigger, but only 40% agreed that the size of an organism is determined by the number of cells it has.

These findings, as well as our findings from the last part of the pre- and posttest, the open-ended question about cell energy production, support the assumptions that students struggle to see beyond the details of the cell's interior. The students' answers show that some of them have an emerging conception of how cell energy production is related to mitochondria and cell respiration, but several answers suggest that the idea of cell respiration is confusing to the students and that their knowledge of this process probably developed to a limited extent during instruction. Some students related photosynthesis to energy production. A common misconception is that animal cells produce energy from cell respiration, while plant cells produce energy through photosynthesis (Bajd et al, 2019; Brown & Schwartz, 2009; Keles & Keferi, 2010). However, the teaching module had a specific focus on cell respiration as energy source for all cells through both key concepts and a key sentence, and we expected that more students would be able to make this connection a few weeks later. While students gained knowledge about different cells and different cellular structures, when they were challenged to make connections between the function of cellular structures and the function of the cell, including energy production, they seemed to struggle to conceptualize the cell as a system.

In addition, the students seem to have had difficulty seeing the cell as a part of an organism. In the pretest (open-ended question), they expressed thoughts indicating that they saw cells as units inside an organism, not as building blocks of the organism. It is not clear how their ideas about multicellular organisms developed, but may be related to the fact that the teaching module to a large extent focused on different types of cells rather than cells as functional parts of an organism. We suggest that having ideas about how the function of cellular structures affects the organism may lead to a deeper understanding of how cells are organized. As an example, knowing what role chloroplasts and mitochondria play in the growth of a plant might enable students to understand why plant cells contain both structures and why animal cells only contain mitochondria.

Support during instruction

The fact that the pre-service teachers sometimes added elements during instruction may have confused the students and led to alternative conceptions. Another striking aspect that emerged from the observations was that there were no discussions regarding the cell nucleus and its genetic content, and students' preconceptions about DNA and genetic material were not addressed. This may have caused students to focus less on the nucleus and its content resulting in minimal development of knowledge about the nucleus during teaching. As others have suggested, teachers need to identify students' previous ideas as well as alternative conceptions, and to be aware that students need help and support to integrate their prior knowledge when learning new concepts (Driver et al., 2014; Leonard, Kalinowski & Andrews, 2014; Vosniadou, Vamvakoussi & Skopeliti, 2008). Despite the fact that the teaching module was designed to enhance student discussions and evidence-based reasoning, the pre-service teachers probably did not address students' alternative conceptions properly. A stronger focus on explaining key concepts may also prevent alternative conceptions.

Conclusions and implications

Our findings show that the students expanded their knowledge of different types of cells and cellular components following instruction with the teaching module "*The Cell as a System*" but that several misconceptions nevertheless arose during instruction. Our findings also indicate that students struggled to combine function of cellular components with systemic functions of the cell.

In such cases, it is important to be aware of these ideas in order to build further knowledge. For novices, help and support integrating and reconstructing existing ideas in light of new knowledge might be of importance. In this study, we identified a lack of awareness among the pre-service teachers towards the students' preconceptions about the cell, which might be the reason students seemed to be less conscious about the genetic material of the cells in the posttest. When students' preconceptions and alternative conceptions are not addressed, it is not possible for teachers to reconstruct students' previous knowledge as correct scientific knowledge.

These alternative conceptions can become deeply rooted and affect future learning (Driver & Easley, 1978). It is therefore necessary to assess student progression and discuss student ideas along with the teaching activities in order to promote conceptual learning (Haug & Ødegaard, 2015). This is in accordance with the renewed science curriculum in Norway implemented in August 2020 (Utdanningsdirektoratet, 2020). For teacher educators, it is also important to introduce knowledge about student preconceptions and conceptual understanding to pre-service teachers. Our findings might indicate that that pre-service teachers need more knowledge about how to support students during inquiry-based teaching and that it may be an advantage for inexperienced teachers to follow the teaching module more rigidly to reduce student misconceptions. Further studies are needed to shed more light on how inexperienced teachers make use of teaching modules such as "*The Cell as a System*".

Finally, our results indicate that reducing the amount scientific information presented might prevent the development of alternative conceptions. We suggest that teachers focus on fewer structures, namely those that are most important for cellular function. We also suggest giving less attention to the difference between the four types of cells, which may lead students to confuse structure and function. A larger focus on the cell as a part of an organism, rather than an isolated system, may help students gain a deeper understanding of the relationship between cellular structure and function. When cellular structure and function are seen in the context of the organism, it may be easier for students to understand how the cell works as a system.

REFERENCES

AAAS. (2019). Assessments. *American Association for the Advencement of Science*. Retrieved January 6th , 2021, from http://assessment.aaas.org/topics

Bajd, B., Praprotnik, L., & Matyášek, J. (2010). *Student's Ideas About Respiration: A Comparison of Slovene and Czech students*. Retrieved January 6th, 2021, from http://www.ped.muni.cz/z21/knihy/2010/26/26/texty/eng/bajd_praprotnik_matyasek_e.pdf

Bell, B. A. (2012). Pretest-Posttest Design. In N. J. Salkind (Ed.) *Encyclopedia of Research Design* (pp.1087-1091). Thousand Oaks: SAGE Publications. doi: 10.4135/9781412961288

Brown, M.H., & Schwartz, R. S. (2009). Connecting photosynthesis and cellular respiration: Pre-service teachers' conceptions. *Journal of Research in Science Teaching, 46*(7), 791-812. doi:10.1002/tea.20287

Cohen, J. I. (2015). Guided Inquiry and Consensus-Building Used to Construct Cellular Models. *Journal of microbiology & biology education, 16*(1), 41. doi:10.1128/jmbe.v16i1.809

Coley, J.D., & Tanner, K.D (2012). Common origins of Diverse Misconceptions: Cognitive Principles and the Development of Biology Thinking. *CBE-Life Science Education 11,* 209-215. doi: 10.1187/cbe.12-06-0074

Dikmenli, M. (2009). Misconceptions of cell division held by student teachers in biology: A drawing analysis. *Scientific Research and Essays, 5*(2), 235-247. Retrieved January 6th, 2021, from http://www.academicjournals.org/app/webroot/article/article1380539915_Dikmenli.pdf

Dreyfus, A., & Jungwirth, E. (1988). The cell concept of 10th graders: Curricular expectations and reality. *International Journal of Science Education, 10*(2), 221-229. doi:10.1080/0950069880100210

Dreyfus, A., & Jungwirth, E. (1989). The pupil and the living cell: a taxonomy of dysfunctional ideas about an abstract idea. *Journal of Biological Education, 23*(1), 49-55. doi: 10.1080/00219266.1989.9655024

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*(1), 61-84. doi:10.1080/03057267808559857

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (2014). *Making Sense of Secondary Science: Research into children's ideas*. 2nd Edition. London: Routledge. doi:10.4324/9781315747415

Flores, F., Tovar, M. E., & Gallegos, L. (2003). Representation of the cell and its processes in high school students: An integrated view. *International Journal of Science Education, 25*(2), 269-286. doi:10.1080/09500690210126793

Hatano, G., & Inagaki, K. (2003). When Is Conceptual Change Intended? A Cognitive-Sociocultural view. In G.M. Sinatra, & P.R. Pintrich (Eds.) *Intentional conceptual change* (pp. 407-427). New York: Routledge. doi.org/10.4324/9781410606716

Haug, B. S., & Ødegaard, M. (2015). Formative Assessment and Teachers' Sensitivity to Student Responses. *International Journal of Science Education, 37*(4), 629-654. doi:10.1080/09500693.2014.1003262

Hodgson, J., Rønning, W., & Tomlinson, P. (2012). *Sammenhengen mellom undervisning og læring. En studie av læreres praksis og deres tenkning under Kunnskapsløftet* (NF-Rapport 4/2012). Retrieved January 6th , 2021, from http://www.nordlandsforskning.no/getfile.php/132403-1412587174/Dokumenter/Rapporter/2012/Rapport_04_2012.pdf

Keles, E., & Keferi, P. (2010). Determination of student misconceptions in "photosynthesis and respiration" unit and correcting them with the help of cai material. *Procedia - Social and Behavioral Sciences 2*(2), 3111-3118. doi:10.1016/j.sbspro.2010.03.474

Koba, S., & Tweed, A. (2009) *Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding*. Arlington: National Science Teachers Association Press. Retrieved January 15th, 2021, from https://static.nsta.org/pdfs/PB238Xweb.pdf

Köse, S. (2008). Diagnosing student misconceptions: Using drawings as a research method. *World Applied Sciences Journal, 3*(2), 283-293.

Retreived January 6th, 2021, from: http://idosi.org/wasj/wasj3%282%29/20.pdf

Langheinrich, J., & Bogner, F. X. (2015). Student conceptions about the DNA structure within a hierarchical organizational level: Improvement by experiment-and computerbased outreach learning. *Biochemistry and Molecular Biology Education, 43*(6), 393-402. doi:10.1002/bmb.20888

Leach, J., & Scott, P. (2003). Individual and Sociocultural Views of Learning in Science Education. *Science & Education, 12*(1), 91-113. doi:10.1023/A:1022665519862

Leonard, M. J., Kalinowski, S.T., & Andrews, T.C. (2014). Misconceptions Yesterday, Today, and Tomorrow. *CBE Life Science Education, 13*(2):179-86. doi: 10.1187/cbe.13-12-0244.

Lewis, J., Leach, J., & Wood-Robinson, C. (2000). All in the genes? - Young people's understanding of the nature of genes. *Journal of biological Education, 34*(2), 74-79. doi:10.1080/00219266.2000.9655689

Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance -Do students see any relationship? *International Journal of Science Education, 22*(2), 177-195. doi:10.1080/095006900289949

Lunde, M.L.S & Gregers, T. F. (2019). From Jelly Beans to Mitochondria - Using Student-Constructed Repre sentations of the Cell to Communicate Understanding of Cell Structure and Cellular Processes. Paper presented at ESERA (August 30th), Bologna, Italy

Naturfagsenteret. (n.d.). Cella som system. Retrieved January 15th, 2021, from https://www.naturfag.no/undervisningsprogram/vis.html?tid=2149766

Prain, V., & Tytler, R. (2012). Learning Trough Constructing Representations in Science: A framework of representational construction affordances. *International Journal of Science Education, 34*(17), 2751-2773. doi:10.1080/09500693.2011.626462

Rennie, L.J., & Jarvis, T. (1995). Children's choice of drawings to communicate their ideas about technology. *Research in Science Education, 25*, 239-252. doi:10.1007/BF02357399

Saka, A., Cerrah, L., Akdeniz, A. R., & Ayas, A. (2006). A Cross-Age Study of the Understanding of Three Genetic Concepts: How Do They Image the Gene, DNA and Chromosome? *Journal of Science Education and Technology, 15*(2), 192-202. doi:10.1007/S10956-006-9006-6

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. *Journal of research in science teaching, 30*(8), 919-934. doi:10.1002/tea.3660300809

Sewell, A. (2002). Cells and atoms-are they related? *Australian Science Teachers Journal, 48*(2), 26-30. Retrieved January 6th , 2021, from https://eric.ed.gov/?id=EJ654549

Shaw, K. R. M., Van Horne, K., Zhang, H., & Boughman, J. (2008). Essay Contest Reveals Misconceptions of High School Students in Genetics Content. *Genetics, 178*(3), 1157-1168. doi:10.1534/genetics.107.084194

Thomas, G.V. & Silk, A.M.J. (1990). *An introduction to the psychology of children's drawings (Developing Body & Mind)*. London: Harvester Whatsheaf.

Utdanningsdirektoratet (2013). *Læreplan i naturfag* (NAT1–03). Retrieved January 6th , 2021, from http://data.udir.no/kl06/NAT1-03.pdf

Utdanningsdirektoratet (2020). *Læreplan i naturfag* (NAT01-04). Retrieved January 6th, 2021, from https://www.udir.no/lk20/nat01-04.

Vosniadou, S., Vamvakoussi, X., & Skopeliti, I. (2008). The framework theory approach to the problem of conceptual change. In S. Vosniadou (Ed.) *International Handbook of Research on Conceptual Change* (pp. 3-34). New York: Routledge.

Zamora, S., & Guerra, M. (1993). *Misconceptions about cells*. Paper presented at the 3rd International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Retrieved January 6th, 2021, from http://www.mlrg.org/proc3pdfs/Zamora_Cells.pdf

Ødegaard, M., Frøyland, M., & Mork, S. M. (2009). *Budding Science and Literacy. A Longitudinal Study of Using Inquiry-Based Science and Literacy in Comprehensive Schooling*. Oslo: Norwegian Centre for Science Education. Retrieved January 6th, 2021, from https://www.naturfagsenteret.no/binfil/download2.php?tid=1488397.

Ødegaard, M., Haug, B., Mork, S., & Sørvik, G. (2016). *På Forskerføtter i Naturfag*. Oslo: Universitetsforlaget.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). New York: Simon & Schuster and Prentice Hall International.