*Research article*

# "As close as it gets to the truth": University students' views on science and scientific models of chemical bonding

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**Abstract:** Distrust of science is a societal concern that could be linked to a limited understanding about the nature of science. Scientific models have an essential role as both tools for doing science and for describing and communicating science. This work investigates first-, second- and third-year Norwegian science students' (*N* = 757) thoughts about what it means that a model is scientific, and their rating of how scientific different models of chemical bonding are. A review of Norwegian secondary school textbooks (*N* = 14) shows agreement between the models first-year students claim as familiar, and the models included in textbooks, but models known from school are not rated by first-year students as more scientific than unfamiliar models. Abstract models, such as an MO diagram or a potential energy graph, are rated as highly scientific by all students, regardless of level of familiarity with the model.

A thematic analysis of students' written explanations of what it means that a model is scientific was conducted and resulted in two main themes. The theme "the Truth" describes how students have a high degree of trust in science and what they perceive as scientific models. For the other main theme, "Research", students more often describe

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scientific models as a product of science than as a tool for doing science and scientific research. In science education, focusing on scientific models' role in the *process* of science could increase students' understanding of scientific models and the nature of science.

**Norsk sammendrag:** Manglende tillit til vitenskap er en samfunnsutfordring som kan knyttes til en begrenset forståelse av naturvitenskapens egenart. Vitenskapelige modeller har en essensiell rolle i naturvitenskapen, både som verktøy i forskning og for å beskrive og kommunisere naturvitenskap. Denne artikkelen undersøker hvordan første-, andre- og tredjeårsstudenter ($N$ = 757) i realfag ved et norsk universitet tenker om hva det vil si at en modell er vitenskapelig, og i hvilken grad de mener ulike modeller for kjemisk binding er vitenskapelige. En undersøkelse av lærebøker fra norsk ungdomsskole og videregående skole ($N$ = 14) viser samsvar mellom hvilke modeller førsteårsstudentene hevder å kjenne igjen, og hvilke modeller som benyttes i lærebøkene, men modellene de kjenner fra skolen blir ikke bedømt av førsteårsstudenter som mer vitenskapelige enn ukjente modeller. Mer abstrakte modeller, som et MO-diagram og en potensiell energigraf, blir i stor grad rangert som vitenskapelige av alle studenter, uavhengig om de kjenner modellen fra før eller ikke.

Studentenes skriftlige beskrivelser av hva det betyr at en modell er vitenskapelig ble analysert med tematisk analyse, noe som ga to hovedtema. Temaet «sannhet» beskriver hvordan studentene har høy tillit til vitenskapen og det de ser på som vitenskapelige modeller. Det andre hovedtemaet, «forskning», viser at studentene oftere beskriver vitenskapelige modeller som et produkt av vitenskap enn som et verktøy for å utføre vitenskap og vitenskapelig forskning. Et økt fokus i utdannelsen på vitenskapelige modellers rolle i *prosessen* vitenskap kan gi studentene økt forståelse av vitenskapelige modeller og naturvitenskapens egenart.

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Keywords:
scientific models, chemical bonding, models of chemical bonding, chemistry education research, university students

# 1 Introduction

Although some worry about public distrust of science (Blancke & Boudry, 2022), a large international survey (*N* = 71,922) found that most people do trust scientists, with Norwegians slightly below the international mean (Cologna et al., 2025). Another international survey, with data from more than 119,000 individuals in 113 countries, reveals that people who know a lot about science trust science and scientists more than those who know less about science (Wellcome Trust, 2021).

A possible source of distrust in science is a lack of understanding about the nature of science (McComas & Clough, 2020), how science supports humankind in making sense of the world when our intuition fails (Blancke & Boudry, 2022), and how scientific uncertainty does not mean science is untrustworthy (Covitt & Anderson, 2022). Scientific knowledge is at the same time “tentative and self-correcting but ultimately durable” (McComas, 2020, p. 59). A recent case study (Schaldach et al., 2024) found an adequate understanding of the nature of science among Norwegian science students.

This work investigates Norwegian science students’ view of science and scientific models. The eight models included in the study all depict the hydrogen molecule, a nonpolar diatomic molecule with covalent bonding. The work aims to answer the following research questions:

- RQ1 To what extent do students find different models of chemical bonding to be scientific?
- RQ2 Do students rate models they recognise from school as more scientific than unknown models?
- RQ3 What does it mean to students that a model is scientific?

Investigating what makes a model appear scientific to students and what it means to students that a model is scientific might reveal students’ opinions about science, and whether they think of science as something trustworthy or not.

# 2 Theoretical background

## 2.1 Scientific models in chemistry education

Scientific models are tools for describing, predicting, and making sense of the natural world. Chemists have used and developed models for centuries, and learning about models is an essential part of any education in chemistry (Justi & Gilbert, 2003). Models are not only products of science, but also tools or methods of doing science (Harrison & Treagust, 2000).

Several typologies for models exist. If models are classified by their ontological status, *scientific models* can be defined as a type of *consensus models* – models agreed upon and used by a group of people – that are a result of empirical testing, are used in research and produce empirically relevant predictions (Gilbert, Boulter, & Elmer, 2000). However, many models used in science education are not currently used scientific models, but rather historical models (Justi, 2000), simplified teaching models (Gilbert, Boulter, & Rutherford, 2000) or hybrid models combining different types of models (Bergqvist et al., 2013; Gilbert, Boulter, & Elmer, 2000).

Lazenby et al. (2019) asked students whether they would classify different representations of chemical phenomena as scientific models or not. The survey was given to students (*N* = 773) at the end of the first of two introductory chemistry courses at a university in the United States. The representations included a Lewis structure and a ball-and-stick model (called "physical model of a molecule"), as well as more mathematical models such as a potential energy graph (called "energy diagram") and an equilibrium constant expression. Their results showed that fewer students classify a potential energy graph (69%) as a scientific model than a Lewis structure (80%) or a ball-and-stick model (85%). Lazenby et al. (2019) argue that this difference could be due to fewer students thinking of the mathematical expressions as models.

Chittleborough et al. (2005) investigated school pupils' and university students' understanding of scientific models and found this understanding to be satisfactory and increasing with age. Kozma and Russell (1997) asked undergraduate students ("novices") and professional chemists ("experts") to group different visual chemistry representations. They found that novices focused more on surface features explicitly available in the representations, while the experts created more chemically meaningful groupings, applying their chemical knowledge in their interpretations of the representations. Similarly, Swedish schoolteachers found that students pay excessive attention to surface features of a model such as colour (Patron et al., 2017).

## 2.2 Chemical bonding

Chemical bonding is what makes atoms, ions and molecules stick together and create the structures that our world consists of. Chemistry is the study of these structures, their properties and their reactions, and chemical bonding is regarded as one of the most important topics taught in chemistry courses (Gillespie, 1997; Hunter et al., 2022; Taber & Coll, 2002). Research in chemistry education has uncovered a myriad of wide-spread alternative conceptions about chemical bonding (see e.g. Hunter et al., 2022; Özmen, 2004; Taber & Coll, 2002; Ünal et al., 2006). Due to the abstract nature of the topic, these are assumed to originate not from every-day experiences, but rather from previous instruction in the topic (Taber, 2001). In particular, overreliance on the octet rule and the octet model is linked to several alternative conceptions (Taber, 1998, 2013).

## 2.3 The role of textbooks in chemistry education

School students mainly use textbooks as reference tools or an aid while studying for tests (Knain, 2002). Surveys, interviews and classroom observations all reveal that Norwegian schoolteachers use textbooks a lot in their teaching (Skjelbred, 2003), and the *Trends in International Mathematics and Science Study* (TIMSS) reveal that textbooks are the most used basis for instruction in natural science internationally, and for Norwegian teachers especially (Martin et al., 2012). 83% of Norwegian teachers (*N* = 756) often use textbooks as the primary basis when presenting the material, and compared to other subjects, teachers rely even more on textbooks in natural science (Bachmann, 2005). In interviews, Swedish upper-secondary school chemistry teachers state that the models of chemical bonding that they use while teaching are the same models shown in school textbooks (Patron et al., 2017), even though the textbooks use some models known to cause students' alternative conceptions or impede further learning (Bergqvist et al., 2013).

Lately, new and digital learning materials challenge the distinguished role of the textbook as the main knowledge source and basis for instruction (Kunnskapsdepartementet, 2023). Most Norwegian schools use a combination of printed and digital learning materials, and there seems to be a shift from mainly printed materials in 2014, to both printed and digital materials in 2021 (Vennerød-Diesen & Pedersen, 2023). However, many digital learning resources require the schools to buy and renew licences that over time are more expensive than physical textbooks that can be used for several years (Kunnskapsdepartementet, 2023). For many schools, budgetary considerations limit the use of digital learning resources.

# 3 Methods

## 3.1 Model selection and categorisation

Eight models of the hydrogen molecule were included in the study: a Lewis structure (model 1), a ball-and-spring model (model 2), an octet model[1] (model 3), a molecular orbital (MO) diagram (model 4), a ball-and-stick model (model 5), a space-filling model (model 6), an overlap model (model 7) and a potential energy graph (model 8). All models are shown in Figure 1.

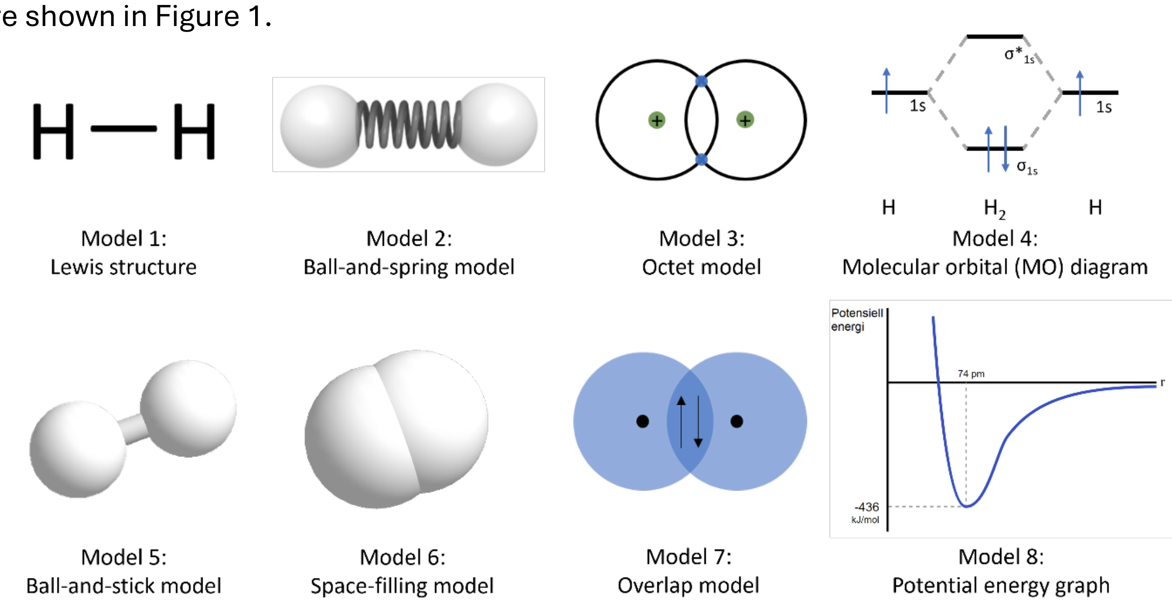


***Figure 1.*** *Eight models of the hydrogen molecule: a Lewis structure (model 1), a ball-and-spring model (model 2), an octet (duet) model (model 3), a molecular orbital (MO) diagram (model 4), a ball-and-stick model (model 5), a space-filling model (model 6), an overlap model (model 7) and a potential energy graph (model 8).*

The selection of models includes both models assumed to be familiar to most Norwegian first-year students (e.g. the ball-and-stick model), and models more commonly introduced at university level chemistry (e.g. the MO diagram). While the number of models had to be limited, one aim of the selection of models was that all models should be substantially different from each other, and that they should illustrate

[1] As there are only two electrons in the hydrogen molecule, this model is also a *duet* model.

different ways of conceptualizing covalent bonding. At the same time, all models should be relevant for the teaching and learning of chemical bonding, at school level, at university level, or both.

## 3.2 Student survey

### *3.2.1 Data collection*

Students of selected chemistry courses at the Norwegian University of Science and Technology (NTNU) answered a short (5-10 minutes) survey in the autumn of 2021, 2022 and 2024. The targeted chemistry courses were taught mainly to first-, second- and third-year students. Some students answered the survey more than one time during their years of study. The survey was administered to the students in one of the first physical lectures of the semester, and the students responded to the survey digitally. The survey had questions about students' understanding of what chemical bonding is, which models of chemical bonding they recognised and how the students perceived different models. This article will present students' answers to three questions related to how scientific they found different models of chemical bonding, and what it means that a model is scientific.

Different cohorts of students answered slightly different versions of the survey. The question "Below are 8 different ways to visualize the hydrogen molecule. Which of these representations have you seen before?" (Q1) was included in all versions of the survey, and all students answered for all eight models shown in Figure 1. The question "The figure below shows a representation of the hydrogen molecule $H_2$. To what extent do you find this representation scientific?" (Q2) was a 5-point Likert-type question answered on the scale *a very small extent* – *a rather small extent* – *neutral* – *a rather large extent* – *a very large extent*. In order to limit the time required to answer the survey, students were asked this question for either models 1-4 or models 5-8. The 2024 version of the survey was only given in courses mainly taken by second- and third-year students, and all students were asked to answer this question for models 1, 3 and 4. In the 2022 version of the survey, the open question "What does it mean to you that a representation is scientific?" (Q3) was given to a random sample (approximately 25%) of the students.

The data collection and management are approved by the Norwegian Agency for Shared Services in Education and Research (SIKT), reference number 763912. The original Norwegian wording of the survey questions is provided in Supporting Information A: Survey questions in English and Norwegian. A subset of the data is published earlier (Aakre, 2025).

### *3.2.2 Data analysis*

The results from all courses and all years were pooled. Students that had only answered parts of the survey, or gave the same answer to all the Likert questions, were removed from the data set. Students were grouped by year of study, and students in their fourth year or later were removed from the data set due to the small number of respondents. Consensus (Tastle & Wierman, 2007) was used as a quantitative measure of the dispersion of the Likert scale data (Q2).

The students written answers to the question "What does it mean to you that a representation is scientific?" (Q3) was analysed by use of thematic analysis (Braun & Clarke, 2022). After several iterations of inductive coding, codes were consolidated and sorted, and themes were created and revised. Each student answer could belong to none, one, or more than one code and theme.

The coding process was performed for the whole data set with answers from all students, without regard to year of study. After this process, the answers were sorted by the student's year of study in order to explore possible differences between students of different years.

## 3.3 Textbook study

Use of models for chemical bonding in textbooks in natural science and chemistry in Norwegian lower and upper secondary school were examined. Relevant textbooks were identified from the webpages of the major publishing companies in Norway, and the university library catalogue. A physical or digital version of the textbooks was surveyed, and use of the models in Figure 1 was recorded. Only textbooks following the natural science curriculum in use from 2013 to 2022 (Kunnskapsdepartementet, 2013) and the chemistry curriculum in use from 2006 to 2022 (Utdanningsdirektoratet, 2006) were investigated. These versions of the curricula were valid when most of the students answering the study went to school. A list of textbooks included in the study can be found in Supporting Information B: List of textbooks.

Natural science is a compulsory course in Norway for grade 8-10 and grade 11, while Chemistry 1 and Chemistry 2 are elective courses for pupils in Programme for General Studies, grade 12 and 13. Natural science in lower secondary school (grade 8-10) has one common curriculum for all three years, and different textbook writers have distributed the different topics between the grades in different ways. For this reason, each set of three textbooks, covering grade 8-10, is treated as one entity in the analysis.

For each textbook or set of textbooks, a model was classified as used if a similar type of model was included as an illustration at least one time and for any chemical compound, real or imagined. No distinctions were made regarding how many times the model was used, or whether it was used to show the hydrogen molecule or some other compound. In the case of small variations in how the models were shown in the textbooks, the main principle used when classifying the model was the question "Will a student familiar with this model recognise it as the same model as the one shown in the survey?"

Lewis structures show bonding electron pairs as lines and lone pairs and other nonbonding valence electrons as dots. The hydrogen molecule has no nonbonding electrons and for this reason the Lewis structure of $H_2$ is indistinguishable from a simpler structural model not including nonbonding electrons. All models using chemical symbols (letters) for the atoms and lines (not dots) for covalent bonds were counted as a Lewis structure (model 1), also where the model omitted lone pairs that should be present in the molecule.

All models where atoms are shown as balls and covalent bonds are shown as balls touching or overlapping, are classified as space-filling models (model 6). These models should not include anything connecting the balls.

To be classified as a potential energy graph (model 8), the graph had to be a continuous graph of energy as a function of distance between the nuclei, with an energy minimum at the bond length. Graphs of reaction progress with reactants, products and activation energy were not counted as potential energy graphs.

# 4 Results and discussion

## 4.1 Students

Out of the students registered in the target courses, 22–88% responded to the survey. Of a total of 793 student respondents, seven students (0.9%) were removed from the data set due to missing answers. Three of these students had not answered any of the open (text box) questions, three had limited text answers and gave the same answer (neutral) to all twenty Likert scale questions in the survey, and one student had left year of study blank. 29 students (3.7%) were removed from the data set due to them being in their fourth year of study or later. This left a total of 757 responses. Due to the differences in the surveys described in section 3.2.1, the number of student answers differs from question to question.

Table 1 shows the number of student answers for each question and year of study. For all questions, the number of first-year students exceeds the number of second-year students, which exceeds the number of third-year students. The question about which of the models are familiar has the largest number of student answers, because this question was given to all students. The text box question about what it means that a representation is scientific has the smallest number of student answers.

***Table 1.*** *Number of student answers arranged after question and year of study. The column "Models" denotes which models the question refers to. A hyphen (-) is used when the question does not refer to any specific model.*

| QUESTION | Question type | Models | Student answers per year of study | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | Total |
| **Which of these representations have you seen before? (Q1)** | Multiple select | all | 475 | 168 | 114 | 757 |
| **To what extent do you find this representation scientific? (Q2)** | Likert scale | 1, 3 and 4 | 202 | 101 | 85 | 388 |
| | | 2 | 202 | 70 | 13 | 285 |
| | | 5–8 | 273 | 67 | 29 | 369 |
| **What does it mean to you that a representation is scientific? (Q3)** | Text box | - | 26 | 16 | 7 | 49 |

## 4.2 Familiarity of the models

Figure 2 shows the percentage of first-year, second-year and third-year students recognising each of the eight models in the survey. With some small and not statistically significant exceptions, all models are recognised by a higher percentage of third-year students than second-year students, and a higher percentage of second-year students than first-year students.

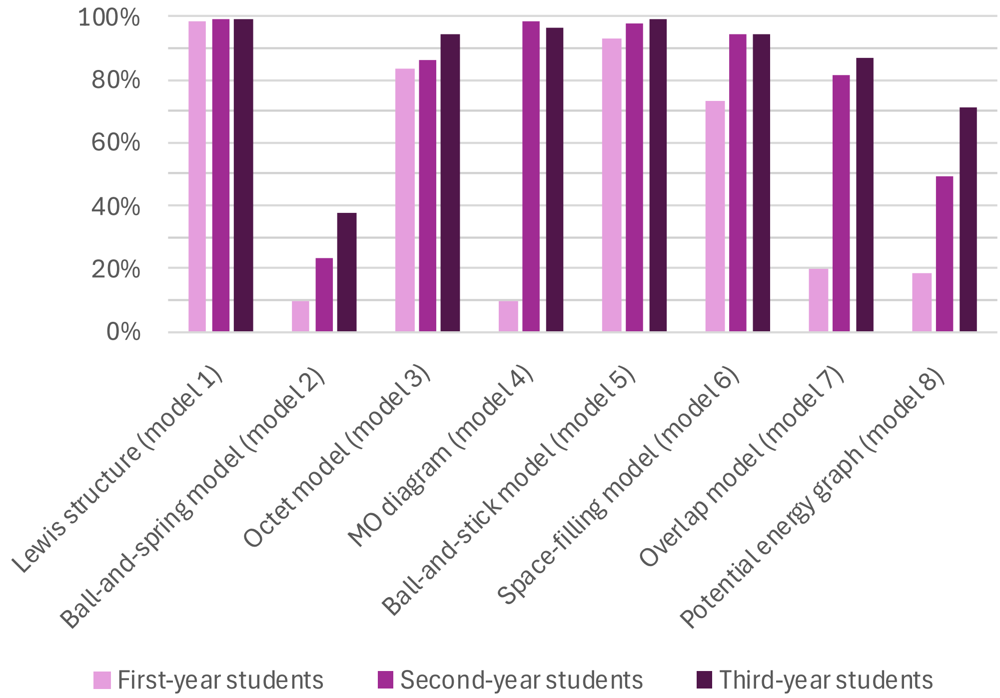


***Figure 2.*** *The percentage of first-year (light purple,* N = *475), second-year (bright purple,* N = *168), and third-year (dark purple,* N = *114) students recognising each model.*

Both the MO diagram (model 4) and the overlap model (model 7) are unfamiliar to most first-year students and familiar to most second-year students, reflecting that these models are used in the mandatory inorganic chemistry course these students take in their first year of university studies. The potential energy graph (model 8) is also used, although to a lesser extent, in both first-year and second-year courses, and the percentage of students recognising this model has a steady increasing trend.

Figure 2 shows that half the models – the Lewis structure (model 1), the octet model (model 3), the ball-and-stick model (model 5), and the space-filling model (model 6) – are known to most (73–99%) of the first-year students. The other half – the ball-and-spring model (model 2), the MO diagram (model 4), the overlap model (model 7) and the potential energy graph (model 8) – are known to only a small minority (10–20%) of the first-year students.

Table 2 presents use of the eight models of chemical bonding in Norwegian secondary school textbooks. The models recognised by most first-year students are used in all the examined textbooks at all grade levels, except the octet model (model 3), which is used in all the natural science textbooks except one, but none of the textbooks for Chemistry 1 and Chemistry 2. The models that only a minority of the first-year students recognise, are not used by any of the examined textbooks. This indicates that the models of chemical bonding used in Norwegian schools are the same models that are used in textbooks, in agreement with the TIMSS results (Martin et al., 2012).

***Table 2**. Use of eight models of chemical bonding in Norwegian science and chemistry textbooks.*

| MODEL | Natural science, grade 8-10 (*N* = 4[2]) | Natural science, grade 11 (*N* = 4) | Chemistry 1, grade 12 (*N* = 3) | Chemistry 2, grade 13 (*N* = 3) |
|---|---|---|---|---|
| **Lewis structure (model 1)** | all | all | all | all |
| **Ball-and-spring model (model 2)** | none | none | none | none |
| **Octet model (model 3)** | 3 out of 4 | all | none | none |
| **MO diagram (model 4)** | none | none | none | none |
| **Ball-and-stick-model (model 5)** | all | all | all | all |
| **Space-filling model (model 6)** | all | all | all | all |
| **Overlap model (model 7)** | none | none | none | none |
| **Potential energy graph (model 8)** | none | none | none | none |

Although the curricula for these courses (Kunnskapsdepartementet, 2013; Utdanningsdirektoratet, 2006) does not explicitly mention any of these models, the results show that different textbooks do use the same or similar models. The investigated models are consistently used by either all or none of the textbooks, with the only exception being the octet model. The exclusion of this model from the chemistry textbooks is surprising, as the model was widely used in contemporary Swedish textbooks (Bergqvist et al., 2013). This could indicate that at least *some* Norwegian textbook authors are aware of the problematic aspects of the octet model (Taber, 1998, 2013) and the pitfalls of applying the octet rule as if it is universally valid (Ringnes & Hannisdal, 2006, p. 108).

Textbooks based on the newest national curriculum in Norway were not included in the study. Based on the students' self-reported age, a maximum of 3% of the students answering the survey could have used the current version of the curricula at upper secondary school, in both natural science (Kunnskapsdepartementet, 2019) and chemistry (Utdanningsdirektoratet, 2021). Some Norwegian private schools use different curricula, but 95% of Norwegian pupils attend public schools (Statistics Norway, 2024). Some students may have a background from other countries or school systems such as International Baccalaureate (IB), but all the targeted university courses are taught in Norwegian and offered only for students who master a Scandinavian language. Although some students may have used different textbooks or other resources such as digital learning materials, it is reasonable to assume that a large majority of the students will have used one or more of the textbooks examined in this study when they took natural science or chemistry at school.

## 4.3 To what extent do students find the representations scientific, and are models taught in school viewed as more scientific than unknown models? (RQ1 & RQ2)

First-year students' answers to the question "To what extent do you find this representation scientific?" is shown as a diverging stacked bar chart in Figure 3. The chart shows that many students choose the neutral alternative, from 23% for the

[2] Four sets of textbooks, each consisting of three books covering grade 8-10.

potential energy graph (model 8), and up to 56% for the ball-and-spring model (model 2). Interestingly, the potential energy graph (model 8), which is unfamiliar to over 80% of first-year students, is the model with the fewest "neutral" answers. Even when they have never seen a model before, students make judgments about how scientific the model is without defaulting to the neutral option.

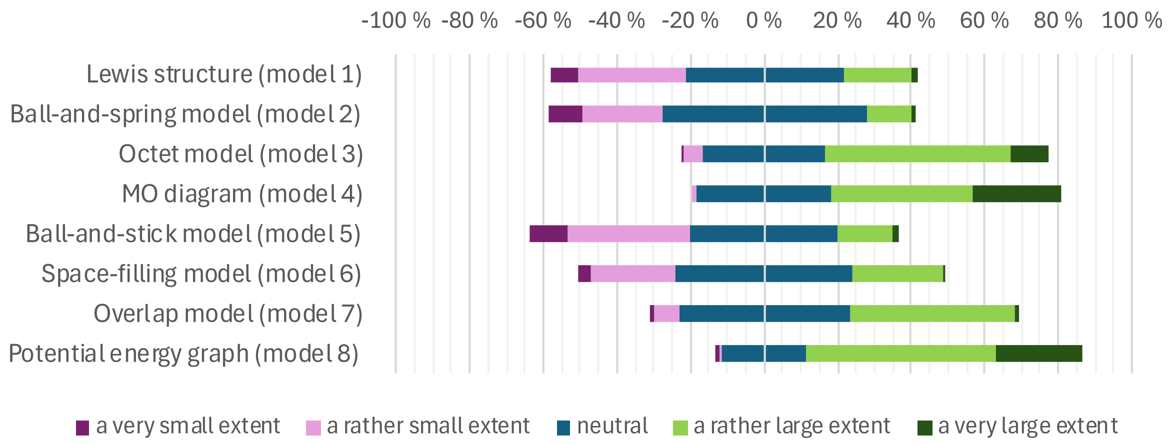


***Figure 3.*** *First-year students' answers to the question "To what extent do you find this representation scientific?"* N *= 202 for the Lewis structure (model 1) and the octet model (model 3),* N *= 200 for the ball-and-spring model (model 2) and the MO diagram (model 4),* N *= 272 for the ball-and-stick model (model 5) and the overlap model (model 7),* N *= 273 for the space-filling model (model 6) and the potential energy graph (model 8).*

Four models – the octet model (model 3), the MO diagram (model 4), the overlap model (model 7) and the potential energy graph (model 8) have less than 8% of students judging them to be scientific to only a small extent. Three of these models – the MO diagram (model 4), the overlap model (model 7) and the potential energy graph (model 8) are unfamiliar to most first-year students (see Figure 2). However, the octet model is recognised by 84% of these students, and their opinion on the octet model is likely to be influenced by prior learning. In the chemistry education research literature, it is well documented that the octet model is highly regarded by students, and that uncritical use of the octet model and the octet rule is related to several alternative conceptions about chemical bonding, chemical reactivity and related topics (Taber, 2013).

The results for the potential energy graph (model 8) are striking, with only 23% of first-year students giving it a "neutral" rating, despite only 18.5% of students recognising the model. This demonstrates that the students are willing to rate the models on visual appearance and their first impression, not only on prior experiences with the models. The MO diagram (model 4), the overlap model (model 7) and the potential energy graph (model 8) are all rated as scientific to a large extent, despite being unfamiliar to most first-year students. These models employ a high degree of symbolism with e.g. arrows, Greek letters and a graph. Students that are unfamiliar with these models could regard them as scientific due to such surface elements of the models (Kozma & Russell, 1997).

All the models are abstract approaches to what a molecule looks like, or what it means that two atoms are bonded together by chemical bonding. Despite this, students may interpret some of the models as less abstract than the other models. Most students will have used molecular modelling sets in secondary school, and for this reason, the ball-and-stick model (model 5) and the space-filling model (model 6) might appear more concrete and tangible to these students. The models that can be understood as a 3D visualisation of the hydrogen molecule (the ball-and-spring model (model 2), the ball-and-stick model (model 5) and the space-filling model (model 6)), are all rated as scientific to a smaller extent than the more abstract models. With the exception of the octet model (model 3), models known from school are generally rated as less, not more, scientific than unknown models.

The results show the opposite trend to those reported by Lazenby et al. (2019), where fewer students (69%) classify a potential energy graph as a scientific model compared to a Lewis structure (80%) or a ball-and-stick model (85%). This can be explained by the difference in how the questions are asked. The students in the study by Lazenby et al. (2019) are asked if they consider the different models to be scientific models, as a yes-or-no question. Mathematical expressions and graphs are considered *not* to be scientific models by many of these students, possibly because the students do not consider them *models*. In this study, the word *representation* is used to avoid confusion about what a model is, and the students rate the different representations based on how scientific they are.

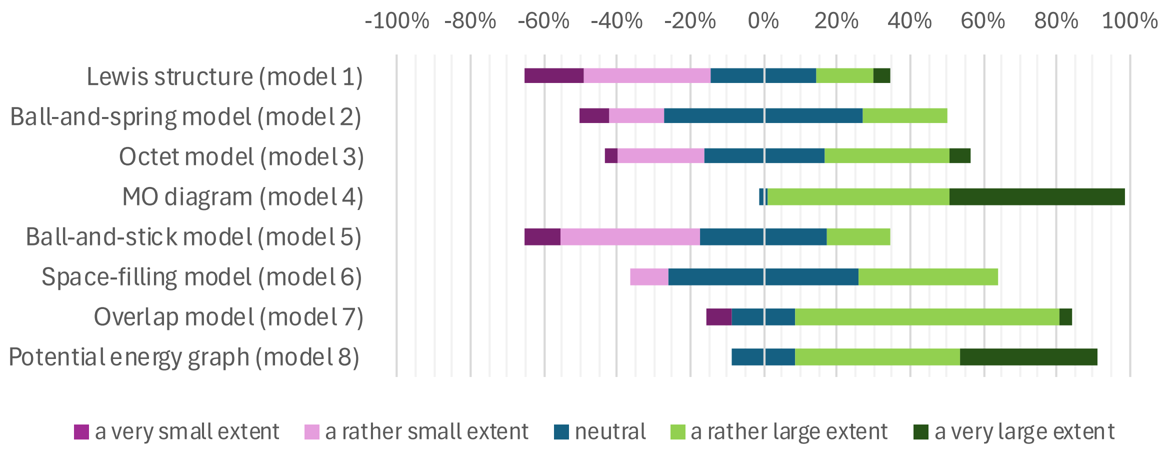


***Figure 4.*** *Third-year students' answers to the question "To what extent do you find this representation scientific?"* N *= 85 for the Lewis structure (model 1), the octet model (model 3) and the MO diagram (model 4),* N *= 13 for the ball-and-spring model (model 2),* N *= 29 for the ball-and-stick model (model 5), the space-filling model (model 6), the overlap model (model 7), and the potential energy graph (model 8).*

Figure 4 shows third-year students' answers to the question about to what extent they find the models scientific. For most models, the percentage of students answering "neutral" is less than for first-year students (Figure 3). This decrease is particularly striking for the MO diagram (model 4) and the overlap model (model 7), which is unfamiliar to most first-year students but familiar to most third-year students. However, there is also a significant decrease for the Lewis structure (model 1), despite this model being familiar to almost all first-year students. This could mean that third-year students feel more confident when rating the "scientific-ness" of models.

For most models, the proportion of students finding the model scientific is steady or increasing with year of study. The octet model (model 3) is an exception, as this model has a significant decrease in how scientific students find the model. This could reflect that more students discover the limitations of the octet model during their first two years of university studies, or it could be a consequence of limited use of the octet model in university level chemistry courses and university level textbooks.

Consensus (Tastle & Wierman, 2007) is a measure of agreement between respondents for ordinal data such as Likert scale data. It has a minimum value of 0 for complete disagreement, and a maximum value of 1 for complete agreement between respondents. For first-year students, all models have consensus values in the 0.68–0.77 range. The consensus is largest for the potential energy graph (model 8), the overlap model (model 7) and the space-filling model (model 6), and smallest for the ball-and-stick model (model 5) and the Lewis structure (model 1). For third-year students, the consensus values for the models have a larger range, from 0.59 for the Lewis structure (model 1) to 0.80 for the MO diagram (model 4). The relatively small consensus value for the Lewis structure means that students disagree about how scientific this model is, while a value of 0,80 for the MO diagram means that the students' answers are almost equally divided between two adjacent answers, in this case "a rather large extent" and "a very large extent". Consensus values for all models all years are available in Supporting Information C: Statistical data.

Data for second-year students tend to lie between the data for first-year and third-year students and will not be discussed here.

## 4.4 What does it mean to students that a model is scientific? (RQ3)

Two main themes, "the Truth" and "Research", were identified in the students' answers ($N$ = 49) to the question "What does it mean to you that a representation is scientific?". Themes, related codes and examples of student answers are shown in Figure 5, with the percentage of students sorted under the relevant theme or code. In two cases, only the relevant part of the student's answer is included in Figure 5. The original Norwegian wording and full student answers are available in Supporting Information D: Selected student answers in English and Norwegian. Some additional, less frequent used codes did not sort under the main themes and will not be discussed here. Five students (10%) expressed not knowing how to answer the question or being unsure about what "scientific" means. Three of them were first-year students, and two of them were second-year students. Two of the first-year students wrote extensive answers despite their uncertainty.

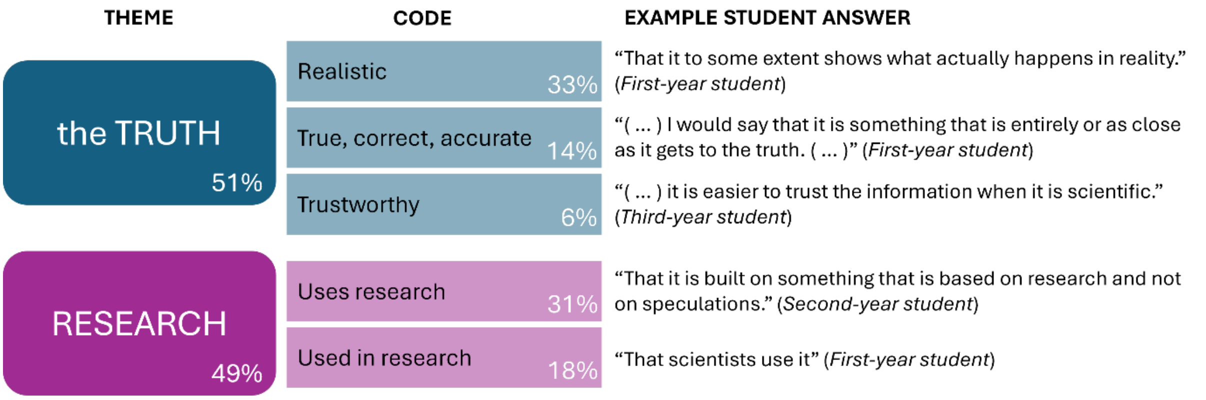


***Figure 5.*** *Main themes (left), related codes (middle) and examples of student answers (right). Themes and codes are organised by percentage of students sorted under the relevant theme or code.*

Just over half of the student answers (25 out of 49 ≈ 51%) were sorted under the theme “the Truth”. The frequency of this theme appeared independent of the students’ year of study. These answers describe a scientific representation as realistic, accurate, trustworthy or simply *correct*. The most frequent code under this theme is *Realistic*, which is used for answers describing the model as realistic or related to nature or reality. In contrast, answers sorted under the code *True, correct, accurate* does not refer to the model in relation to the physical world, but rather as a representation of science itself or a metaphysical truth. The code *Trustworthy* is used for answers highlighting how the student finds it easier to trust a model if it is scientific.

The student answers indicate a high degree of trust in science and scientific models. This is perhaps not surprising, as most people across the world do trust scientists (Cologna et al., 2025), and people who know a lot about science – such as science students – trust science and scientists more than people who know less about science (Wellcome Trust, 2021). Problematic public distrust of science is usually linked to controversial topics, which in Norway includes topics such as climate change or gender studies (NTB, 2020). However, even people that dispute specific areas of science, tend to trust science in general (Cobern et al., 2022), and scientific models of chemical bonding is a relatively uncontroversial topic.

Do the student answers show an excessive and naïve trust in science, or is this high level of trust in science appropriate? Although science is acknowledged as our most successful method of gaining reliable and durable knowledge and understanding about the natural world, scientific knowledge is not perfect and permanent, but rather tentative, ever-changing, and self-correcting (McComas, 2020). This is reflected in the answer from the first-year student who describe a scientific model as “something that is entirely or as close as it gets to the truth”. A scientific model is not the absolute truth – and the students do not claim that it is – but rather a human-made construct that reflects some of our current understanding of the world and a useful tool for research and guided exploration.

Just under half of the student answers (24 out of 49 ≈ 49%) were sorted under the main theme “Research”. These students use terms such as *research*, *researchers*, and/or they refer to *experiments* and *the scientific method*. Most of these students describe how a scientific model uses research, is a result of research or is built on research (coded Uses research), while the rest describe a scientific model as something that is *used in* research or by scientists (coded Used in research). When all student answers are regarded as one entity, both these perspectives on a scientific model are present – a scientific model is both a product of science *and* something that is used in the process of doing science – but it is interesting to note that *none* of the student answers incorporates both perspectives. The main theme “Research” was present to a comparable degree in the answers from first-year and second-year students, but only one of the seven third-year students’ answers (14%) were sorted under this theme.

# 5 Conclusions and implications for teaching

In typologies of models, the “scientific-ness” of a model is treated as a dichotomous variable – a model either *is* scientific, or it is not. In this study, students are asked about to what *extent* a representation is scientific (Q2), and what it *means* to them that a representation is scientific (Q3). When rating the models on the Likert scale, students find models of chemical bonding scientific to a varying extent. In general, more abstract representations such as a molecular orbital (MO) diagram (model 4) or a potential energy graph (model 8) are rated as highly scientific, while models such as a ball-and-stick model (model 5) and a ball-and-spring model (model 2), that can be understood as 3D representations of what a molecule “really” looks like, are rated as less scientific. The Lewis structure (model 1) is also rated as scientific to a small degree by many students, but this model has a relatively small consensus value, meaning that the students disagree about how scientific this model is. This could imply that different students interpret the Lewis structure differently. The reason for this is unclear, but could be a possible venue for future research, and is something to keep in mind for chemistry teachers.

With some exceptions, first-year students rate models known from school as less scientific than unknown models. This can be explained by surface features of the unfamiliar models, e.g. the Greek letters in the MO diagram (model 4), that make them appear highly scientific. When confronted with a model they have never seen before, the students have limited information on which to rate the model, and such a reliance on surface features does not necessarily mean they have a naïve understanding of scientific models. However, when first-year students’ opinion on the MO diagram (model 4) is compared to their opinion of the equally unfamiliar ball-and-spring model (model 2), it appears that the more abstract model is rated as more scientific. This suggests that students view science as something advanced and abstract and could possibly affect how the students evolve from students to scientists.

Students show a high level of trust in science when they describe a scientific model as *realistic*, *trustworthy*, and related to the *truth*. The words *science* and *research* are used almost as honorifics in the students’ answers. More students emphasise that a scientific model *uses* research, than how it is *used in* research, and it appears that students view models as primarily a *product* of science. Scientific models’ role in the *process* of science should be emphasized in science education, not only to give students a better understanding of models, but also to improve their understanding of the nature of science and scientific research.

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# List of Supporting Information

Supporting Information A: Survey questions in English and Norwegian
Supporting Information B: List of textbooks
Supporting Information C: Statistical data
Supporting Information D: Selected student answers in English and Norwegian

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