What models and representations do Swedish upper secondary school teachers use in their teaching about the atom?

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# What models and representations do Swedish upper secondary school teachers use in their teaching about the atom?

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**Sammanfattning**
This report presents the results from a survey study on Swedish upper secondary school physics and chemistry teachers’ use of models and representations in teaching the atom. The study builds upon an earlier systematic international literature review on the role of models and representations in the teaching, learning and understanding of the atom. The overall aim of the study is to explore what models and representations are used by Swedish upper secondary school physics and chemistry teachers in their teaching about the atom, what informs teachers’ selection of the atomic models and representation forms and how they specifically use them in their teaching of the atom. The method for collecting the data for this study was an electronic questionnaire containing six introductory questions followed by nine open and four closed items, which were analysed both quantitatively and qualitatively. Thirty-one responses were received and analysed in this study.

The results of the study indicate that Swedish teachers’ selection and use of atomic models and representation forms in their practice correspond with findings in the previously conducted literature review. For example, the Bohr atomic model was shown to be the most popular for teaching about the atom amongst the Swedish teachers in this study, since it is deemed intuitive and easy to visualize. A further result revealed that the de Broglie atomic model was only used by physics teachers, and that physics teachers overall used more atomic models in their teaching than chemistry teachers, a finding that might be related to the different teaching content in physics and chemistry. The study also shows that Swedish teachers are very comfortable with, and advocate, using different representation forms in their teaching. One interesting finding in this regard was that the use of physical models is predominantly more popular among chemistry than physics teachers. In line with the findings in the previous literature review study, students’ prior knowledge and individual learning styles were found to be important influencing factors in teachers’ selection of representation forms to use in the classroom. The majority of the teachers also agreed on that it is important to explain to students how models should be interpreted and used, but one interesting finding, that differs from the previous research, is that some teachers were of the opinion that students have an already well-developed modelling ability when encountering different models of the atom.

**Nyckelord**
Physics education, chemistry education, atomic models, representation forms, atomic concepts, mental models, alternative conceptions, science teaching, student understanding
5.8 Do teachers use multiple forms of representations, and how do they go about using them together with their students? ........................................................................................................36

5.9 What determines teachers’ choice of representation forms when teaching about the atom and related phenomena to their students? ..................................................................................................................37

6 Discussion ..................................................................................................................................40

6.1 Discussion of obtained results ..................................................................................................40

6.1.1 What models of the atom do teachers use to describe and explain the atom? ..................40

6.1.2 What representation forms do teachers use to communicate the atomic models in their teaching of the atom? .................................................................................................................................43

6.1.3 What informs teachers’ selection of the atomic models and representation forms above, and how do they specifically use them in their teaching of atom related phenomena? .........................46

6.2 Discussion of the method used to collect data .........................................................................48

6.3 Conclusions and implications ..................................................................................................51

7 References ....................................................................................................................................54

7.1 Acknowledgement of sources for figures ..................................................................................58

Appendix I .........................................................................................................................................59
1 Introduction

This report presents a study conducted as a part of the Upper Secondary School Teacher Programme at Linköping University. The study builds upon an earlier systematic international literature review on the role of models and representations in the teaching, learning and understanding of the atom and atomic concepts. The current study presents the results from a survey among Swedish upper secondary school physics and chemistry teachers’ use of models and representations in teaching the atom.

Models are simplified depictions of reality, and are necessary tools for explaining abstract scientific phenomena that cannot otherwise be directly observed. The atom is an example of an abstract phenomenon and there are several different atomic models to choose from to teach aspects of the atom, that include the Thomson, Rutherford, Bohr, de Broglie or the Schrödinger models. These atomic models can be externally communicated in the world in different representational forms, that is to say, as static 2D pictures, animations, computer simulations, physical models or virtual reality interfaces. Based on the results of the earlier literature review, it emerged that it is important that teachers reflect upon how models and representations will be interpreted by students when selecting appropriate models and representations to use in the classroom. How learners interpret models and representations are influenced by their prior knowledge and individual learning styles, and if more than one model or representation form are used, students might need support in the translation process required to link between them. This study aims to explore what models and representations Swedish upper secondary school physics and chemistry teachers use in their teaching about the atom, what informs their selection of the models and representation forms, and how they specifically use them to communicate atomic concepts during their teaching practice.

An electronic questionnaire comprising of both closed and open items was designed and used as the method for collecting data in this study. The study was implemented in Google Forms, and sent out to teachers in Linköping, Norrköping, Finspång, Söderköping, Stockholm, Uppsala, Lund, Göteborg and Malmö through e-mail.
2 Aim of the study

The overall aim of this study is to explore what models and representations are used by Swedish upper secondary school physics and chemistry teachers in their teaching about the atom. More specifically the following research questions were raised:

- What models of the atom do teachers use to describe and explain the atom?
- What representation forms do teachers use to communicate the atomic models in their teaching of the atom?
- What informs teachers’ selection of the atomic models and representation forms above, and how do they specifically use them in their teaching of atom related phenomena?
3 Background

In this section the background of the study is presented, followed by a subsection that describes the theoretical framework used for analysing and discussing the results.

3.1 Background

Based on the current national policy documents for physics and chemistry education in Swedish Upper Secondary School, students should be given the opportunity to use computer-based equipment to support learning physics (Skolverket, 2011a; Skolverket, 2011b). This aim supports the use of digital aids in physics education, such as simulations and visualizations, to help students interpret and understand physical and chemical phenomena.

According to the Swedish school curriculum programme for the Physics 2 course, teaching content should cover:

- The electron structure of atoms, and absorption and emission spectra.
- [...] Models and theories as simplifications of reality. Models and their areas of applicability and how they can be developed, generalised or replaced by other models and theories over time.
- The importance of experimental work in testing, re-assessing and revising hypotheses, theories and models (Skolverket, 2011a, p. 14).

According to the Swedish school curriculum programme for the Chemistry 1 course, teaching content should cover:

- Models and theories of the structure and classification of matter.
- [...] Models and theories as simplifications of reality. How models can change over time.
- [...] The importance of experimental work in testing, re-assessing and revising hypotheses, theories and models (Skolverket, 2011b, p. 3).

In the Chemistry 2 course, teaching content should cover:

- Models and theories as simplifications of reality. Models and their areas of applicability and how they can be developed, generalised or replaced by other models and theories over time.
- [...] The importance of experimental work in testing, re-assessing and revising hypotheses, theories and models (Skolverket, 2011b, p. 7).
Apart from “The electron structure of atoms, and absorption and emission spectra”, and “Models and theories of the structure and classification of matter”, all of the learning objectives are the same across both Chemistry and Physics curricula.

Based on the above, it is important that teachers present different models of the atom, and different forms of representations to do so, to their students in both physics and chemistry. The atomic models are simplifications of reality and teachers should emphasise that new models have replaced historical models of the atom over time. One of the conclusions drawn in the preceding literature review study, which this study builds upon, was that it is important that the teacher explicitly compares and contrasts different models of the atom to allow the students to move from one model to another and integrate the new information into their current conceptual understanding (Netzell, 2015).

3.1 Models to describe and explain the atom

Atoms are structural entities that cannot be observed directly with the naked eye. Models are therefore necessary tools for teaching and understanding the atom and related concepts (Harrison & Treagust, 1996). In this section, different atomic models and their development through history are presented. Based on the findings in the earlier performed literature review, which this study builds upon, the most commonly used models to describe the atom in science education are also described.

3.1.1 Historical models of the atom

Some of the most frequently appearing historical models of the atom are the Thomson model, the Rutherford model, the Bohr model, the de Broglie model and the Schrödinger model of the atom.

In the Thomson model of the atom negatively charged electrons are embedded in a positively charged mass (Lindgren, n.d.). In the mid-19\textsuperscript{th} century, Thomson discovered the negatively charged electron, and since he knew that the atom was neutrally charged he assumed that there must be some type of positively charged mass around the electrons that neutralize the total charge of the atom. This model is often called the “plum-pudding-model” since the
electrons can be seen as plums distributed in a pudding (the positively charged mass) (see figure 1).

In the early 20th century, Rutherford discovered that the positively charged particles must be concentrated in the centre of the atom (Lindgren, n.d.). His theory was a result of his experiments with alpha rays striking gold foil, where the scattering angle of the alpha rays led to the conclusion that there must be a positively charged core in the atom. These results of these experiments gave rise to the solar system model of the atom (see figure 2).

![Figure 1: The Thomson atomic model.](image1.png)

![Figure 2: The Rutherford atomic model.](image2.png)

In the early 20th century, quantum mechanics started to be explored, and according to classical mechanics the solar system model of the atom would not be electrodynamically stable (Lindgren, n.d.). As a result of the loss of energy caused by the emission of radiation, the electrons in the solar system model would eventually fall into the nucleus of the atom. In 1913, Niels Bohr presented a new atomic model where the electrons were modelled as being located in specific orbits, depending on their energy level.
Louis de Broglie presented a further refined model of the atom in 1924 (Andersson, n.d.). The model was based on de Broglie’s theory of the wave property of matter, wave-particle duality, where the electrons moved like waves in the atom. Stable states of the electrons correspond to an even number of half wavelengths.

In 1926, Erwin Schrödinger presented the Schrödinger equation (Andersson, n.d.). The Schrödinger equation is a wave equation appropriate to the matter waves in de Broglie’s theory, and by solving the equation for particles in a confined space, the equation showed that solutions are only possible for a number of discrete energy values (Rae, 2008). In the Schrödinger model of the atom, the electrons have sets of quantum numbers that describe their individual states in the atom (Andersson, n.d.).
3.1.1.2 What models are most commonly used to teach about the atom?

As revealed by the previous literature review, when teaching about the atom in the school classroom, models derived from the Bohr model of the atom seem to be most commonly used. When it comes to teaching about electrostatic interaction, the Schrödinger model is also popular (Adbo & Taber, 2009; McKagan, Perkins, & Wieman, 2008; Wheeldon, 2012).

Based on a study by Harrison and Tregust (1996) the solar system model of the atom was viewed as the most popular atomic model among students, since it is concrete and easy to understand. However, the study also showed that students often dislike the Schrödinger model of the atom since it is more abstract and unfamiliar to them. Several of the articles analysed in the literature review that this study builds upon, mention that the Bohr model has a very strong influence on students’ conceptual understanding of the atom (Netzell, 2015). This influence is so significant that the Bohr model, in a certain respect, could actually hinder subsequent learning about the quantum nature of the atom (see section 3.1.3.2).

3.1.2 Different representation forms for depicting atomic models and atomic phenomena

In this section, different representation forms used to teach about the atom and related concepts are presented. In this section, the idea of multiple external representations and the potential advantages of using them for effective learning will also be reported.

3.1.2.1 What representation forms are most commonly used to teach about the atom and related concepts?

Based on the results of the former literature review (Netzell, 2015), which this study builds upon, the following types of representations are used to teach about the atom and related phenomena:

- Two-dimensional static pictures or diagrams (e.g. pictures of the atom in a textbook or static pictures on a screen)
- Two-dimensional dynamic pictures (e.g. films and simulations)
- Computer simulations (e.g. three-dimensional virtual reality experiments or demonstrations)
- Physical models (e.g. ball-and-stick models to represent molecules)
To this list, spontaneous representations created by the teacher her/himself during teaching, such as pictures, drawings and text externalised on a whiteboard, would also constitute an additional representation form.

One commonly used representation form to teach about the atom and atomic concepts are 2D pictures of historical and scientific models of the atom found in textbooks (Adbo & Taber, 2009). Pictures of the atom derived from scanning tunnelling microscopy are also common in textbooks (Taber, 2002). When using 2D pictures to teach about molecules, different types of atoms are often depicted with different colours to help the students distinguish between different elements (Albanese & Vicentini, 1997).

When teaching about molecules, ball-and-stick 3D-models are often used (Albanese & Vicentini, 1997). The balls represent the atoms and the sticks represent the bonds. The recently advancing technology of 3D printing has also become more accessible and affordable as a representation form for teaching science concepts (Robertson & Jorgensen, 2015). 3D-printing can be used to create 3D-models for teaching about orbitals and molecular structures, and in a report by Robertson and Jorgensen (2015) the authors demonstrate how 3D print files of molecular orbitals can be generated.

A conclusion from the literature review is that different types of computer simulations are effective learning tools when teaching science (Netzell, 2015). The students are used to working with computers, and they often enjoy interacting with such representation forms. Yet, it is important that the computer-based representations are well designed to support effective learning. In a study by Trindade, Fiolhais and Gil (2005) a virtual reality environment was used to help students understand the particle nature of matter. The students were allowed to “step inside” the learning environments through the help of 3D graphics. The study showed this learning tool to be promising and effective.

According to the constructivist theory of learning, it is important that the learner has an active role in the process of understanding information, and that the new information builds meaningfully upon students’ prior knowledge (Woolfolk, 2010). Liguori (2014) describes a representation form where students were involved in a role-play to learn about the orbital concept of the atom. The representation was designed as a chocolate shop, with the aim of
being an environment familiar to students’ everyday life. The familiar environment and the role-play activity allowed the students to be active in the learning process, and they could assimilate the new analogies of the atom to their already existing knowledge about the chocolate-shop environment. In a study by Scherr et al. (2013), a learning activity called “Energy Theatre” is used to promote students’ conceptual understanding of energy. The learning activity is based on a metaphor where energy is described as a substance, and each student who participates in the theatre identifies as a unit of energy at a specific form at a specific point in time. The students indicate their energy form by a hand sign, and their movement between different regions in the room represents the transfer of energy. When energy changes form, the students change their hand signs. The number of students in a specific energy region represents the amount of energy of different forms in a certain object. When examining this type of learning activity, the authors suggest a participationist theory of learning, where learning is indicated by changes in behaviour and speech. Therefore, this type of learning activity can be well suited for formative assessment.

3.1.2.2 Multiple external representations (MERs) in science learning

Multiple external representations (MERs) are a combination of more than one external representation to describe the same phenomenon (Ainsworth, 2006). An example of a MER could be an animation of a moving car, together with the simultaneous presentation of a velocity-time graph to represent the car’s movement (Ainsworth, 1999).

One important advantage of working with multiple representations in science education is that it is more likely to capture the interest of the learner (Ainsworth, 1999). The different representations provide equivalent information to the students, but highlight different aspects. Learning with multiple representations also provide the opportunity for students to choose to work with the representation they prefer most.

When using multiple representations in learning, students learn that there is more than one way to describe a certain phenomenon. Ainsworth (1999) suggests that doing so can develop and improve students’ problem-solving ability. However, it can be demanding for students to translate between different representations, which will be further discussed in section 3.1.3.3.
Sunyono, Yuanita and Ibrahim (2015) performed a study where the aim was to identify the effectiveness of a learning model of multiple representations to teach about the concept of atomic structures. Their research showed that multiple representations are more effective than conventional representations to teach and support effective learning about atomic structures. The authors also drew the conclusion that low-achieving students in particular benefitted from working with the multiple representations-based model. By using the multiple-representation based model, the low-achieving students were able to keep up better with the higher-achieving students in creating their mental models about atomic structure.

3.1.3 Selecting and using atomic models and representations in teaching about the atom and related concepts

Based on the former literature review, this section describes how teachers should select appropriate models and representations, and how to use them in order to support effective learning among their students. When selecting models and representations it is important for the teacher to reflect upon how the students might interpret them (Harrison & Treagust, 1996). The students might already have existing mental representations that they use to understand a phenomenon, and the interplay between these models and new external models are a complex process (Scaife & Rogers, 1996). If the students cannot interpret the models meaningfully, it will place demands on integrating new information with their prior knowledge.

When teachers select models and representations to present to their students, it is important for the teacher to reflect upon how the students will interpret them (Harrison & Treagust, 1996). The students might already have existing mental representations that they use to understand a phenomenon, and the interplay between these models and new external models are a complex process (Scaife & Rogers, 1996). If the students cannot interpret the models meaningfully, it will place demands on integrating new information with their prior knowledge.

It is important for teachers to have their students’ prior knowledge in mind when selecting appropriate models and representations (Netzell, 2015). From a constructivist point of view it is important to select models and representations that can be related to the students’ already existing knowledge (Woolfolk, 2010). The mental models that students create will depend on
their already existing models, which influence their attention and perception of new information, and they will often use their prior knowledge to select information from representations and models (Cook, 2006). Therefore, students’ existing knowledge will affect what will be learned from a model or representation, and it is when the learner consciously selects and organizes information and integrates it with their prior knowledge that learning becomes meaningful (Moreno & Mayer, 2007).

### 3.1.3.2 How do learners interpret atomic models and different forms of representations?

Research has shown that students often find it difficult to select appropriate models and representations to describe scientific phenomena on their own (Harrison & Treagust, 2000). They tend to believe that only a single model is appropriate to describe a specific phenomenon, and they have difficulties understanding that different models can be used to describe the same phenomenon, but highlight or dampen different aspects of that phenomenon. An example is different models of the atom, where the Bohr model seems to be especially popular among students. For students to understand how to use multiple representations and models to describe a phenomenon, it is important that the teacher explicitly teaches how to use the models and representations and how to interpret them (Harrison & Treagust, 2000).

The particle nature of matter has shown to be demanding for learners to conceptualize (Kelly, 2014). In this regard, students also have difficulties with adjusting any alternative conceptions that they might already have. A study by Kelly (2014) showed that students’ lack of metacognitive skills for self-assessment is an obstacle for developing and correcting their alternative conceptions. A conclusion of the study was that it is important that the students are given the opportunity to evaluate their mental models and reflect upon what they have learned when using different models. As mentioned in the section above, it is important that the teachers teach modelling-skills to their students.

As mentioned in subsection 3.1.2.1, 2D-pictures from textbooks are commonly used to teach about the atom. These pictures often depict an oversized nucleus (Adbo & Taber, 2009). Even though the pictures are in 2D, students do not seem to have difficulties understanding that the atom is spherical. However, visualizing relative distances within the atom has been shown to be more challenging, since the relative size of the nucleus does not map onto scientific reality.
Some textbooks show colourful pictures of the atom derived from scanning tunnelling microscopes. As a consequence of the colour in the pictures, students might develop the conception that atoms have colour, or that aspects of colour are manifested at the nano and picoscale (Albanese & Vicentini, 1997). Albanese and Vincentini (1997) performed a study that showed that 80% of 30 students believed that the atoms were coloured. They also believed that the colour of the atom corresponded to the colour of the macroscopic matter that the atoms constituted.

Some notions used in science education are synonymous to other notions used in students’ everyday life and this might also contribute to confusion. An example of a notion that has shown to be confusing to students is the term “electron cloud” (Harrison & Treagust, 1996). The students are already familiar to the word “cloud” from their everyday life, and if they learn something new where the term “cloud” is involved, they might try to assimilate the new information into their prior knowledge about clouds. When the new term “electron cloud” is presented to them, they might formulate a mental model that the electron cloud is like a matrix of sorts with electrons embedded into it, instead of understanding that it is the electrons that “form” the cloud.

As mentioned in section 3.1.1.3, the Bohr model has a strong influence on students’ conceptual understanding of the atom. In a conclusion of a study by Park and Light (2009), it was found necessary that students understand the concepts of probability and quantization of energy to be able to develop their conceptual understanding in moving beyond the Bohr model of the atom. The study showed that it is not only important that the students understand the wave property of the electron, but also that they understand energy quantization. If they understand the wave properties but not the energy quantization, they might develop incorrect hybrid models of their own. It follows that the students needed to be well versed with both concepts to be able to understand the Schrödinger model of the atom. Özcan (2013) performed a study among pre-service physics teachers, which showed that the students’ concepts of atomic spin was related to their concepts of the atom constructed during their high school years. Students that are very familiar with the Bohr model of the atom considered spin as the rotation of an object around its’ own axis. The study also emphasized the importance of teaching the quantum model of the atom to students at high school level, because the probability concept is important in moving beyond the Bohr model towards the Schrödinger model. It seems that the Bohr model could be an obstacle for learning the quantum nature of
the atom. Interestingly, a study by McKagan, Perkins and Wieman (2008) showed that students could move beyond the Bohr model of the atom if the teacher explicitly compares and contrasts the Bohr model to the other models of the atom, and informs the students about the advantages and limitations of the different models.

Students often interpret models as accurate and complete truth statements of reality (Adbo & Taber, 2009). To avoid this, it is important that the teacher explicitly teach about the limitations of models. Another way of preventing potential alternative conceptions is to work with multiple representations to describe the same phenomenon (Harrison & Treagust, 2000). When learners discover that there is more than one model and representation form to describe the same phenomenon, they discover that no model is completely correct, and that different models complement each other.

3.1.3.3 Translating between more than one model and representation form

When using multiple representation forms to describe a phenomenon, for example a static picture and a dynamic simulation of the Schrödinger model, students may often find it demanding to translate between them (Ainsworth, 2006). The learner might require support in the translation process, and the level of support needed depends, among other things, on the learner’s prior knowledge. Students learn in different ways and the support should therefore be individualized for effective learning, where possible. Kozma and Russel (1997) performed a study where they examined the ability to translate between representations among experts and novices in a chemistry context. The study showed that novices found it more difficult to translate between more than one representation, especially if they were to translate between animations or videos to other representation forms. The reason why novices find the translation process difficult seems to be that their knowledge often consists of unconnected fragments. The experts found it easier to make the translations since their knowledge is more structured and hierarchical, and they therefore have the ability to see how the same phenomenon can be represented in different ways. Kozma and Russel (1997) referred to the ability to translate between different representation forms of a phenomenon as “representation competence”. Since students’ representation competence often is often not fully developed, it is important that they are provided with individual support.
Support in the translation process can also be given as implicit cues in different representations, such as using the same colour in different representations to represent the same thing (Ainsworth, 2006). Computer representations can also perform the translations externally, so when the student changes a parameter in one representation, the result of his or her act can be seen in another. This type of computerized support is called “dynamic-linking” and it can help students interpret connections between multiple representations.

3.2 Theoretical framework

In this subsection, the theory of scientific modelling will be presented.

Gilbert (2004) suggests that using models and modelling in science education can form a basis for a curriculum where science education is made more authentic. Models can be idealisations and/or simplified depictions of reality, created to enable understanding and communication of abstract concepts and theories. Models and modelling have been used in science since the mid-twentieth century, especially in chemistry, and Gilbert (2004) therefore suggests that the theory of modelling should also be integrated in science education. If modelling is explicitly taught to students, they will be able to better understand how models are developed and used, and how to create models of their own. In this way, students participate in the creative process of modelling, which is an important aspect of the cultural value of science.

The notion “model” has a variety of ontological status (Gilbert 2004). Ontology is the philosophical study of what entities exist and in what forms they exist (Brinkkjær & Høyen, 2013). One way of categorising models is to differentiate between “mental models” and “external models” (Haglund & Jeppsson, 2013). “Mental models” are models that individuals create themselves to describe reality (Gilbert, 2004; Haglund & Jeppsson, 2013; Harrison & Treagust, 2000). A mental model is only accessible for the individual who possesses it, but it can be expressed as an ”external model”. ”External models” are models that can be used in communication with others, and according to Black (1962) the external models can be divided into five subcategories: scale models, analogical models, mathematical models, theoretical models and archetypes.
”Scale models” are models that often resemble the external proportions of the objects modelled (Black, 1962). A scale model can be an enlargement of something small, such as an atomic model, or a size reduction of something large, such as a map of the world.

”Analogical models” are models that share information with, and map to the phenomenon that they describe (Black, 1962; Harrison & Treagust, 1996). Analogical models are created in a medium that differs from the medium of the target modelled, and the model reflects correspondences between the analogy and the target (Harrison & Treagust, 1996). If more than one target is represented in the analogical model, the model is called an “extended analogical model” (Harrison & Treagust, 2000). In this regard, the solar system model of the atom is an example of an extended analogical model since the analogy can be used to explain several aspects of the atom. Here, the sun represents the nucleus, and the planets represent the electrons. The electrons orbit the nucleus as the planets orbit the sun, and the electrons and the nucleus attract each other just as the sun and the planets. When used to teach scientific concepts analogical models are referred to as “pedagogical analogical models” (Harrison & Treagust, 1996). Analogical models can be concrete, such as a scale model, or abstract, such as a scientific model of the atom (Harrison & Treagust, 2000). Chemical reaction formulae, symbolic equations, atomic models and the periodic table are examples of pedagogical analogical models.

“Mathematical models” are models where variables are used in formulae to describe different scientific phenomena (Black, 1962). With the help of mathematical models, consequences of hypotheses can be calculated and compared to observations (Haglund & Jeppsson, 2013). Examples of mathematical models are physical formulae, such as $F = m \cdot a$ (the force $F$ on an object is equal to the object’s mass $m$ multiplied with the acceleration vector of the object $a$), mathematical equations and graphs (Harrison & Treagust, 1996).

“Theoretical models” are models that represent abstract nonmaterial phenomena, such as magnetic or electric fields (Black, 1962). An example is Maxwell’s model of electric fields where it was suggested that the fields were analogous to incompressible fluids.

“Archetypes” are models that can be transferred from one area of science to another (Black, 1962). “Pressure” is an example of a notion that originates from the physics, but has been transferred to psychology for example (Haglund and Jeppsson, 2013).
The five types of external models suggested by Black (1962) is one classification system among others, and there are some additional model categories that occur in literature. As mentioned earlier, when students create models of their own to describe reality, these models are often called “mental models” (Harrison & Treagust, 2000). If the teacher presents a new model that describes the same phenomenon in a different way, students’ existing mental models can be influenced and changed. Newly developed models are often called “synthetic models”. If the mental models are expressed to others (e.g. through drawing) they are called “expressed models”, and if a model is accepted and used by more than one individual it is called a “consensus model” (Gilbert, 2004). Classic examples of consensus models are the models of the atom that have been developed through the history. An atomic model is a symbolic depiction of the atom used to describe the abstract theory behind the atomic concept. Examples are the Thomson, Rutherford, Bohr, de Broglie and Schrödinger models of the atom. Atomic models that are considered as scientifically correct at a point in time are called “scientific models”. Models considered scientifically correct in the past but considered limited in the current understanding of atomic phenomena (but still perhaps useful for teaching the atom from a historical perspective) are called “historical models”. In this regard, the Schrödinger model could be seen as a scientific model, and the Thomson model as an example of a historical model. When using models in science education, it might be necessary to use simplified versions of scientific or historical models to aid the interpretation process for students. Gilbert (2004) refers to these models as “curricular models”. If aspects from more than one model are combined in one model, the model is called a “hybrid model”.

The models can be communicated to public with the help of different representation forms. Gilbert (2004) suggests that there are five modes of representation:

- “The concrete mode” is physical models in 3D, such as plastic molecular or orbital models often used in chemistry.
- “The verbal mode” is spoken or written descriptions of representations, such as describing that the balls represent the atoms and the sticks represents the bonds in a ball-and-stick model of a molecule.
- “The symbolic mode” is mathematical equations, chemical symbols, and chemical and physical formulae.
- “The visual mode” is 2D static or dynamic pictures, such as animations, graphs or diagrams.
“The gestural mode” is representation of phenomena with the use of physical gestures and movement with our bodies.

A representation is an illustration or an example used to describe an object or a phenomenon (Gärdenfors, n.d.). A representation form is defined as the format used to depict information externally in the world (Scaife & Rogers, 1996). Examples of different representation forms are static or dynamic 2D-images (e.g. pictures in textbooks, films or animations), computer simulations (experiments and/or demonstrations), physical models (e.g. plastic ball-and-stick models in chemistry to teach chemical bonding), teacher-generated models (e.g. pictures or formulae on the whiteboard) and 3D virtual learning environments (Taber, 2002; Trindade, Fiolhais, & Gil, 2005; Scaife & Rogers, 1996). An atomic model can be communicated through different representation forms, such as pictures and simulations. Combinations of more than one external representation used to communicate the same phenomenon are called “multiple external representations” (Ainsworth, 2006).
4 Method

This study was carried out in the form of a research survey. An electronic questionnaire created in Google Forms was used to collect data. The questionnaire consisted of 13 total items (excluding six introductory items) - nine open items and four multiple-choice items. A qualitative and quantitative approach was used to analyse the data.

4.1 Study design and implementation

In this section, the method used for data collection will be described and discussed. In the first subsection, the questionnaire used in the study will be described. In the second subsection, the potential benefits and limitations of the selected method will be discussed.

4.1.1 Design of the questionnaire

To answer the research questions of this study, the data-collection method should be able to record and document teachers’ reasoning. When research focuses on documenting the individual views and opinions of the respondents, a qualitative method of research is suitable (Bryman, 2002). Examples of qualitative research methods are unstructured interviews or observations. However, the aim of this study is also to compare the results from the literature review to Swedish physics- and chemistry education. The results from the earlier conducted literature review (Netzell 2015), allowed hypotheses for the current research to be formulated in the form of potential questions to ask practicing physics and chemistry teachers in relation to their model and representation use. This study aims to collect data in regard to these hypotheses. The method of research where several hypotheses are confirmed or rejected is termed “deduction” (Bryman, 2002; Fejes & Thornberg, 2015). Research methods suitable for deductive studies are often quantitative survey studies such as questionnaires, or structured interviews. To fulfil both the aim of obtaining teachers’ reasoning as well as the aim to obtain answers to more specific questions, an electronic questionnaire method with open and closed questions, that could be analysed both with qualitative and quantitative approaches, was adopted. Since open questions were used, the study also has an “inductive” aspect, since analysis of the teachers’ individual answers can result in new themes of meaning and reasoning that were previously unanticipated. In “inductive” studies, the researcher arrives at
conclusions based on the data material used in the study (Fejes & Thornberg, 2015). The questionnaires also included closed multiple-choice questions, to provide the respondents with some possible alternatives when suitable. The content of the questions in the survey questionnaire were informed by the findings in the literature review. The first section of the survey consisted of demographic questions about the respondents, including age, gender, education and teaching experience. The responses to these questions were used to obtain a sample description of the context of the teachers and how teaching experience, experience from other fields, or additional university degrees, may influence the teachers view and use of models and representations.

In the development of the questionnaire, there were four iterations of design. Initially, a draft was constructed, which was revised twice into a second and a third version, respectively, after discussion with the supervisor. A face-validity screening (see section 4.3) was performed on the third version with two of the author’s colleagues and one of the supervisor’s science communication colleague, who provided feedback on the items. Based on the feedback, the questionnaire was revised into a fourth and final version and implemented on an electronic survey interface.

To reach out to a potentially large sample of teachers, an electronic questionnaire created in the programme “Google forms”, was used to administer the survey and gather responses. A link to the questionnaire was sent out via e-mail to physics and chemistry teachers in Linköping, Norrköping, Söderköping, Finspång, Uppsala, Lund, Göteborg, Malmö and Stockholm. A link to the questionnaire was also published on the Swedish Facebook group “Lärarnätverket”, which is an open networking-group for teachers and student teachers. The questionnaire was delivered in Swedish. The responses have been translated into English for communication in the results section (see chapter 5). The questionnaire used in this study is included in Appendix I.

4.1.2 Teacher sample and data collection

A limitation of survey questionnaires is that the response rate is often low (Bryman, 2002). To be able to obtain an acceptable sample size for this study, the questionnaire was initially sent out to a large number of teachers in different cities in Sweden. The questionnaire was sent out to approximately 170 teachers by e-mail, and it was also posted in the networking-group
“Lärarnätverket” on Facebook. After one week, 25 responses were received from the e-mail sample. In the following week, a reminder-e-mail was sent out, which resulted in 6 additional responses. Overall, 31 responses were received and analysed, giving a response rate of 18%.

4.2 Data analysis

Both qualitative and quantitative methods were used to respond to the research questions raised by the study. The open-ended questions of the survey were analysed qualitatively. When analysing open items, common criteria and categories that emerge iteratively can be used to group the answers (Bell, 2006). The qualitative data can be quantified based on frequency of arguments, attitudes or themes for example, and for this study a quantification based on thematic analysis will be performed (Harboe, 2013). If for example two different answers indicate that the teachers have their students’ prior knowledge in mind when choosing appropriate models, these two answers will be grouped into the same category. Subsequently, the quantitative analysis will be used as a support in the qualitative analysis of the individual answers. The qualitative analysis will be as objective as possible in the result section (see chapter 5), and thereafter, the results will be compared and contrasted to the background in the discussion section (see chapter 6). The questionnaire is designed to possibly answer the research questions of this study, which, in turn, are formulated based on the results of the literature review. The results of the current study can therefore be compared and contrasted to corresponding results from the literature review, which are presented in the background section. When studying which model is the most popular for teaching about the atom, the result will be compared and contrasted to the findings about the most popular atomic models in the literature review, for example. The results of the study will be presented quantitatively in tables, and qualitatively in running text.

4.3 Evaluation of validity and reliability

When designing a study, it is important to critically examine the methods for data collection (Bell, 2006). The levels of reliability and validity of the study should be high to be able to generalize the findings.
High validity of a question means that it has a high trustworthiness and that it measures what it is designed to measure (Bell, 2006; Bryman, 2002). To assure that the level of validity was high enough, two of the author’s colleagues and one of the supervisor’s science communication colleagues, were asked to perform a “face-validity screening” of the questionnaire before the survey was sent out to the respondents. “Face validity” is a measurement of how well a test or assessment, in this case the questionnaire, succeeds to pick up the concepts of the study (Bryman, 2002). The colleagues and the science communication expert were asked to intuitively evaluate if the questionnaire was readable as well as easy to understand and respond to.

Reliability is a measurement of a study’s consistency (Bell, 2006). If a study has a high level of reliability, one should be able to perform the same study again and obtain the same results. For a survey study to have a high level of reliability, it is of interest to obtain multiple respondents. If the number of respondents is too low, the results are less generalizable. This study was performed over a short period, so the size of the sample was limited to a minimum of 30 respondents to enable analysis of a fair representation of the Swedish physics and chemistry teaching community. As mentioned earlier in this chapter, the response rate of questionnaires can be quite low, and it requires a long period and multiple efforts to induce and retrieve answers from the respondents.

4.4 Research ethics

When humans are involved in research, the researcher must take ethical aspects into consideration (Vetenskapsrådet, 2016a). The participants should be clearly informed about the research and be able to choose freely if they wish to participate or not (Vetenskapsrådet, 2016b). In addition, the participant should be allowed to withdraw at any time during the research process. If the researcher will have access to personal information about the participants, the participants should be informed beforehand regarding how the information will be used in the research. In this study, the participants were assured confidentiality, which means that only the researcher will have access to the personal information and no personal information about the respondents will be presented in the report. In this study, the respondents were asked to specify personal information such as age, gender, workplace and years of teaching experience. This information was only used to categorize the answers, and
the respondents were assured that this data would be treated anonymously in the written report.
5 Results

In this section, the results of the survey are reported. The analysis section is presented as subsections based on the respective questions of the questionnaire (Appendix I). Some of the questions are interwoven into the same subsection. The introductory background questions (1-6) will be summarized in the first subsection.

5.1 Demographic characteristics of the survey respondents

In this section, the demographic characteristics of the participating teachers are presented (see table 1).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15</td>
</tr>
<tr>
<td>Male</td>
<td>16</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>45 years</td>
</tr>
<tr>
<td>Range</td>
<td>27-65 years, median 43 years</td>
</tr>
<tr>
<td>Subjects taught</td>
<td></td>
</tr>
<tr>
<td>Physics</td>
<td>16</td>
</tr>
<tr>
<td>Chemistry</td>
<td>15</td>
</tr>
<tr>
<td>Teaching experience</td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td>6-10 year interval</td>
</tr>
<tr>
<td>Range</td>
<td>0-40 years</td>
</tr>
</tbody>
</table>

Responses were received from 16 teachers in Linköping, two from Uppsala, four from Lund, one from Norrköping, three from Söderköping, one from Finspång, one from Malmö, one
from Göteborg and two from Stockholm. Fourteen of the respondents also had an additional university degree, of whom six had bachelors or masters in engineering, two had a doctorate, one a licentiate degree, five bachelor degrees, and two master degrees (some of the teachers had more than one degree). None of the responding teachers taught both physics and chemistry.

5.2 What models do teachers use to teach about the atom?

This section presents the results from questions:

- 7. What models do you usually use to teach about the atom? You can choose more than one model.

- 8. If you selected the alternative “other” above, describe the model you use.

Question 7 is a closed multiple-choice question, where the teachers could select which atomic models they use in their teaching. The question also permitted more than one alternative to be chosen. The teachers can choose the alternative “other”, and if they do, they are asked to describe the model they use in question 8. The teachers’ responses are presented in Table 2.

Table 2: The different alternatives of atomic model that could be chosen are listed in column 1. The number of teachers responding to the respective model choices is presented in column 2.

<table>
<thead>
<tr>
<th>Atomic model</th>
<th>Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomson’s model</td>
<td>13</td>
</tr>
<tr>
<td>Rutherford’s model</td>
<td>25</td>
</tr>
<tr>
<td>Bohr’s model</td>
<td>30</td>
</tr>
<tr>
<td>de Broglie’s model</td>
<td>13</td>
</tr>
<tr>
<td>Schrödinger’s model</td>
<td>20</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
</tbody>
</table>

The teachers, who selected the alternative “other” in the question above, reported that they Dalton’s model (1 teacher) and Democritus’ model (1 teacher). One teacher mentioned that he or she used an “orbital model”, but it is undefined if the teacher refers to one of the models in Table 2 or an alternative model.
Overall, 6 teachers reported that they used all the different models to teach and explain the atom. All of them were physics teachers. Three of the respondents reported that they only use one model for teaching and explaining the atom. All of these were chemistry teachers, and two of them used the Bohr model and one used the Rutherford model. The reported models used among physics teachers respectively chemistry teachers are presented in table 3.

<table>
<thead>
<tr>
<th>Atomic model</th>
<th>Physics teachers</th>
<th>Chemistry teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>All models</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>A single model</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Thomson’s model</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Rutherford’s model</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Bohr’s model</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>de Broglie’s model</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Schrödinger’s model</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

According Table 3, the Bohr model is the most popular model for describing and explaining the atom in both physics and chemistry courses. Among chemistry teachers, the Rutherford model is the second most popular model, whilst the Schrödinger model is the second most popular model in physics education accompanied with the de Broglie model and the Rutherford model on a shared third ranking. None of the chemistry teachers in this study have reported use of the de Broglie model in their teaching about the atom.

5.3 Why do teachers use the different models that they reported, and what are the strengths and limitations of the models in their opinion?

This section presents the results from question:

- 9. Why do you use the models that you reported, and what are their strengths and limitations in your opinion when teaching about the atom?

When analysing the responses to this question, the answers will be categorized into different common themes that emerged in the answers. The results are presented in table 4.
Table 4: In column 2 and 3, the strengths and limitations of each atomic model reported by the teachers are presented. Number of teachers who reported the strengths and limitations are presented in brackets.

<table>
<thead>
<tr>
<th>Atomic model</th>
<th>Strengths (number of teachers)</th>
<th>Limitations (number of teachers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomson’s model</td>
<td>Effective for teaching about the components of the atom (1)</td>
<td></td>
</tr>
<tr>
<td>Rutherford’s model</td>
<td>Easy to visualize (7)</td>
<td>Not scientifically correct (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No link to energy levels (1)</td>
</tr>
<tr>
<td>Bohr’s model</td>
<td>Intuitive and easy to visualize (13)</td>
<td>Not scientifically correct (1)</td>
</tr>
<tr>
<td></td>
<td>Effective for explaining energy transitions (2)</td>
<td>Fails to explain ion charge in chemistry (1)</td>
</tr>
<tr>
<td></td>
<td>The quantum concept (1)</td>
<td>Shells might be an obstacle for learning orbitals (1)</td>
</tr>
<tr>
<td></td>
<td>Can explain ion formation and chemical bonding in chemistry (2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Common in textbooks (1)</td>
<td></td>
</tr>
<tr>
<td>de Broglie’s model</td>
<td>A link to wave physics (3)</td>
<td></td>
</tr>
<tr>
<td>Schrödinger’s model</td>
<td>An introduction to modern physics (2)</td>
<td>Mathematically demanding (1)</td>
</tr>
<tr>
<td></td>
<td>Good for discussing the atom at a more advanced level (6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Common in textbooks (1)</td>
<td></td>
</tr>
</tbody>
</table>

Overall, 16 of the 31 (52%) teachers answered that use of all or several models are important for teaching modelling to students and to emphasize how models have developed over time. Eight teachers also responded that different models are suitable for different situations, such as level of education, or different groups of students. Translated into English, one teacher wrote that:
Thomson and Rutherford are used to get a historical overview of the development of theories and models. Bohr's/Schrödinger's models are excellent for discussing the validity and limitations of different theories.  

In addition, on the same topic, another teacher wrote that:

I think that it is stimulating for students to understand how the theories of the structure of matter have developed throughout history. That no model is perfect, but that every new model is a refinement and an improvement of the former.  

One teacher implied that an overall limitation of all models is that no model is an exact description of reality, and that no model is completely correct:

[...]All these [models] have the limitation of not showing all the parts of the atom and therefore inadequately appear as the “entire” truth about what the atom looks like.

A commonly reported strength of the Bohr model, which is the most popular model among both chemistry and physics teachers, is that it is intuitive and easy to visualize. The de Broglie model is good as a link to wave physics, while Schrödinger model was deemed good for explaining the atom at a more advanced level. The Rutherford model, which is popular among chemistry teachers, has the strength of being simple and easy to understand for students. Few strength or limitations were reported about the Thomson model, probably since it is not used that often, but one teacher implied that it is good for teaching about the different components of the atom at an introductory level.

Few individual limitations were reported about the models, but the fact that no model is completely correct was reported as an overall limitation of all models. One teacher mentioned that the use of the notion “shell” when teaching the Bohr model might be an obstacle for students to adapt the notion “orbital” when studying the atom at a more advanced level. A

1 The original Swedish quotation is: “Thomson och Rutherford används för att få en historisk överblick over teoeriers och modellers utveckling. Bohrs/Schrödingers modeller är ypperliga till diskussionen om teoriers giltighet och begränsningar”.

2 The original Swedish quotation is: ”Jag tycker det är utvecklande för eleverna att förstå hur tänkandet kring materiens uppbyggnad har utvecklats genom historien. Att ingen modell är perfekt, men varje ny modell är en förfining och förbättring av den föregående.”

3 The original Swedish quotation is: “[...] Alla dessa [modellerna] har ju t ex svagheten att inte visa alla atomens delar och därför felaktigt ge sken av att vara ‘hela’ sanningen om hur atomen ser ut.”
limitation of the Schrödinger model seems to be that it is seen as being mathematically demanding for students at upper secondary school level.

5.4 How teachers go about using more than one model to describe the atom in their practice

This section presents the results of question:

- 10. If you use more than one model of the atom, how do you go about when presenting a new model to your students when you and your students have used a previous model?

In this question, the responding teachers reported answers that were very similar to each other, and three salient themes emerged from the data. They all seemed to agree that it is important to explain that models can be refined and developed over time, as well as emphasizing that different models are suitable for different occasions. Students’ prior knowledge was also mentioned as a factor that should be taken into consideration when selecting models to work with in class. Some teachers implied that they compared and contrasted the different models to each other. In presentation of the results to this question, the answers were divided into three categories based on their approach when presenting new models (see table 5).

<table>
<thead>
<tr>
<th>Approach when presenting new models</th>
<th>Number of teachers who reported this approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explains that models can be refined and developed over time.</td>
<td>14</td>
</tr>
<tr>
<td>Explains that different models are suitable for different occasions.</td>
<td>8</td>
</tr>
<tr>
<td>Compares the models and emphasizes their strengths and limitations</td>
<td>12</td>
</tr>
<tr>
<td>Uses a new model without emphasizing that it is another model</td>
<td>1</td>
</tr>
</tbody>
</table>
Assumes that the students accepts the new models  
Do not know  

As it can be seen in table 5, the number of teachers who reported use of the approaches, was quite evenly distributed between the highest three emerging alternatives. These alternatives are quite similar to each other, and can be summarized into an approach where the teacher explains that there are different models to describe and explain the same phenomenon. However, the approach of explaining that models can be developed and refined over time was the most popular. Translated into English, one teacher, who had the approach that different models are suitable for different occasions, provided the following explanation:

Describes that the new [model] is a more exact model of how it is, and what model to use depends on how exact one has to be. [...] Measurement accuracy is central in physics and this can also be related to what model to refer to.

Another teacher wrote that:

I usually point out from the beginning that what I teach is a model, and that this [...] is a good model for our purpose at the moment. When we learn more and have new aims, e.g. understanding quantum phenomena, it becomes natural to use a more refined model, since the older one is no longer fit for the purpose. However, the old model is still useful within its area of application.

One teacher reported that he or she did not always explicitly point out that he or she was using a new model, but explained a phenomenon in a new way without commenting on the new model as such. One teacher assumed that the students accept the new models, while one teacher had not reflected on his or her approaches and answered that he or she did not know.

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4 The original Swedish quotation is: "Beskriver att det nya är en mer exakt modell av hur det förhåller sig och att det beror på hur exakt man måste vara vilken modell man använder. [...] Mätnoggrannhet är centralt i fysiken och då handlar det även om vilken modell man refererar till."

5 The original Swedish quotation is: "Jag brukar poängtera från början att det jag lär ut är en modell, och att i nuläget är detta [...] en bra modell för vårt syfte. När vi sedan lär oss mer och får andra syften, t ex att förstå kvant-fenomen, så blir det naturligt att använda sig av en mer förfinad modell, eftersom den gamla inte längre är ändamålsenlig. Den gamla modellen är dock fortfarande användbar inom sitt giltighetsområde."
5.5 Is the Bohr model an obstacle for learning the quantum nature of the atom?

This section presents the results from questions:

- 11. Do you teach the quantum nature of the atom to your students, i.e. that the electrons move in probability clouds (orbitals) in the atom and not in shells as described in the Bohr model?

- 12. If you answered “yes” to the question above, have you experienced that it is demanding for students to understand the quantum concept when they are used to the Bohr model? If you have, please describe in which way this occurs.

In question 11, 28 teachers (90% of the respondents) answered that they teach the quantum nature of the atom to their students, and three teachers (10% of the respondents) reported that they did not. In question 12, the teachers were asked if they thought that the Bohr model could be an obstacle for learning the quantum nature of the atom and the Schrödinger model. Their answers are presented in table 6 below, and are divided into different categories based on the type of answer.

<table>
<thead>
<tr>
<th>Is the Bohr model an obstacle for learning the quantum nature of the atom, and in which way does this show?</th>
<th>Number of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes, the Schrödinger model is abstract and it is easier to imagine fixed shells rather than orbitals.</td>
<td>11</td>
</tr>
<tr>
<td>No, the students are aware that different models are suitable for different occasions.</td>
<td>10</td>
</tr>
<tr>
<td>Different depending on students</td>
<td>2</td>
</tr>
<tr>
<td>No, the students do not work with the quantum model on their own.</td>
<td>3</td>
</tr>
<tr>
<td>I do not know.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6: Categories of responses related to teachers’ use of the Bohr model. The number of teachers in each category are shown.
The number of teachers, who thought that the quantum nature of the atom is difficult for students, and the number of teachers who thought that the students do not have difficulties understanding the concept, are very even. The teachers, who answered that the students find the quantum concept difficult, implied that it is the level of abstraction that is demanding for students. In this regard, there was a view that students easily reverted back to referring to shells, when they have been working with atomic models of orbitals. Another teacher believed that students often tended to assimilate the orbital concept into their already existing mental models based on the Bohr model, which can lead to confusion.

The teachers who answered that they did not find that their students had obstacles with adapting to the quantum concept, motivated their position with the notion that the students had a well-developed modelling ability and that they were aware that different models are suitable for different occasions. One of the teachers who did not think that the quantum concept is demanding, motivated the answer with the argument that students today are used to an abstract reality from working with computers, and that they have developed their fantasy and imagination in this way.

Two teachers implied that it differs among students. It seems that high-achieving students find it easier to adapt new models compared to lower-achieving students. Three teachers also reported that they only use the quantum model in their explanations, and that the students did not work with the model on their own. One teacher had not reflected upon this question, and answered, “I do not know”.

**5.6 Do teachers explain to their students how atomic models should be interpreted and used?**

This section presents the results from the question:

- 13. Do you explain to your students how the models you use in your teaching should be interpreted and used?

Twenty-two of the responding teachers reported that they, in some way, teach their students how atomic models should be interpreted and used. A categorisation of their answers is presented in table 7.
Table 7: Types of explanations for how atomic models should be interpreted and used. The number of teachers who reported responses in the categories is shown.

<table>
<thead>
<tr>
<th>Type of explanation to how the models should be interpreted and used</th>
<th>Number of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>That models are simplifications of reality</td>
<td>6</td>
</tr>
<tr>
<td>Explains when the models can be used</td>
<td>5</td>
</tr>
<tr>
<td>Shows examples of how to use them</td>
<td>5</td>
</tr>
<tr>
<td>Points out strengths and limitations</td>
<td>3</td>
</tr>
<tr>
<td>Discusses different models in class</td>
<td>1</td>
</tr>
<tr>
<td>Yes, without motivation</td>
<td>7</td>
</tr>
</tbody>
</table>

According to the responses on this question, it seems like it comes quite natural to explain how to use a model when presenting it. However, the explanation can be made to a greater or lesser extent. Translated into English, one teacher wrote that:

[I] carefully explain that they [the models] are precisely models, and that they can be good in different aspects, but also that better models can develop with time.\(^6\)

One teacher implicitly expressed the importance of explaining to students how the models should be used, by writing:

Yes, it would be meaningless otherwise, would it not?\(^7\)

Twenty teachers answered in line with some of the five first categories in table 7, which mean that they focus on explaining the area of applicability of the model in some way. However, some of the responses presented in table 7 contradict to the responses in table 5. In table 7, only 3 teachers report that they point out strengths and limitations of the models they use, while 12 teachers report that they do so in table 5. This might indicate that the teachers misinterpreted one or both of the questions.

\(^6\) The original Swedish quotation is: "[Jag] är noggrann med att säga att de [modellerna] är just modeller och att de kan vara bra på olika sätt men också att det kan komma bättre modeller med tiden."

\(^7\) The original Swedish quotation is: "Ja, annars vore det väl meningslöst?"
Seven teachers did not provide a motivation to how they explained how to use the models. Among these, one teacher did not want to expand the answer, one thought that it would be pointless not to explain how to use models, and the remaining five teachers did not motivate how they go about when explaining the new models.

5.7 What representation forms do teachers use to teach about the atom and related phenomena?

This section presents the results from questions:

- 14. What representation forms do you use to teach about the atom and related phenomena? You can choose more than one alternative.
- 15. If you answered “other” to the question above, what representation form(s) do you use?
- 16. With respect to your answer to questions 14 and 15, could you give an example of the specific source of that type of representation that you use (e.g. a specific textbook picture, a specific animation, an internet resource, software program, a particular physical model, etc.)?

Question 14 is a multiple-choice question, where the teachers were asked to designate the representation forms that they use to communicate the atomic models or related concepts in their teaching. They were allowed to choose more than one alternative if necessary, and they could also choose the alternative “other” and then describe the representation form in question 15. The result of the teachers’ answers is presented in table 8.

Table 8: Representation forms used by teachers to communicate the atomic models and related concepts. The number of teachers who reported that they use the representation forms are also shown.

<table>
<thead>
<tr>
<th>Representation form</th>
<th>Number of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static pictures, e.g. pictures in textbooks or static pictures on a screen</td>
<td>26</td>
</tr>
<tr>
<td>Pictures and/or text created by the teacher, e.g. pictures and text on a whiteboard</td>
<td>26</td>
</tr>
<tr>
<td>Dynamical pictures, e.g. film or animation</td>
<td>25</td>
</tr>
<tr>
<td>Computer simulations, e.g. virtual</td>
<td>16</td>
</tr>
</tbody>
</table>
experiment or demonstration
Physical models, e.g. plastic ball-and-stick models to represent molecules
Other

Overall, static and dynamic pictures together with pictures and text created by the teacher on the whiteboard seem to be the most popular representation forms to teach about the atom and related concepts. To enable analysis based on subject, the reported representation forms among physics and chemistry teachers is presented in table 9.

Table 9: Representation forms used by physics teachers and chemistry teachers. The number of teachers who use the representation forms are also shown.

<table>
<thead>
<tr>
<th>Representation form</th>
<th>Physics teachers</th>
<th>Chemistry teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static pictures, e.g. pictures in textbooks or static pictures on a screen</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Pictures and/or text created by the teacher, e.g. pictures and text on a whiteboard</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Dynamical pictures, e.g. film or animation</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Computer simulations, e.g. virtual experiment or demonstration</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Physical models, e.g. plastic ball-and-stick models to represent molecules</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>- Uses Duplo to demonstrate nuclear reactions</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Mathematic formulae, e.g. the Schrödinger equation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Draws probability clouds on the whiteboard</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>- Uses Styrofoam balls with magnets that can be attached to the</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Role-play where the students are assigned with different attributes of an atom. The students’ mission is then to form a model of a hydrogen atom complete with all quarks and exchange particles.

Some of the teachers who selected the alternative “other” have described a representation form that could fit into one of the other alternatives, e.g. using Duplo or Styrofoam balls are physical models, and probability clouds drawn on the whiteboard are teacher-generated models. Nevertheless, these descriptions of alternative representations were still included in the table since they carried interesting information. One distinctive representation form was the role-play that one teacher described, where the students were assigned with different attributes of an atom. Next, the students were asked to form a model of a hydrogen atom complete with quarks and exchange particles etc.

The majority of the representation forms are equally popular in physics and chemistry, with one exception. Physical models are substantially more popular among chemistry teachers than physics teachers, where 14 chemistry teachers reported use of physical models compared to the two physics teachers. This might be a result of different focus in the teaching content between the two subjects. This will be discussed further in the discussion section.

In question 16, the teachers were asked if they could provide any specific examples of sources from where they retrieve the representation forms they use in their teaching. A selection of the answers were as follows:

- Videos from You tube (http://www.youtube.com/)
- Simulations from PhET Colorado (http://phet.colorado.edu/)
- Power-point presentations that the teachers have produced themselves
- Geogebra (www.geogebra.org)
- Wolfram Alpha (www.wolframapha.com)
- Textbooks, e.g. "Impuls 1"\(^8\), "Heureka 1"\(^9\), "Gymnasiekemi 1"\(^10\) and "Gymnasiekemi 2"\(^11\)

5.8 Do teachers use multiple forms of representations, and how do they go about using them together with their students?

This section presents the results of questions:

- 17. *Do you sometimes use more than one representation form in combination to describe the same atom-related phenomenon (e.g. show both pictures and a simulation to describe the same phenomenon)?*

- 18. *If you answered “yes” to the question above, describe how you go about using combinations of multiple representations that describe the same phenomenon (e.g. if you give any kind of support to your students in the translation process between the different representations)?*

Twenty-one of the 31 responding teachers reported that they sometimes use multiple representations to explain the same atomic phenomenon. Ten teachers answered that they did not use multiple representations.

Of the 21 teachers who answered that they used multiple representations, 17 described how they go about when using a combination of different representations to their students. The majority (10) of the teachers who use multiple representations reported that they try to explain what the different representations show and points out similarities and differences between the representations. Six teachers implied that they use different representations in some kind of progression, e.g. first presents a static image and explains it, and then presents a simulation that represents the same phenomenon and explains that. One teacher wrote that different representations are good in different situations. Overall, the teachers seem to use additional

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representations with the aim of explaining another representation, such as drawing pictures on the whiteboard to explain what can be seen in a simulation on a computer screen.

5.9 What determines teachers’ choice of representation forms when teaching about the atom and related phenomena to their students?

This section presents the results from question:

- 19. What determines your choice of representation forms when teaching about the atom and related concepts to your students?

In the final question of the survey the teachers were asked to describe what determines their choice of representation forms to use for teaching about the atomic models and related concepts to their students. The answers were categorized into different groups, and the result is presented in table 10.

Table 10: The influencing factors for selecting representations are listed. The number of teachers who reported answers in line with the categories is also shown.

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Number of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>The students’ prior knowledge</td>
<td>11</td>
</tr>
<tr>
<td>The students’ individual learning styles</td>
<td>6</td>
</tr>
<tr>
<td>The students’ attitudes, e.g. if they are willing to learn or if the class is disordered</td>
<td>2</td>
</tr>
<tr>
<td>The level of education and the context</td>
<td>8</td>
</tr>
<tr>
<td>The access to material</td>
<td>3</td>
</tr>
<tr>
<td>The amount of time the teacher has</td>
<td>3</td>
</tr>
<tr>
<td>The fact that variation of representations and models is a part of the national curriculum of the courses</td>
<td>2</td>
</tr>
<tr>
<td>The representation must be user-friendly and effective for learning</td>
<td>2</td>
</tr>
<tr>
<td>The teacher’s level of inspiration</td>
<td>1</td>
</tr>
</tbody>
</table>
Eleven teachers considered students’ prior knowledge to be an important determinant factor when selecting representation forms to describe and explain the atomic models and related concepts. Translated into English, one teacher wrote:

I need to check their [the students’] prior knowledge, I have some students that totally lack understanding of the atomic concept, and then it is even more important to explain the Bohr model of the atom explicitly from the beginning.12

The teaching context and students’ level of education were also considered as factors that must be taken into consideration, as well as the students individual learning styles. One teacher wrote that:

I try to mix different [representation] forms because I know that some people work better with pictures and others with physical models.13

Access to teaching material and how much time the teacher has for preparations, are other aspects that determine the choice of representation forms for the teachers. Most of the responding teachers implied, in some way, that it comes naturally to use multiple representations, but only two of them mentioned that using multiple models and representations to diversify the teaching is mentioned in the national curriculum for chemistry and physics. One teacher wrote that:

It is a part of the course to go over different [representations] and point put when the different views are appropriate.14

The national curriculum of chemistry and physics states that teaching should cover the area of applicability and development of different models, together with their strengths and limitations, and the students should be allowed to use computerized equipment (Skolverket, 2011a; Skolverket, 2011b). Other factors that influence teachers’ choice of representation forms are how much inspiration the teacher has at the moment, the students’ attitudes (e.g. if

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12 The original Swedish quotation is: ”Jag behöver ju kolla förkunskaperna, jag har en del elever som kommer som helt saknar uppfattning om atombegreppet, då är det ännu viktigare att förklara Bohrs atombegrepp tydligt från början.”

13 The original Swedish quotation is: ”Jag försöker att blanda olika former för jag vet att vissa elever jobbar bättre med bilder och andra med fysiska modeller.”

14 The original Swedish quotation is: ”Det ingår i kursen att gå igenom olika och visa när varje synsätt passar.”
they are willing to learn or if the class is in disorder), and how effective and user-friendly the representations are.
6 Discussion

In this chapter, the results of the study, together with the methods used to collect the data, are discussed.

6.1 Discussion of obtained results

In this section, the results of the survey will be compared and contrasted to the theoretical framework in the background section of this study. The posed research questions will revised to frame the discussion.

6.1.1 What models of the atom do teachers use to describe and explain the atom?

Among both the physics and chemistry teachers who participated in this study, the Bohr model was the most popular model for describing and explaining the atom. This result corresponds to the findings in the previous international literature review, where models derived from the Bohr model were found to be most frequently used (Netzell, 2015). According to the participants in the current study, the main strength of the Bohr model, as a teaching tool for explaining and describing the atom, is that it is intuitive and easy to understand. It is also effective for explaining energy transitions and to teach chemical bonding in chemistry education. A reported limitation of the Bohr model is that the notion of a “shell” might hinder the subsequent need to learn about “orbitals”. In fact, 11 of the 31 participating teachers agreed that the Bohr model could actually be an obstacle in students’ understanding of the Schrödinger model, and for them to assimilate it into their already existing mental models of the atom. This limitation of the Bohr model was also reported in the literature review, where several articles mentioned that the Bohr model has a major influence on students’ conceptual understanding of the atom (Netzell, 2015). The orbital concept is abstract and difficult for students to understand, and the term “electron cloud” has also shown to be demanding for learners (Harrison & Treagust, 1996). One teacher in this study mentioned that even if the students have been introduced to the orbital concept, they easily revert to referring to “shells”. Another teacher believed that students often have difficulties separating the aims of the different models, and that they sometimes try to assimilate the orbital concept into their already existing mental models based on the Bohr model. This might lead to confusing hybrid
models. This was also an aspect of the results in the study by Park and Light (2009), where it was shown that it is important that students understand both the concepts of probability, as well as the energy-quantization concept, as components of the Schrödinger model, in order to be able to move beyond the Bohr model of the atom.

The Rutherford model, i.e. the solar system model, was the second most popular atomic model for teaching reported in this study. It was also the second most popular model among chemistry teachers, and the third most popular together with the de Broglie model among physics teachers. Seven of the participating teachers in this study mentioned that the strength of the Rutherford model is that is it very easy to visualize. According to the study by Harrison and Treagust (1996), this model is the most popular among students, probably since it is concrete and easy to understand. The model resemble objects that students are familiar with in their everyday life, and the electrons are presented as separate entities moving around the nucleus in fixed paths. The theory of fixed paths is more concrete and gives a material feeling compared to the more abstract orbital concept. The reported limitations of this model in the current study were that it is not a scientifically accurate model and that it lacks any links to atomic energy levels.

The second most popular model revealed among physics teachers was the Schrödinger model. The reported strengths of using the Schrödinger model is that it is good for teaching and discussing the atom at a more advanced level, and it can be used as an introduction to the field of modern physics. Özcan (2013) has emphasized the importance of teaching the Schrödinger model of the atom to students at upper secondary school level, so that they are familiar and confident with it when embarking on tertiary education. The study was performed with pre-service teachers, and indicated that many of them had mental models of the atom that were based on the Bohr model, which led to alternative conceptions of atomic spin, for example. A difficulty with teaching the Schrödinger model at upper secondary school level is that it is abstract and challenging to understand, and one teacher in the current study mentioned that the mathematics of the Schrödinger equation is too demanding for students at this level. Some of the teachers in this study, who used the Schrödinger model in their teaching, mentioned that they presented it very briefly to the students and that the students were not expected to interpret the quantum model on their own. However, in contrast with the results from the literature review, 10 of the 28 teachers, who taught the quantum concept to their students, had not experienced the concept as being too demanding for their students. They suggested that
students are aware of the fact that different models are suitable for different objectives, and that each of the atomic models are appropriate for explaining the atom depending on the context. One teacher also mentioned that s/he thought that today’s students are so familiar with an abstract reality stemming from interaction with computers and virtual worlds, that they have developed their imagination to an extent where they no longer find it demanding to integrate new abstract models into their already existing mental models. The Schrödinger model emerged to be twice as popular for the physics teachers that the chemistry teachers in this study, where 14 physics teachers reported using the Schrödinger model compared to six chemistry teachers.

The de Broglie model shared an overall fourth ranking together with the Thomson model. Among physics teachers, the model ranked third used together with the Rutherford model, and 13 physics teachers reported that they use the model in their teaching about the atom and related concepts. However, none of the Chemistry teachers who participated in this study reported use of the de Broglie model. Three of the physics teachers mentioned that a benefit from presenting the de Broglie model is that it can be used as a link to wave physics concepts. The de Broglie model is based on de Broglie’s theory of the wave property of matter, and it can therefore be an effective model for discussing wave-particle duality (Andersson, n.d.).

Thirteen of the participating teachers in this study use the Thomson model in their teaching. The majority of them use it when they teach about the development and refinement of atomic models during scientific progress. Albeit so, one teacher mentioned that s/he felt that the model was good for explaining different components of the atom. Two teachers reported that they also use the Democritus model and the Dalton model to describe the historical development of the atom.

The fact that no model is a complete representation of scientific reality was reported as a natural limitation for all atomic models. Correspondingly, a strength of all models is that they show how models are developed and refined over time, a fact that the national curricula for both chemistry and physics state should be taught to students (Skolverket, 2011a; Skolverket, 2011b).

In summary, the Bohr model is the most popular model among both physics and chemistry teachers. Among chemistry teachers, the Rutherford model is the second most popular, whilst
the Schrödinger model is the second most popular model among physics teachers. Following closely behind the Schrödinger model, the de Broglie model and the Rutherford model share a third ranking in popularity for teaching the atom among physics teachers. The Thomson model is least popular among teachers in both subjects. Overall, six of the responding teachers reported that they use all the different models in their teaching, and all of them were physics teachers. Three teachers reported that they only use a single model, and all of these teachers taught chemistry. In conclusion, the physics teachers who participated in this study use more different atomic models in their teaching than the chemistry teachers. A possible reason for this finding might lie in the respective teaching content in the two subjects. The teaching content in both subjects should cover the development of models over time, but this study has shown that the models are used in slightly different ways in the two subjects (Skolverket, 2011a; Skolverket, 2011b). In chemistry, students should learn about the structure and classification of matter, as well as chemical bonding, and so forth. (Skolverket, 2011b). The responding chemistry teachers mentioned that the concrete and simple Rutherford and Bohr models are effective for teaching the different components of the atom and the Bohr model can be used to explain chemical bonding. However, in physics students should learn about the electron structure of atoms and absorption and emission spectra, together with the wave-particle duality and modern physics (Skolverket, 2011a). According to the responding teachers the more simple models such as the Rutherford model and the Bohr model are powerful for explaining the structure of the atom and the energy transitions, whilst the de Broglie and Schrödinger models can be used to introduce wave physics and wave-particle duality in modern physics.

6.1.2 What representation forms do teachers use to communicate the atomic models in their teaching of the atom?

This study has shown that static pictures, teacher-generated representations and dynamical pictures are the most popular representational forms for communicating the atomic models and related concepts overall (see table 8). The distribution of teachers who use the representation forms is fairly even between physics and chemistry. The frequent use of static 2D-pictures, such as illustrations or pictures derived from scanning tunnelling microscopy, in teaching about the atom is also supported by research (Adbo & Taber, 2009; Taber, 2002). A reason for the popularity of static 2D-pictures might be the high accessibility fo this form, since they can be easily sourced in textbooks or on the internet. The same goes for dynamic
2D-pictures such as films or animations. Several teachers in this study reported that they use YouTube as a source for retrieving dynamic images about the atom and related concepts to show to their students. In most classrooms, the teacher also has access to a whiteboard or an alternative tool to compose teacher-generated representation forms that can be used. Access to material was shown to be one important influencing factor in teachers’ selection of representational forms. This is discussed further in section 6.1.3.

Sixteen teachers reported that they use computer simulations to communicate atomic models and related phenomena, of which nine were physics teachers and seven were chemistry teachers. When the teachers were asked to provide specific examples of representations or sources from which they retrieve the representations, simulations from Phet Colorado was mentioned as a good source. Students are often used to working with computers, and they often enjoy interacting with computer-based representations (Netzell, 2015). In addition, the computer simulations often have the power of making abstract concepts, such as the Schrödinger model of the atom, easier to visualize. If every student has access to a computer, the computer simulations can also be used to perform virtual experiments in the classroom.

Sixteen teachers also reported using physical models as a representation form, across an interesting distribution of 14 chemistry teachers and 2 physics teachers respectively. This result indicates that physical models seem to be more popular among chemistry teachers than physics teachers. One possible reason that physical models are more popular among chemistry teachers might be that it suits the teaching content in chemistry better, for example when teaching about molecular structure or orbitals. In support of this, research presented in the theoretical framework of this study shows that physical models are common tools for teaching about molecular structures (e.g. in the form of plastic ball-and-stick models where the balls represent the atoms and the sticks represent chemical bonds) (Albanese & Vicentini, 1997). The higher accessibility of 3D-printers as an educational resource also enables the printing of teacher-generated physical 3D-models to describe and explain orbitals and atomic structures. (Robertson & Jørgensen, 2015). As a part of physical models being predominantly used by chemistry teachers among the participants in this study, one physics teacher explained that s/he sometimes used Duplo® building blocks to describe nuclear reactions, so there are possibilities of applying physical models as learning tools in teaching atom-related content in the physics as well.
One teacher who responded with the alternative “other” on the question about what representational forms the teacher uses to communicate the atomic models and related phenomena, wrote that s/he allows students to participate in a role-play to represent the hydrogen atom. The students were assigned with different attributes of an atom, and their task is then to together produce a representation of the hydrogen atom complete with quarks and exchange particles. This type of representation is also mentioned in the theoretical framework in this report, where students participated in a role-play about a chocolate shop to learn about the orbital concept (Liguori, 2014). In application of the constructivist theory of learning, it is beneficial when students are active in their own learning process and that they are creators of their own knowledge (Woolfolk, 2010). When students are given the opportunity to map the location of their body onto the location of a subatomic particle in formation of a hydrogen atom, they actively participate in the learning process, and they can use the activity to assimilate concepts of the atom into their prior knowledge.

Overall, the representation forms that teachers in this study use are varied, and together, the teachers used all the representation forms identified in the questionnaire. In addition, apart from physical models, the distribution was quite even. As a conclusion, it can be noted that Swedish physics and chemistry teachers seem to be very comfortable with using various representation forms in teaching about the atom.

Twenty-one of the 31 responding teachers sometimes use multiple representations to explain and describe an atomic phenomenon. The remaining ten teachers reported that they did not use more than one representation at a time. Research has shown that multiple external representations are successful tools for teaching and learning unobservable phenomena in science education (Ainsworth, 1999; Sunyono, Yuanita, & Ibrahim, 2015). Multiple representations are more likely to capture the interest of the learner, and the student can select a representation that best suits their individual learning styles (Ainsworth, 1999). According to Sunyono, Yanita and Ibrahim (2015), low-achieving students in particular were found to benefit from interacting with multiple representations, since their findings showed that students with a low modelling capability, who used the authors specific learning model, were able to better keep up with the higher achieving students. Using multiple representations can also improve students’ problem-solving ability, since they come to realise that there is more than only one way to describe a phenomenon (Ainsworth, 1999). Further discussion about how teachers in the current study actually go about presenting multiple representations to
their students during their teaching, is discussed in section 6.1.3.

6.1.3 What informs teachers’ selection of the atomic models and representation forms above, and how do they specifically use them in their teaching of atom related phenomena?

This study suggests that when teachers select atomic models to use in their teaching about the atom, the most important factor seems to be that the models are effective for teaching the specific content. For example, the Bohr model was considered the most popular model since it is simple and intuitive, and strongly facilitates discussion of the composition of the atom and energy transitions. If the teaching content is in the area of modern quantum physics, the de Broglie or Schrödinger models were revealed as more powerful.

Twenty-eight of the responding teachers reported that they use more than one model of the atom in their teaching. When presenting new models to students, 14 teachers reported that they explain that models can be developed and refined over time, 12 compares the models to each other and points out their individual strengths and limitations, and 8 explain that different models are suitable for different purposes. These approaches are in line with both the Swedish national curricula for physics and chemistry, as well as previous research in the field. According to the national curricula in physics and chemistry, teaching content should include the historical development and refinement of models over time, and that students should be exposed to the idea that models are only simplifications of reality (Skolverket, 2011a; Skolverket, 2011b). Students tend to believe that a phenomenon can only be described in a single manner, but by using different models, students learn that there is more than one way to represent the same phenomenon (Harrison & Treagust, 2000). In addition, they have the opportunity to learn that models can complement each other, and that no model is completely correct, but rather a snapshot of scientific reality. The approach of comparing models to each other and explicitly informing students about the strengths and limitations of the different models, is also supported by research. For example, the study by McKagan, Perkins and Wieman (2008) showed that students could move beyond the Bohr model to the Schrödinger model, if the teacher explicitly compares and contrasts the Bohr atomic model to the other atomic models.
As mentioned in section 6.1.2, 21 teachers in this study reported that they use multiple representations to communicate atomic models. Students often find it demanding to translate between representation forms, and often need support in the process (Ainsworth, 2006). To support students’ translation between the different representations, the majority of these teachers explained that they try to discuss similarities and differences between the representations that they use and explicitly point out what aspects of the actual atomic concept the different representation forms show and which they do not. Multiple representations are also used in progressions; where the teacher initially presents one representation form, which is followed by another representation form later on, for example, first presenting a 2-D picture followed by a simulation of the same phenomenon. In support of using a particular representation form, teachers in this study often include additional representation forms that describe the same phenomenon.

For students to be able to use multiple representations effectively, it is important for the teacher to explicitly teach how the models and representations should be interpreted and how to apply them (Harrison & Treagust, 2000). Twenty-two of the teachers who participated in this study indicated that they explicitly teach their students, in some manner or other, how to use models and how they should be interpreted. The study by Kelly (2014) showed that students often lack the metacognitive skills needed for self-assessment and evaluation of their mental models, which is an obstacle for adjustment and development of their existing alternative conceptions. An example of an approach the teachers in this study use when teaching modelling-skills to their students is that they explain that models are simplifications of reality, and according to Gilbert (2004), the notion of a “model” can be defined as a depiction of reality. Other approaches that emerged in the study were that the teachers explain when different models can be used and also present examples of how to use them, points out the respective models’ strengths and limitations, and also discusses different models in class. Among the Swedish teachers who participated in this study, to teach modelling skills seemed to be part of their natural teaching approach to some extent or other.

A specific phenomenon can be communicated in different ways through different representation forms. Students’ prior knowledge was exposed as one important influencing factor in the selection of representation forms among the teachers in the current study, and this was also one of the main conclusions of the previous literature review that this study builds upon (Netzell, 2015). Students use their prior knowledge to select information from
representations, and their existing prior knowledge will significantly affect what will be learned from a specific model or representation (Cook, 2006; Moreno & Mayer, 2007). One teacher mentioned that students are often familiar with the notion “shell” from interpreting the Bohr model, and as a consequence, they might have difficulties with adapting the subsequent “orbital” notion. This can be compared to the previous finding in the literature review, which showed that students had difficulties understanding the notion “electron cloud” since they already were familiar with the term “cloud” from their everyday experience, and therefore believed that the electron cloud was a type of matrix-entity where electrons are embedded as a structural entity rather than understanding that the cloud represents a probability distribution of the electrons (Harrison & Treagust, 1996). Students’ individual learning styles as well as the context and level of education, are other popular influencing factors suggested by teachers. Access to material and the time the teacher has for preparation, are other factors that determine the choice of representation form. Additionally, two teachers mentioned that the manner of teaching should be varied according to the national curricula in physics and chemistry. What representation forms teachers select for their students also depend on the students’ attitudes, the teacher’s level of inspiration and creativity, and how user-friendly and effective the representation forms are.

6.2 Discussion of the method used to collect data

In this section, the overall methodological approach to collecting and analysing data in the study is discussed.

One benefit of using quantitative methods is that they are often suited to mapping problem areas in a field, and can therefore provide structure to a qualitative analysis (Harboe, 2013). In qualitative research, so called “quasi-quantification” is often used to further describe then obtained data (Bryman, 2002). Quasi-quantification means that the researcher makes references to quantity with words such as “often/seldom” or “many/few”. These expressions are vague if there are no quantitative data to support the assertions. When conducting qualitative research, one could therefore benefit from empirical data that can be analysed quantitatively as well.

One advantage of using electronic questionnaires compared to structured interviews is that they are more flexible and less time consuming (Bryman, 2002). When performing
interviews, a meeting must be arranged between the respondent and the interviewer. A questionnaire is more flexible since the teacher can respond when s/he has the time and opportunity. A questionnaire also allows for a wide dissemination and multiple responses can be obtained at once. When conducting interviews, the interviewer can only perform one interview at a time, whereas several questionnaires can be answered concurrently and responses can be obtained more rapidly. Another advantage of using questionnaires instead of interviews is that any interviewer-effects are minimised. The interviewer-effect is the phenomenon that the respondents answer according to what they believe the interviewer wishes to hear. This effect can be reduced by using questionnaires where the respondents provide responses anonymously (Bryman, 2002).

An advantage with questionnaires is that they can be sent out to many respondents, but a well-known drawback is that the response rate can be quite low (Bryman, 2002). In this study, the response rate was approximately 18 % after an e-mail reminder was sent out. One reason for the low response rate to the questionnaire in the current context was the point in time when it was sent out. The questionnaire was sent out in mid-May, when teachers are usually very busy performing grading. Responses were gathered during a period of two weeks, due to the design of the current study, and if possible, one might consider expanding this period for future research. However, two weeks can be a reasonable time for a questionnaire according to Bell (2006). The questionnaire was also published in the Facebook group “Lärarnätverket”, but no responses were received. The post was only published once, and if this method was used in the future, one might benefit from publishing the post at several times. Response rate could also have been improved by publishing a link to the questionnaire on more than one Facebook group, and perhaps also on other social media. Albeit so, inspection revealed no other public groups for Swedish physics and chemistry teachers.

The intention of a survey study is to, at best, have a sample that is high and representative of a population (Bell, 2006). If the study is small-scale, as in the current 10-week investigation, it is difficult to get a random sample this extensive. More numbers are more desirable, but not always feasible, and this study received 31 responses. However, the study got responses from 9 cities spread across the southern parts of Sweden: Linköping, Norrköping, Söderköping, Stockholm, Lund, Uppsala, Malmö, Göteborg and Finspång. In a study, it is important to have a sample as representative as possible, and in this study, several cities are represented. The participants of this study consisted of 15 women and 16 men, and the sample was also equally
represented between both genders. In addition, the sample consisted of 15 chemistry teachers and 16 physics teachers, so teachers in both subjects were equally represented. In questionnaire design, it is also important to include an introduction letter to the questionnaire, where the aim of the research is explicitly formulated and explained, together with clear explanations about the respondents’ right to confidentiality (Bryman, 2002; Bell, 2006). By using electronic questionnaires, there is no financial cost of creating or sending out the questionnaires, which could be a peripheral drawback of paper-based questionnaires (Bryman, 2002).

An appropriate sample size for a study depends on both the research questions underpinning the study and how the material will be analysed (Bryman, 2002). This questionnaire can be considered semi-qualitative, as it can be analysed both quantitatively and qualitatively. The relatively small sample was appropriate for a study of this size, since the questionnaire consisted of open text-answer questions that were analysed qualitatively and categorized for a quantitative analysis. However, to be able to make generalizable inferences to the whole population, a much larger sample size would have been required.

Bryman (2002) and Bell (2006) have implied that open questions should be avoided in surveys, since respondents often find it tiresome to write long comments. This might also lead to “survey fatigue”, where less effort is given to responding to questions following later in the questionnaire, or even responding to the questionnaire at all (Porter, Whitcomb, & Weitzer, 2004). It is also important to ascertain the quality and validity of the questions before sending them out to the respondents (Bell, 2006). For example, one message is that one should avoid asking questions with sub-questions, since it might result in respondents providing incomplete answers. Furthermore, the questions must not require any specialist knowledge from the research field from the respondents, that is, the teachers’ interpretation of the questions should not be hindered by the fact that they are not already familiar with research about models and representation forms. Every-day language, familiar to the respondents, should be used where possible in question design (Bryman, 2002). Text-based questions were used in this questionnaire, and constructed with the aim of being as explicit and clear as possible, so that the respondents would have as few difficulties as possible in interpreting them. The responses received indicated that the respondents to the questionnaire were able to clearly interpret the questions overall, which is beneficial for formulating the outcomes of the study. However, in the questions were the teachers where asked to indicate what models and representation forms
they use in their teaching, a few teachers had difficulties categorizing the models and representations that they use into the intended categories. For example, a few teachers answered with the alternative “other” in these questions, and then described a model or representation that could otherwise fit into one of the suggested categories. This observation might also stem from how familiar the teachers are with the concepts of models and representation forms in science education. Although simple language was used as much as possible in the survey questions, notions such as “models” and “representation forms” were required in the questionnaire. In this regard, in order to support the respondents, explanations of these two notions were included in the questionnaire. A face validity screening was also performed on the questionnaires before they were sent out to the respondents (see section 4.3).

A final drawback of employing questionnaires is that there are no possibilities to attend to any unclarity in question interpretation, or to ask follow-up questions (Bryman, 2002). To circumvent these potential shortfalls, the formulations of the questions were carefully reflected upon to avoid misunderstandings.

### 6.3 Conclusions and implications

The aim of this study was to explore what models and representations are used by Swedish upper secondary school physics and chemistry teachers in their teaching about the atom, and to compare and contrast the findings with the results of the previously conducted international literature review, which this study builds upon. Overall, the results from the survey study correspond with the results of the literature review, but also differ somewhat in this regard to the Swedish context presented here.

The Bohr model of the atom is the most popular model for communicating atomic concepts among both physics and chemistry teachers, as revealed by the Swedish sample investigated in this study. This result was also found in the literature review. The Bohr model and the Rutherford model are simple and easy to understand, and effectively demonstrate the construction of the atom. Therefore, these models are popular for communicating the atom at an elementary level, especially among chemistry teachers. The de Broglie and Schrödinger models are more popular among physics teachers, since they link to wave-particle duality and
serve as an inroad to modern physics. As the teachers in this study imply, different models are suitable for different times and purposes.

Regarding representation forms, the most accessible representation forms were also the most frequently used. Static and dynamic 2D pictures can be retrieved in textbooks or on the internet, and are popular among teachers according to both this study and previous research analysed in the literature review. Computer simulations are also a popular element in science education, since they enable experiments that are difficult or otherwise impossible to perform in the classroom environment. One interesting finding was that physical models were considerably more popular among chemistry teachers. This finding is supported by the literature review where it was found that physical models could be effective for teaching about molecular structure. Taken together, the teachers used all the representation forms that were suggested in the questionnaire, and the number of teachers was in fact quite evenly distributed between the different representation forms overall. In conclusion, it appears that Swedish physics and chemistry teachers seem to be very comfortable and fluent in using various representation forms, and the use of multiple representations might also increase due to the increasing accessibility of new educational tools such as computers and 3D printers.

Several teachers who participated in this study used more than one atomic model as well as multiple representations in their teaching. For students to be able to understand how to use a new atomic model when they are already used to another, research has shown that it is important for the teacher to compare and contrast the models with each other, and to explicitly point out their individual strengths and weaknesses.

When using multiple representation forms, research has shown that students might require support in the translation process between the representations, based on their already existing prior knowledge. However, one noteworthy aspect was that some teachers in this study were of the opinion that the students have an already well-developed modelling ability, and seem to reason that there is no great need for explicitly teaching on how to use and interpret models to their students. In this regard, this opinion counters the findings from the literature review, where it was emphasized that students of this age do not have a fully-developed modelling ability, and find it demanding to interpret and select appropriate models and representations on their own. To raise the bar and have high expectations of students’ abilities could perhaps
help develop students modelling and interpretation skills. This would be a topic worthy of further research.

According to the results of the earlier literature review, it is important for teachers to have their students’ prior knowledge and individual learning styles in mind when selecting appropriate representation forms to use in the classroom. These were also found to be two of the most popular influencing factors for teachers in this study when selecting representations for communicating atomic concepts to their students. The access to time and material was another aspect that greatly affects how representation forms can be used. Even if the teacher knows what representations forms would be the most effective, he or she might not be able to retrieve them based on the access of material and time available. Access to computers in schools has increased swiftly lately, and with more computers, the greater the possibilities of using computer simulations to perform in silico experiments and demonstrations in science education. Development and advances in the 3D printing technology have made it more accessible and affordable as an educational resource, and in the near future, this might enable construction of teacher-generated physical models.
7 References


http://www.ne.se.e.bibl.liu.se/uppslagsverk/encyklopedi/lång/representation


### 7.1 Acknowledgement of sources for figures

All the images used in this document are creative commons and were retrieved from Wikimedia Commons, [http://commons.wikimedia.org](http://commons.wikimedia.org).

The plum pudding model of the atom, as proposed by JJ Thomson (figure 1). Retrieved June 9, 2016 from Wikimedia Commons: [https://commons.wikimedia.org/wiki/File:Plum_pudding_model.svg?uselang=en](https://commons.wikimedia.org/wiki/File:Plum_pudding_model.svg?uselang=en) by Kurzon (License Creative Commons Attribution-Share Alike 4.0 International [https://creativecommons.org/licenses/by-sa/4.0/deed.en](https://creativecommons.org/licenses/by-sa/4.0/deed.en))

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deBroglie atom (figure 4) Retrieved June 9, 2016 from Wikimedia Commons: [https://commons.wikimedia.org/wiki/File:Atom_deBrogie.jpg](https://commons.wikimedia.org/wiki/File:Atom_deBrogie.jpg) by Pieter Kuiper (licence Public Domain)

Model of the Schrödinger atom, showing the nucleus with two protons (blue) and two neutrons (red), orbited by two electrons (waves) (figure 5) Retrieved June 9, 2016 from Wikimedia Commons: [https://commons.wikimedia.org/wiki/File:Helium_atom_with_charge-smaller.jpg](https://commons.wikimedia.org/wiki/File:Helium_atom_with_charge-smaller.jpg) by Vojayer (license Public Domain)
Hej!


Jag hoppas att du vill och har möjlighet att besvara enkäten. Med vänliga hälsningar,

Elisabeth Netzell

*Obligatorisk

Inledande frågor
Följande avsnitt handlar om vem du är, var och vad du undervisar samt din utbildning och erfarenhet. Svaren kommer att användas för att kategorisera resultaten, men informationen kommer att behandlas konfidentiellt och personlig information kommer inte att synas i forskningsrapporten.

1. Kän: *
   Markera endast en oval.
   - Kvinna
   - Man

2. Ålder: *
3. I vilken stad och på vilken skola undervisar du? *

4. Vilka ämnen undervisar du i? *

5. Har du någon ytterligare examen utöver lärarexamen?

6. Hur länge har du arbetat som lärare i fysik och/eller kemi? *
Markera en oval.
- 0-5 år
- 6-10 år
- 11-20 år
- 21-30 år
- 31-40 år
- >40 år

Atommodeller
Följande frågor handlar om hur du använder atommodeller i din undervisning.

7. Vilken/vilka modeller brukar du använda i din undervisning för att beskriva atomen? Du kan välja fler än en modell. *
Markera alla som gäller.
- Thomsonmodellen (Negativt laddade elektroner ligger inbäddade i en positivt laddad massa, ibland även kallad plum-pudding-modellen eller russinkakemodellen.)
- Rutherfordmodellen (Positivt laddad kärna i centrum med elektroner i banor runt om. Solsystem-modellen.)
- Bohrmodellen (Baserad på solsystem-modellen, men elektronerna rör sig i speciella orbitaler beroende på energinivå.)
- de Broglie-modellen (Elektronerna uppvisar en vågnatur och rör sig som vågor i atomen. Stabila tillstånd svarar mot ett antal hela våglängder.)
- Schrödingermodellen (Elektronerna rör sig som vågor inom sannolikhetsmoln runt kärnan.)
- Annan modell
8. Om du kryssade i alterniven "annan modell" på frågan ovan, beskriv den modell du använder.

...\\...\\...\\...

9. Varför använder du just de modeller du angivit och vilka tycker du är deras styrkor respektive svagheter vid undervisning om atomen?

...\\...\\...\\...

10. Om du använder fler atommodeller än en, hur går du tillväga när du skall presentera en ny atommodell efter att du och dina elever använt en annan tidigare?

...\\...\\...\\...

11. Undervisar du om atomens kvantnatur för dina elever? Det vill säga att elektronerna rör sig i sannolikhetsmoln (orbitaler) kring atomkärnan och inte i fasta skal som i Bohrmodellen.

Markera endast en oval.

[Ja] [Nej]

12. Om du svarat ja på frågan innan, har du upplevt att eleverna har svårt att ta till sig atomens kvantnatur om är vana vid att använda Bohrmodellen? Om ja, beskriv gärna på vilket sätt detta yttrar sig.

...\\...\\...\\...

https://docs.google.com/forms/d/1w38LA5E8swgvwuNnz1T9aPA1HX8hqf4A72hapuVFj9Rk/printform?responses

Representationsformer av atomen
Följande frågor handlar om hur du använder olika representationsformer för att undervisa om atomen och relaterade fenomen i din undervisning. En representation är en illustration eller förklaring av något, och de kan vara exempelvis statiska, dynamiska, fysiska eller virtuella. En modell kan representeras på olika sätt, t. ex. både som bild och simulering.


* Markera alla som gäller.

- Statiska bilder, t. ex. bilder i böcker eller stillbilder på en skärm
- Bilder eller text som du som lärare själv skapar, t. ex. bilder och text på en whiteboard
- Dynamiska bilder, t. ex. film eller animationer
- Datorsimuleringar, t. ex. virtuell laboration eller demonstration
- Fysiska modeller, t. ex. bygga molekylmodeller med plastkulor
- Annat

15. Om du svarade ”annat” på frågan ovan, vilken/vilka representationsform/-er använder du då?

16. Baserat på ditt svar på frågorna ovan, kan du ange exempel på specifika representationer eller källor från vilka du hämtar representationer av de typer du använder i din undervisning (t. ex. en bild i en speciell lärobok, en specifik simulering, en internet-källa, mjukvaruprogram, en speciell fysisk modell etc.)?

https://docs.google.com/forms/d/1w38LA5E8swgwvNu2T9a4A1HXX8hqfA772hapuVFjRk/printform#responses
17. Använd du ibland flera representationsformer i kombination för att förklara samma atomrelaterade fenomen (t. ex. visar både bilder och simulerings för att påvisa samma fenomen)?

Markera endast en oval.

☐ Ja
☐ Nej

18. Om du svarat ja på frågan ovan, beskriv hur du går tillväga när du presenterar kombinationer av flera representationsformer som påvisar samma fenomen (t.ex om du ger eleverna någon form av stöd i översättningsprocessen mellan de olika representationsformerna)?

..............................................................
..............................................................
..............................................................
..............................................................

19. Vad avgör dina val av representationsformer när du skall undervisa om atomen och relaterade fenomen för din aktuella elevgrupp?

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