Enhancing Students' Knowledge by Meta-conceptual Instruction

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1 Introduction

For the past decades, scientific knowledge representations have generated considerable research interest (Johnstone, 1982, 1993). Scientific representations are required to explain observable phenomena at the unobservable, model-based level. Consequently, the importance of macroscopic, submicroscopic and symbolic representations has been demonstrated in a remarkable variety of studies in science education (Ben-Zvi, Eylon, & Silberstein, 1987; Chandrasegaran, Treagust, & Mocerino, 2007, 2008; Davidowitz & Chittleborough, 2009; Hinton & Nakhleh, 1999; Kozma, Chin, Russell, & Marx, 1997; Nakhleh & Krajcik, 1994). Scientific representations play a key issue to form a solid conceptual understanding of chemistry (Kozma, 2000, 2003; Kozma & Russell, 1997). Chemistry lessons often focus on macroscopic and symbolic representations without considering submicroscopic entities. Teachers as professional chemists can easily slide from one to another representation (Johnstone, 1993). Understanding submicroscopic entities demands a comprehension of scientific models as instrument to describe, explain and predict the world (Boulter & Buckley, 2000). Nevertheless, research studies in chemistry education have illustrated students' difficulties in understanding scientific phenomena at the sub-microscopic domain (Boo, 1998; Davidowitz & Chittleborough, 2009). Learners have problems in transferring between different representations (Kozma & Russell, 1997), in separating macroscopic and submicroscopic elements (Jaber & BouJaoude, 2012) and understanding chemical equations with submicroscopic representations (Hinton & Nakhleh, 1999; Nurrenbern & Pickering, 1987; Pickering, 1990).

Increasing comprehension of chemical concepts demands students' awareness of their constructed explanatory frameworks. Students need to reveal their own thinking while reasoning about scientific phenomena. Therefore, it is generally accepted that meta-conceptual awareness is significant in learning science (Cheng, 2012; Cheng & Brown, 2010; Vosniadou & Ioannides, 1998; Yürük, 2007; Yürük, Beeth, & Andersen, 2009). However, understanding chemistry at a meta-level involves students' conceptions about scientific representations including its modelled nature (Schwarz & White, 2005; White, Collins, & Frederiksen, 2011; White & Frederiksen, 1998).

Previous research approaches have detected the influence of a macro-micro-symbolic teaching approach on improving students' building links between the different representations (Jaber, 2009; Jaber & BouJaoude, 2012). This teaching approach has a positive impact on conceptual understanding. While many researchers underline the importance of the three representations, there is still a lack of addressing the influence of knowing explicitly about chemical representations. However, research has to aim at identifying the decisive and causal factor of explicitly teaching about representations. Moreover, it can be assumed that adapting the meta-modelling approach from Schwarz and White (2005) to scientific representations has a positive influence on the development of conceptual knowledge.

It can be summarised that researchers have established the importance of meta-events in learning science. However, students rarely communicate at a meta-level (diSessa, 2002a). Therefore, instructional approaches and prompts are used to scaffold students' knowledge (Bannert, 2009; Veenman, van Hout-Wolters, & Afflerbach, 2006; Wirth, 2009) and to initiate reflection (Davis & Linn, 2000). The goal of this research project is the development and evaluation of an experimental learning environment in which students are instructed to use and reflect on the different representations. They are empowered to think about the modelled nature of chemical knowledge at a meta-level. Therefore, this study takes into account the ways in which scientific meta-knowledge about representations including its modelled nature has an influence on students' conceptual understanding of electrochemistry. Moreover, the impact of prompts stimulating students' communication shall be investigated.

2 Theoretical and Empirical Background

The importance of scientific models and representations has been demonstrated since the early beginning of science (Giere, 1988; Hacking, 1983). Explaining natural phenomena which "exist at scales beyond our temporal, perceptual, or experiential limits" (Kozma, 2000, p. 11) requires the development of scientific models and representations (Giere, 2004). In science education, students face the challenge of acquiring knowledge about them, applying them to explain as well as predict phenomena and understanding their multiple nature and purposes (Gilbert, 2004; Gilbert & Boulter, 1998; Justi & Gilbert, 2003a, 2003b). It is generally accepted that meta-conceptual awareness as general thinking of one's own conceptual structure is a distinctive factor in learning science (Vosniadou, 1994; Vosniadou & Ioannides, 1998; Yürük, 2007; Yürük et al., 2009). Meta-conceptual awareness in respect of science involves scientific meta-knowledge like meta-modelling and meta-representational knowledge.

The purpose of this chapter is to clarify the theoretical constructs of scientific models, representations and the related scientific meta-knowledge including the meta-conceptual awareness in the context of learning science. Furthermore, empirical evidence is discussed in order to provide implications for learning science.

2.1 Scientific Models

It is generally accepted that models are an essential element to acquire scientific knowledge and to understand science (Giere, 1988; Gilbert & Osborne, 1980; Gilbert, 1991). However, there is no commonly agreed definition of a scientific model. Yet, the nature and the purpose of models as well as the model construction are commonly considered modalities (Cheng & Lin, 2015; Oh & Oh, 2011). The variety of multiple dimensions of scientific models demands a systematic typology of them. Consequently, the main aim of this chapter is to clarify the use of the term scientific model in order to attempt a comprehensive framework for models and modelling in science education. Hence, recent research and its role in and implications for learning science are presented.

2.1.1 Definition and Categorisation

The central problem in characterising a scientific model is the ubiquitous use of the term ‘model’ in everyday life or scientific language. In everyday life language, models are just simplified versions of a related object like toy-size models (Grosslight, Unger, Jay, & Smith, 1991; Oh & Oh, 2011). Such models almost represent the external structure of observable facts but the interior remains hidden. They are defined as scale models (Harrison & Treagust, 1996, 1998, 2000b). In the context of science a model can be described “as a structure that is intended to represent another structure by virtue of an abstract similarity relationship between them” (Godfrey-Smith, 2003, p. 187). Hence, a model aims to represent the target system. A widespread used definition in science education is that “a model can be defined as a representation of an idea, an object, an event, a process or a system” (Gilbert & Boulter, 1998, p. 53) for a specific purpose (Gilbert, Boulter, & Elmer, 2000). In addition, models “can be concrete, abstract or theoretical depending on the needs of their author and audience, but above all models must enhance investigation, understanding and communication and this makes them key tools in thinking and working scientifically” (Harrison & Treagust, 2000b, p. 1012). In other words, scientific models vary considerably in terms of the related target system such as an object or an event, in appearances (concrete physical or abstract theoretical) and in their purpose (investigation or understanding). These complex characterisations of a model emphasise two different distinctive facts of scientific models. **Scientific models relate to representations** (cf. Downes, 2011; Harrison & Treagust, 2000b; Sibley, 2009; van der Valk, van Driel, & de Vos, 2007; Windschitl & Thompson, 2006), instead not all representations are scientific models as it will be clarified in chapter 0. **Scientific models as products and methods for a specific aim** establish the second distinctive fact of a scientific model. The representative aspect of a scientific model demands an understanding of how models are constructed and involves questions such as: What is the nature of scientific models? What do they represent? The construction of a model relates closely to the philosophy of science issues, because the question arises how models represent reality and what is the relationship between them (Giere, 2005; Gilbert, Pietrocola, Zylbersztajn, & Franco, 2000; van Fraassen, 1980). Depending on the different philosophic perspectives of sciences, the relationship between the world and its representation varies (Cartwright, 1999; Hacking, 1983; van Fraassen, 1980). According to scientific realism a representation of an atom is a human produced description, yet in contrast to constructive empiricism, the atom as an entity really exists although it is not directly observable (cf. van Fraassen, 1980). According to Gilbert and colleagues (2000) authentic science education can only be performed in a realist view of science in contrast to an anti-realist view. Students cannot construct scientific knowledge away from the anti-realist argument that reality does not exist. “Scientific realism says that the entities, states and processes described by correct theories really do exist” (Hacking, 1983, p. 21). Therefore, the following modelling process is mentioned in a realistic view of science.

„One way to construct a model for a set of observable correlations is to exhibit hidden variables with which the observed ones are individually correlated“ (van Fraassen, 1980, p. 31). This citation emphasises the correlation between the observed target and modelled entity. An analogy relation is important to built a model (Duit, 1991). Hence, the modelling process refers to abstraction and concretization (Portides, 2005) as well as idealization and approximation (Portides, 2007) in the context of organising phenomena for a specific purpose (Oh & Oh, 2011). The interrelation between concretization and abstraction or idealization and approximation results from the problem of over-representing (concretization/ idealisation) and under-representing (abstraction/ approximation) empirical phenomena (Woods & Rosales, 2010). Modelling empirical phenomena involves such processes in order to represent the black box of a phenomenon. Furthermore, the construction of a scientific model is an iterative process (Cheng & Lin, 2015; Homer, 1996; van Driel & Verloop, 2002). Although the importance of scientific modelling is generally agreed, there is no commonly accepted guideline or principle rule how to build a scientific model (Morrison & Morgan, 1999). An attempt to visualize the process of modelling is shown in Figure 1.

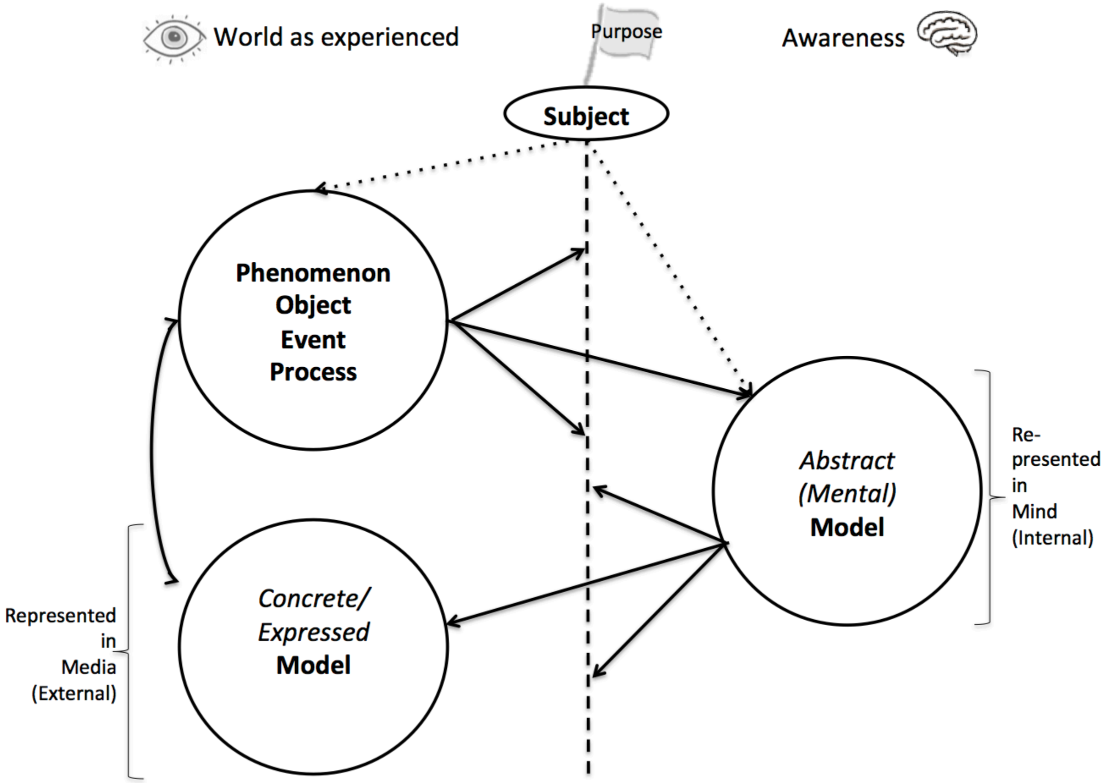


Figure 1. Understanding the model construction according to Steinbuch (1977), Buckley & Boulter (2000) and Stachowiak (1973)

In general, there is an object or a specific phenomenon at the beginning of the modelling process which can be defined as "an event, a change in spacetime, or a series of events that could result from the interaction among the constituents of a particular system and/or among different systems" (Halloun, 2006, p. 4). Science aims to understand the world (Hacking, 1983; Justi & van Driel, 2005). Consequently, the goal of science is to understand the behaviour and properties of scientific phenomena. Analysing them is the main way to gain considerable "insights into potential elements, relations, operations, and rules" (Schwarz et al., 2009, p. 634). Hence, the first step of building a scientific model involves analysing and organising a phenomenon by perceiving the world as experienced. Experimental data provide empirical evidence to support a model (Schwarz et al., 2009). As shown in Figure 1 the model construction depends on the purpose of a subject or scientific community. This part of the modelling process is underlined in Oh and Oh's (2011) definition of a scientific model as a representation of "specific aspects of a target which are selected by a modeller with a certain purpose" (p. 1113) and reflects Stachowiak's (1973) pragmatical characteristic of a model. The arrows in Figure 1 indicate that an abstract mental model as well as the concrete/ expressed model does not relate to all aspects of the world as experienced (Stachowiak, 1973) and "there is no claim that all aspects of the model correspond to 'elements of reality'" (van Fraassen, 1980, p. 31). According to Steinbuch (1977), a mental model is a human instrument like a thinking tool to deal with issues too complex for the human brain, because "human beings do *not* apprehend the world directly; they possess only internal representations of it" (Johnson ‐ Laird, 1980, p. 98). Consequently, mental models are cognitive representations in mind (cf. Carley & Palmquist, 1992; Gilbert, Rutherford, & Boulter, 1998; Johnson ‐ Laird, 1980, 1983) in order "to reason about phenomena, and to describe, explain, predict, and, sometimes, control them" (Boulter & Buckley, 2000, p. 120). Therefore, understanding scientific phenomena depends on getting an access to the phenomena in order to interact with them indirectly (Kozma, 2000). This fact of human's limitation and the resulting mental models support Giere's (1988) view of science as a cognitive activity.

However, mental models involve the problem that they are not fully appreciated by externals or even by the individual itself (Gilbert et al., 1998) because "they do not exist in any reified form" (Jonassen & Henning, 1996, p. 434). Franco and Colinvaux (2000) describe this problem as "mental models involve tacit knowledge" (p.100). In order to communicate and to interact with the mental model an expressed model is verbally, non-verbally or visually articulated (Gilbert & Boulter, 1998; Gilbert, Boulter, et al., 2000; Gilbert et al., 1998). The relationship between a mental and an expressed model is complex and the activity of expressing a mental model into an expressed model changes the mental model by itself (Gilbert, Boulter, et al., 2000). These expressed models "enhance understanding because some part(s) of an everyday object or process resembles some part(s) of a scientific object or process" (Harrison & de Jong, 2005, p. 1136). Hence, they vary in a wide range of types.

According to the modelling framework of Justi and Gilbert (2002a) the modelling process is an iterative cycle. Therefore, the expressed model is empirically tested and optionally modified. As pointed out, the modelling process is affected by the purpose. Consequently, it is limited to this purpose. In the last step scientists or the scientific community test the expressed models to reach a general agreement or disagreement of scientific knowledge construction. If an expressed model gains acceptance, a consensus model results (Gilbert & Boulter, 1998; Gilbert, Boulter, et al., 2000; Gobert & Buckley, 2000). A particular consensus model is a theoretical model as a representation of electro-magnetic lines of force as a human construction to describe a theory (Harrison & Treagust, 1998, 2000b).

The presented modelling process establishes the different modes of representations like abstract, concrete, mental, external, verbally, non-verbally and visually (further modes of representations related to models are discussed in Chapter 0.) and justifies the different types of models like mental, expressed and consensus model. In summary, “a model can be a way to do something as well as being a representation of a familiar or non[-]observable entity“ (Harrison & Treagust, 2000a, p. 355).

2.1.2 The Role of Models in Science Education

In the context of science education further types of expressed models play an important role. These are presented in the different approaches of a typology of models in science education (Coll, 2006; Harrison & Treagust, 1998,2000; Gilbert & Boulter, 1998, Boulter & Buckley, 2000). Particular in chemistry education, models like the atomic, molecular or particle model attract widespread interest in understanding the non-observable entities. In order to represent them, pedagogical analogical or teaching models are used in chemistry lessons which relate to different scientific models as depicted in Figure 2.

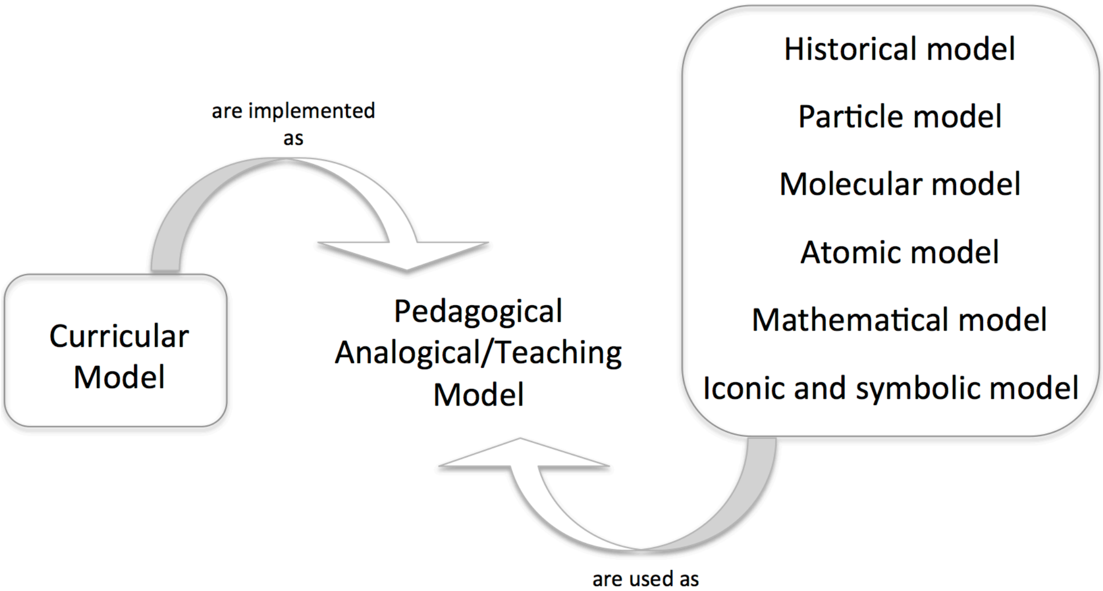


Figure 2. Models in science education according to Gilbert and colleagues (2000)

The educational value of science models and modelling is justified in many science curricula in different countries [Germany: Educational Standards (KMK, 2005; Niedersächsisches Kultusministerium, 2009); USA: A Framework for K-12 Science Education (NRC, 2012)]. These incorporated models are defined as *curricular models*. “That version of an […] scientific model which is included in a formal curriculum, often after some further simplification, is a curricular model” (Gilbert, Boulter, et al., 2000, p. 12). To implement them in science lessons *teaching models* (Gilbert, Boulter, et al., 2000; Gilbert et al., 1998) or *pedagogical analogical models* (Harrison & Treagust, 1998, 2000b) are used in order to simplify the related consensus model and to enhance students’ understanding (Gilbert, 2004; Gilbert & Boulter, 1998). Pedagogical analogical model is analogical models used in teaching and learning processes (Harrison & Treagust, 2000b), while the quality of analogy in an explanatory context relates to “the number […], the similarity […] and […] the conceptual significance of the features compared” (Glynn, 1991, p. 226). An analogical model describes “some material object, system, or process designed to produce as faithfully as possible in some new medium the structure or web of relationships in the original” (Gilbert & Osborne, 1980, p. 4). The purpose of a pedagogical analogical model is to enhance students’ construction of conceptual knowledge. A ball-stick-model is an example for a pedagogical analogical model, because the balls symbolise atoms, the stick represents a bond and it is used to acquire a comprehensive understanding of the molecule concept (Harrison & Treagust, 2000b). Moreover, the ball-stick-model symbolise that there is no directly accessible link between the model and the phenomenon (Boulter & Buckley, 2000). Such models are also defined as molecular models (Francoeur, 1997). Furthermore, in school science lessons the development of an understanding of particles introduces students to the submicroscopic world (Gabel, 1993; Harrison & Treagust, 2002, 2006). Ideas of particles help students to make sense of the macroscopic world (Papageorgiou & Johnson, 2005). *Historical models* are produced in a particular context and are limited to a specific purpose (Gilbert, Boulter, et al., 2000; Justi, 2000). Characteristic examples are the Dalton, Thompson or Bohr atom model. Moreover, iconic and symbolic models like chemical formulae and mathematical models such as the formula of the ideal gas law ($p \cdot V = n \cdot R \cdot T$) are used in science lessons. These models need to be interpreted in a scientific context (Harrison & Treagust, 1998, 2000b). Otherwise, a formula is just a sequence of letters and signs without any directly accessible content. The same applies equally to a ball-stick-model.

According to Hodson (1992), science education has the purpose that students should learn science, learn about science and learn to do science. This goal is closely linked to models and modelling (Justi & Gilbert, 2002b) and involves an understanding of the nature of models and modelling (Gilbert & Boulter, 1998). In the context of learning science students need "satisfactory explanations of phenomena in the world-as-experienced" (Gilbert, 2004, p. 115). Consequently, models function as a bridge between them. As Harrison and Treagust (2000b) point out models are important tools to think and work scientifically. The modelling activity engages students' scientific view about phenomena. Hence, students in science classes have to learn about models and learn how to construct a model (Gilbert & Boulter, 1998). According to many authors (Gilbert & Boulter, 1998; Harrison & Treagust, 2000a; Ramadas, 2009) models and modelling are important to understanding science.

Furthermore, an understanding of scientific models has a positive influence on learning science (Gobert & Buckley, 2000; Gobert & Discenna, 1997; Gobert et al., 2011; Schwarz & White, 2005). Compared to science research in laboratories, many scientific experiments cannot be replicated in science lessons (Harrison & Treagust, 2000b). Accordingly, science education addresses the problem that students develop a "mental model of a phenomenon towards scientists' mental model" (Gilbert & Osborne, 1980, p. 7). Moreover, students in science classes do not develop models to support their own thinking; they are told to create a model. In contrast, scientists reflect a need for creating a model in order to support their thinking process and to share it with the scientific community (Schwarz et al., 2009). Accordingly, much research in recent years has focused on students' difficulties in learning to handle scientific models and be engaged in the modelling process (Cheng & Lin, 2015; Gobert & Discenna, 1997; Grosslight et al., 1991; Harrison & Treagust, 1996; Treagust, Chittleborough, & Mamiala, 2002, 2004).

2.1.3 Recent Research on Models in Learning Science

Students' Difficulties in Understanding Models

The most commonly cited empirical study is "Understanding models and their use in science: Conceptions of middle and high school students and experts" (Grosslight et al., 1991, p. 799). The results of an interview study showed that students' understanding of models can be divided into three levels. The levels differ in the relationship between the world as experienced and the model, the epistemological views about models and their use.

Level 1. Students see models as exact replicas of reality, objects or actions like a "simple copy theory epistemology" (Grosslight et al., 1991, p. 819).

Level 2. Students are aware of the purpose of the modelling construction and the choices made by the modeller. They have the understanding that a scientific model does not have to be an exact copy of a real thing. Yet, students still focus on the relationship between reality and the model instead of also considering a model as an idea.

Level 3. Students show a deep understanding of models. A model is more built in order to develop and test ideas than to provide a replica of a real thing. Moreover, students are aware of the active modeller role.

Thirty-three 7th-grade and 22 11th-grade students from Boston participated in the interview study. Students' had to response to questions such as “What comes to mind when you hear the word ‘model’?” or “What is the purpose of models?” (Grosslight et al., 1991, p. 804). Their answers were analysed according to the different levels of understanding based on six scored dimension (“(a) the role of ideas, (b) the use of symbols; (c) the role of the modeller, (d) communication, (e) testing, and (f) multiplicity in model building” (Grosslight et al., 1991, p. 818)). The results demonstrate that no student achieves level 3 but a development of understanding occurs between the lower- and higher-grade students. While the majority (67%) of 7th-grade students reaches level 1, only 23% of 11th-grade students still remains on this level (Grosslight et al., 1991). Another interview study with 45 UK students from higher education levels obtained similar results related to the use of analogue models (Ingham & Gilbert, 1991). In this study the majority of students sees a “model as a self-consistent system which corresponds to reality“ (Ingham & Gilbert, 1991, p. 197). Treagust and colleagues (2002) developed and evaluated a highly internally consistent paper-pencil test (called SUMS: Students' Understanding of Models in Science) in order to measure students' understanding of “scientific models as multiple representations; models as exact replicas; models as explanatory tools; how scientific models are used; and the changing nature of scientific models” (p. 357). In contrast to the interview study by Grosslight and colleagues (1991), the results of this questionnaire demonstrate that students understand models as multiple representations. However, the questionnaire confirms their view of models as exact copies of a real target. Moreover, the study reveals two apparently contradictory results. On the one hand, students agreed that models are used as a visual representation of something. On the other hand, students agreed that models are used to show an idea. The results suggest students' limited knowledge about the role of models in the development of scientific ideas and theories (Treagust et al., 2002). A further study by Treagust and colleagues (2004) has shown students' insufficient understanding of the predictive nature of teaching models. An empirical study with 402 Taiwanese students confirms previous research results that students have a limited understanding of the nature and purpose of scientific models (Cheng & Lin, 2015). A descriptive interview study indicates students' scientifically unsophisticated view on the relation between their mental model of an atom and reality (Harrison & Treagust, 1996).

Based on the interview questionnaire used in Grosslight and colleagues (1991), Gobert and Discenna (1997) developed a paper- and pencil-test to measure the relation between students' understanding of models and their conceptual knowledge about plate tectonics phenomena in earth science. Hence, 23 students have got a learning task about this phenomenon and subsequently had to apply this knowledge in the paper- and pencil- test. The results suggest that a deeper understanding of the sophisticated epistemology of science involves more conceptual knowledge in students' responses to reason of plate tectonics. Schwarz and White (2005) also indicate the influence of scientific model comprehension on physics content knowledge. Therefore, the understanding of scientific models is important to learn science. However, using models without understanding them, hinders students' ability to understand science (Cosgrove & Schaverien, 1997).

As many research studies have demonstrated, students experience considerable difficulties in understanding scientific models. Students have a limited understanding related to the nature and purpose of scientific models. These difficulties have generated considerable recent research interest in order to promote students' understanding of models.

Promoting Students' Understanding of Models

A national evaluation study investigated the influence of learning about particles on students' understanding of models (Mikelskis-Seifert, 2002). In 12 physics lessons, 120 nine- and ten-graders were taught about models and their specific character as thinking tools. The pre-post comparison considering students' concept maps and multiple-choice tests about particles and models indicates the positive impact of learning explicitly about particles on understanding scientific models (Mikelskis-Seifert & Fischler, 2003a). A further intervention study adapted the learning instruction about particles and investigated the development of the model competence from sixth- to 10th graders. The instructional approach demonstrates the development of understanding scientific models; instead, students have not achieved a great satisfactory level of the model competence (Leisner-Bodenthin, 2006).

An explicit approach focuses on modelling activities considering the "representational assistance", "model pieces acquisition", "model pieces integration", "model-based reasoning" and " reconstruct, reify and reflect"-activity (Gobert et al., 2011, p. 660). Students are supported in using multiple representations, in taking over multiple perspectives of the phenomenon, in combining model components, in making predictions and explanations with a model and in reflecting their modelling activity. This study has shown that engaging model-based learning positively influences students' understanding of the nature of scientific models (Gobert et al., 2011).

The theoretical background underlines the complexity of scientific models. Computer modelling is a powerful tool to understand complex dynamic systems and has a positive impact on solving complex items (van Borkulo, van Joolingen, Savelsbergh, & de Jong, 2012). Moreover, computer modelling influences students' reasoning process positively while doing inquiry activity (Löhner, van Joolingen, Savelsbergh, & van Hout-Wolters, 2005). In a review, de Jong and van Joolingen

(1998) emphasise the importance of instructional support while working with computer simulations.

2.1.4 Implication for Learning Science

Justi and Gilbert (2002a) conclude that a student has to satisfy the following conditions in order to learn scientific models: “an understanding of scientists’ view of the nature of ‘model’; suitable experience of the phenomenon that is being represented; knowledge of why the model was originally constructed” (p. 384). Grosslight and colleagues (1991) pointed out that students’ opportunity of using and designing

> models for multiple purposes may be a natural way to lead them to reflect on a variety of epistemological concerns including the purpose of one’s inquiry, the nature of what one wishes to communicate, explain, or understand, how one is informed, and the interplay between reality and one’s ideas about it. (p. 820)

In other words, students implicitly reflect the nature of a model while learning with models for multiple purposes. In addition, as the results by Treagust and colleagues (2002) demonstrate, there remains a need for making “more use of interpretive and predictive models” (p. 366). Therefore, Schwarz and colleagues (2009) require the use of “the generative nature of models as tools for explaining and predicting” (p. 639). Consequently, Harrison and Treagust (2000b) reasonably request encouraging students “to use multiple explanatory models wherever possible” (p. 1023). These outcomes affect the first implication for learning science that students have to use models for multiple purposes and multiple models for the same purpose. This implication can prevent students’ conception that a model is ‘right’ or ‘wrong’ (Harrison & Treagust, 2000b).

Another consequence arises from Harrison and Treagust (1996), who present a considerable demand for explicitly reflecting and discussing the nature of scientific models. This reflection can be content-specific or in a metacognitive way. Additionally, students need the opportunity to discuss and reflect their modelling process (Schwarz et al., 2009; Schwarz & White, 2005). The demand for scientific knowledge reflection is accepted (Carey & Smith, 1993). Thus, the second implication for learning science can be framed. Students have to explicitly reflect on the nature of scientific models.

Schwarz and White (2005) illustrate the importance of learning about scientific modelling instead of just learning to do scientific modelling. According to the empirical approach by Gobert et al. (2011) to engage students' understanding of the nature of scientific models, students have to be aware of the different aspects in the modelling process. These results provide the third implication for learning science. Students need explicit instruction addressing scientific modelling. Moreover, Prins, Bulte, and Pilot (2011) developed a design principle of modelling for enhancing students' epistemological view on models. They require students' engagement in different authentic modelling practices to foster their epistemological view.

This chapter has underlined the strong relation between scientific models and representations such as abstract, visual or mental. Hence, scientific representations are presented in Chapter 2.2.

2.2 Representation

Representations are generally defined as “something stands for something else” (Palmer, 1978, p. 262) and are used in many fields like linguistics, mathematics, arts or sciences. Accordingly, they have different functions and purposes. An impressionistic painting as a representation in arts pursues another aim than a description of an ion lattice in science. These examples emphasise the most important differences between representations in sciences and in other fields. In science, representations can be non-natural representations, which “are produced by human beings for the purpose of communicating something” (Callender & Cohen, 2006, p. 5). In general, “a representation is a likeness or simulation of some idea, concept, or object” (Rapp & Kurby, 2008, p. 31) and can be summarised as an artefact (van Fraassen, 2008). This definition indicates the ambiguity and the complexity of the concept of representations because many different terms are related to representations. Furthermore, many related adjectives like mental, internal, physical, external, symbolic, mathematical, abstract, visual, iconic, pictorial, graphical, verbal and gestural (cf. Boulter & Buckley, 2000; Callender & Cohen, 2006; Chandrasegaran et al., 2008; Chandrasegaran, Treagust, & Mocerino, 2009; Gilbert, Boulter, et al., 2000; Johnstone, 1982) underline representations as “a loose system of distinctions and classifications” (Palmer, 1978, p. 261).

2.2.1 Definition and Categorisation

“Scientists, a scientific group, or a larger scientific community […] use X to represent some aspect of the world for specific purposes” (Giere, 2004, p. 743) while X can be different media of representations such as pictures, graphs, diagrams, scientific models or theory (Giere, 2004). For example, salt or sodium chloride can be an experienced phenomenon *(aspect of the world).* In order to predict what properties salt will have or to explain why salt will have these properties *(specific purpose)*, X can be used like a ball-and-stick version of an ion lattice *(X as representation).* “To present a theory is to specify a family of structures, its models; and secondly, to specify certain parts of those models (the empirical substructures) as candidates for the direct representation of observable phenomena" (van Fraassen, 1980, p. 64). Therefore, a scientific representation is considered as the relationship between real entities on which scientists focus and its representation (Suarez, 2003). Nevertheless, scientific representations are necessary to communicate ideas about the world (Cartwright, 1999). Representing the world is one of the most important aims of sciences (Hacking, 1983; van Fraassen, 1980).

The most obvious distinction can be made between internal versus external (J. Zhang, 1997) or mental versus physical (Paivio, 1990) representations. "By creating external structure that anchors and visually encodes our projections, we can push further, compute more efficiently, and create forms that allow us to share thought" (Kirsh, 2010, p. 454). By saying this, the author emphasises the function of a representation as a helping tool. In contrast to external representations "internal representations are the knowledge and structure in memory, as propositions, productions, schemas, neural networks, or other forms" (J. Zhang, 1997, p. 180). Furthermore, the classification of representations is closely related to the variety in concreteness and abstractness (Paivio, 1990). For example, a photo of salt is a concrete external representation compared to *NaCl* as chemical formulae.

In summary, according to the different terms such as 'concrete', 'abstract', 'internal', 'mental' or 'external' the nature and purpose of the representation changes. In addition, the different examples suggest the closed link to scientific models.

2.2.2 Relation to Models in Science Education

"Scientists use models to represent aspects of the world for various purposes" (Giere, 2004, p. 747), for example to build a bridge between theory and the world as experienced (Gilbert, 2004). Although scientific models can be described as representational tools in science, they do not themselves represent any aspects of the experienced world. Consequently, "it is not the model that is doing the representing; it is the scientist using the model who is doing the representing" (Giere, 2004, p. 747). Furthermore, the representational function of a model is just one of multiple functions. Scientific “models are representations of a selected part or aspect of the world“ (Frigg, 2006, p. 50). This model can be expressed in different modes of representation: concrete, verbal, mathematical, visual, symbolic and gestural (Gilbert, Boulter, et al., 2000). A ball-and-stick model provides a concrete analogy between balls and atoms as well as bonds and sticks but it still represents a non-observable abstract entity (see Chapter 2.1.2; Harrison & Treagust, 1998). The verbal mode is related to models expressed in speech or in written form (Boulter & Buckley, 2000; Gilbert, Boulter, et al., 2000). Mathematical models are represented in formulae and equations, which depict a conceptual relation (Harrison & Treagust, 1998, 2000b). The visual or pictorial mode (cf. Twyman, 1985) includes models that can be observed like maps or diagrams (Boulter & Buckley, 2000; Gilbert, Boulter, et al., 2000; Harrison & Treagust, 1998). Chemical formulae are symbolic models which are embedded in the specific chemical language (Harrison & Treagust, 1998, 2000b). The gestural mode means to express a model in action (Gilbert, Boulter, et al., 2000) like the representation of particles’ movement by students running across the classroom. Expressed models are often considered on multiple representation modes. Hence, Boulter and Buckely (2000) use mixed modes of representation to classify them: concrete mixed, verbal mixed, visual mixed, mathematical mixed and gestural mixed. For example a concrete model can also include visual or verbal modes.

In summary, scientific models are related to different modes of representations. Consequently, scientific models relate to representations. A mental model is an internal representation (Collins, 1987; Gentner & Gentner, 1983; Gentner & Stevens, 1983) and an expressed model is an external representation (Gilbert & Boulter, 1998; Gilbert & Osborne, 1980), but in general a representation does not have to be a scientific model. Figure 3 shows external representations which are just representations (e.g., a photo) and modelled representations (e.g., an illustration of an ion lattice). The photo of sodium chloride is not a scientific model compared to the illustration of the ion lattice.

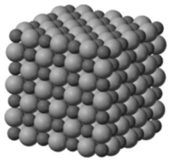
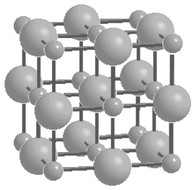
World as perceptibly modelled (External Representation)		**World as scientifically modelled** (External Representation)	
	A photo of sodium chloride		A submicroscopic representation of sodium chloride Balls represent ions
	A photo of a sodium chloride crystal		A submicroscopic representation of sodium chloride Balls represents ions, sticks are only used to represent also the insight

Figure 3. External perceptibly modelled and scientifically modelled representations

As depicted in Figure 3, an external representation can be scientific or just experienced in nature. In the science classroom, students often have to write an experimental protocol in which they have to represent the experimental setup. This kind of representation such as a photo or a drawing is not a scientific model. In contrast, if students are asked to explain the properties of sodium chloride, they need scientific representations such as an expressed model of an ion lattice. Moreover, if an internal representation is scientifically represented than it is also a mental model compared to a cognitive representation such as a picture in mind of the phenomenon.

In addition to the visual, verbal or concrete modes and forms such as a photo or a drawing, macroscopic, submicroscopic and symbolic representations are a key issue in science, particularly in chemistry. This triplet relationship of representations is also well known as Johnstone's chemical triangle (Johnstone, 1982, 1993).

2.2.3 Johnstones' Chemical Triangle

Johnstone's chemical triangle has attracted wide spread interest in science and especially in chemistry education research for more than 30 years (Bucat &

Mocerino, 2009; Champagne, Halbwachs, & Meheut, 1983; Chandrasegaran, Treagust, & Mocerino, 2007; Chandrasegaran et al., 2008, 2009; Chittleborough & Treagust, 2007; Closset, 1983; Davidowitz & Chittleborough, 2009; Stains & Talanquer, 2007; Talanquer, 2011; Treagust, Chittleborough, G., Mamiala, T. L., 2003; Wu, Krajcik, & Soloway, 2001; Wu & P. Shah, 2004). Johnstone's "Macro- and Microchemistry" (1982) describes the view on chemistry at the following three levels.

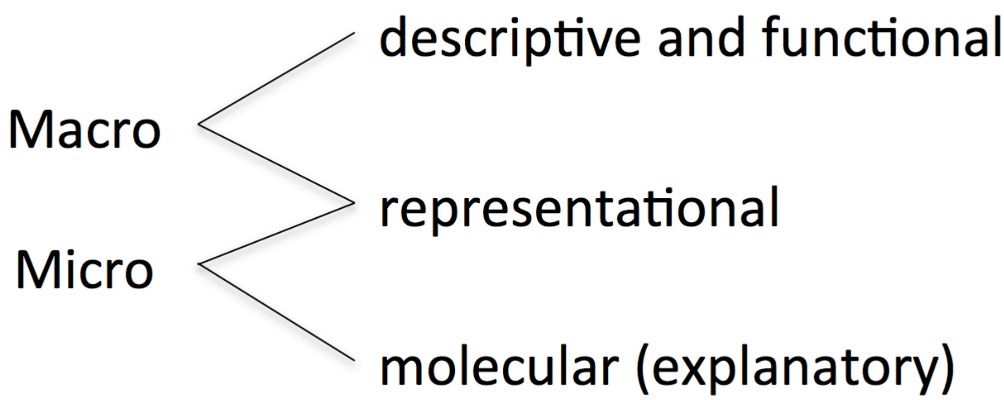


Figure 4. First version of Johnstone's chemical triangle (1982, p. 378)

The macroscopic level includes all directly accessible properties such as colour, temperature, etc. It aims to describe the material and its properties as well as property changes caused by the conversion of one material into another. Thus, this level can be called descriptive and functional. The representational level relates to the macro- and microscopic because it tries to represent the material and its changes by chemical formulae and equations. The molecular level considers explaining the behaviour of chemical substances by using atoms, molecules, ions, etc. Accordingly, it can also be called the explanatory level. These levels of chemistry are important for understanding, but they are difficult to separate (Johnstone, 1982). In Johnstone's later versions he defines the levels as macroscopic, submicroscopic and representational (Johnstone, 1993, 2000a, 2000b) as the following triangle displays visually.

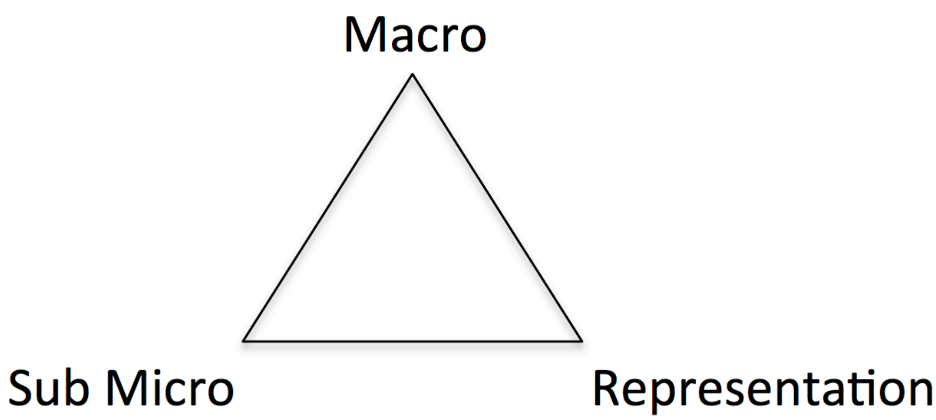


Figure 5. Johnstone's chemical triangle (Johnstone, 1993, p. 703)

These levels form the basis of chemistry: "the macrochemistry of the tangible, edible, visible; the submicrochemistry of the molecular, atomic and kinetic and the representational chemistry of symbols, equations, stoichiometry, and mathematics" (Johnstone, 1993, p. 702). Chemists can easily operate within this triangle, but this relationship makes chemistry difficult to learn for students (Johnstone, 1993).

As a consequence of widespread research interest, these representations are used and developed in various ways and linguistic terms (cf. world of chemistry, phenomenological type or molecular, atomic or symbolic, representational). Gabel (1999) uses the term *symbolic* instead of *representational*. De Jong and van Driel (2004) replace *submicro* with *microscopic* and *representational* with *symbolic* representations. All these changes are made without considerable justifications. Gilbert and Treagust (2009a) consider the ambiguous meaning of the term 'level'. They prefer the term 'type' in order to easily discuss the macroscopic, submicroscopic and symbolic representations and "the word 'level' is more useful when discussing the cognitive relationship between all three" (p. 346). The meaning of the term 'level' can relate to scale, size or measure as well as a change from concrete to abstract mode. Rappaport and Ashkenazi (2008) share this point of view of concreteness and abstraction while macroscopic representations are more concrete than submicroscopic and symbolic representations. For example, the colour of macroscopic objects makes them more concrete compared to colourless atoms. A considerable difference arises from the fact that “submicro particles do not inherit the macro-level properties of the substance, but rather the properties of the substance arise from interactions of the particles” (Rappoport & Ashkenazi, 2008, p. 1588). Accordingly, these authors attempt to link the meaning of ‘level’ to the origin of the chemical triangle in the following way. To avoid problem with the term ‘level’, the term ‘domain’ is used. In Figure 6 the different adaptions of the chemical triangle are presented.

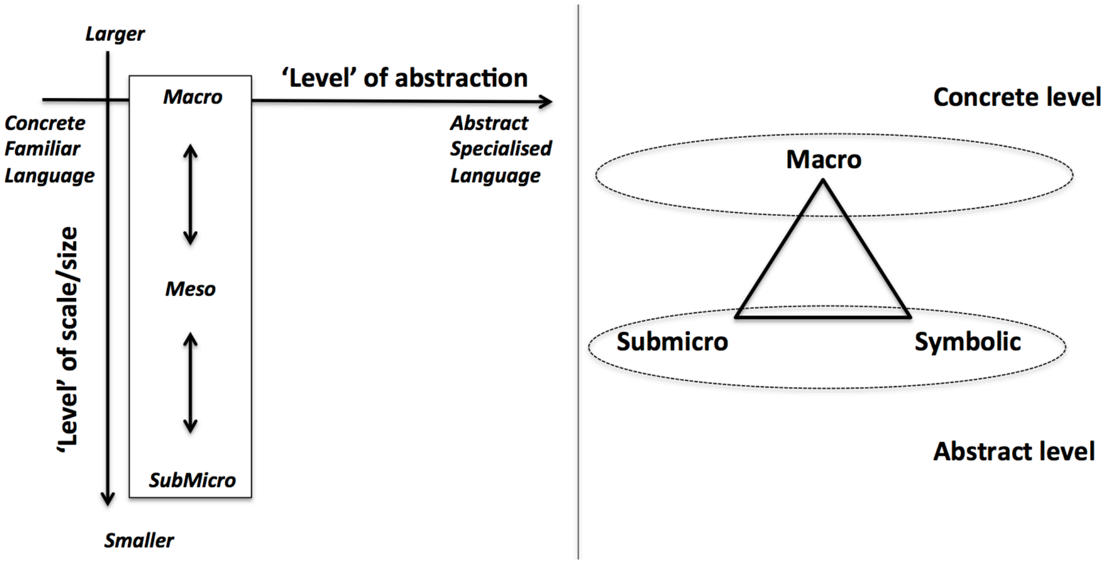


Figure 6. Integrating meaning of level (Gilbert & Treagust, 2009a, p. 347; Rappoport & Ashkenazi, 2008, p. 1587)

This fuzziness of terms address different difficulties and cause problems in understanding the nature of a representation: “In which way can the macro level, of the things that are visible and tangible, be called a “representation”?” (Talanquer, 2011, p. 181). To avoid these problems, the following differentiated framework of the chemical triangle has been developed based on the considerations by Dettweiler and Fechner (2014).

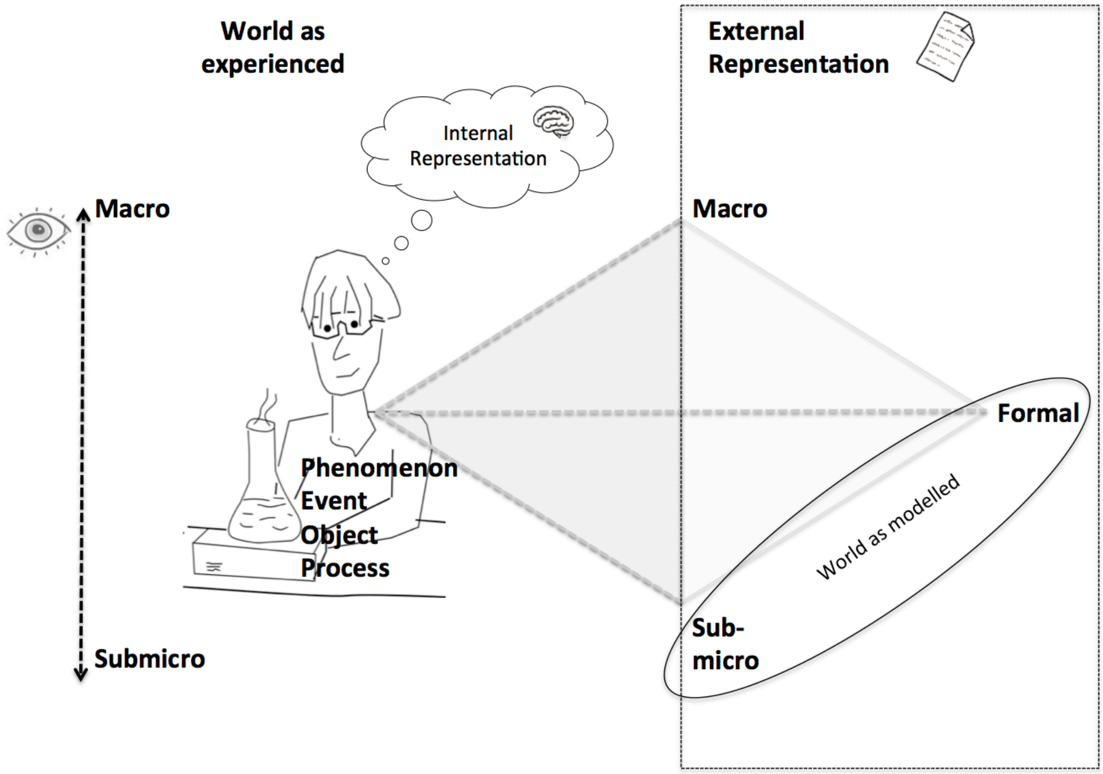


Figure 7. Development of Johnstone's chemical triangle (1993)

The most important aspect of Figure 7 is the distinction of the observable phenomenon, event, object or process and the external representation of it. The development of this framework was stimulated by a realist view of science. Hence, the world as experienced can be understood as a scale from macroscopic to submicroscopic. An atom probably exists; yet, humans are not able to see it. Further, this figure emphasises the difference between mental and external representations. As it points out, submicroscopic and formal representations are related to scientific models (cf. 2.1.1). The term 'symbolic' (cf. de Jong & van Driel, 2004; Gabel, 1999) or as Johnstone (1993) called this type 'representational' was intentionally omitted from this approach to avoid problems like 'What is a symbol?' or 'What is representational compared to submicroscopic?'. Furthermore, external representations can take several different forms like a picture of an experiment considering the macroscopic domain or a description of an atomic model considering the submicroscopic domain or a chemical equation considering the formal domain. Furthermore, representations are related to different modes like verbal, visual, mathematical, etc. Moreover, the term 'level' is intentionally excluded from Figure 7.

In summary, Table 1 according to Boulter and Buckley (2000), and Harrison and Treagust (2000b) classifies the differently presented terms including representation type, representation form and representation mode. However, there is no claim that Table 1 is completed.

Table 1. Classification of the relationship between representation type, form and mode

Type	Form	Mode	Example
Macroscopic	Photo	Visual	Photo of an experimental setup
	Video		Video of an experiment
	Drawing		Drawing of an experimental setup
	Scale model	Concrete	Model of an extinguisher
	Description	Verbal	Description of observation
Submicroscopic	Theoretical model	Abstract	Orbital model
	3D-Model	Concrete	Ball-and-stick model
	Analogy/ Description	Verbal	Description of the ion lattice
	Animation	Gestural	Particles movement represented in students' movement
		Visual	Particles movement represented in computer-based animation
Formal	Chemical equation/ formulae	Formal	$Zn \rightarrow Zn^{2+} + 2e^{-}$
	Mathematical equation/ formulae	Mathematical	$p \cdot V = n \cdot R \cdot T$

Ainsworth (1999, 2006) describes the different forms related to the modes of representations as multiple representations. The specific characteristics of the three representation domains are their relation to reality. While macroscopic and submicroscopic things can relate to real entities as well as to the representation domain, the term 'formal' is strongly linked to representation as Figure 8 demonstrates. Formal representations are a construct of scientists. They are not real.

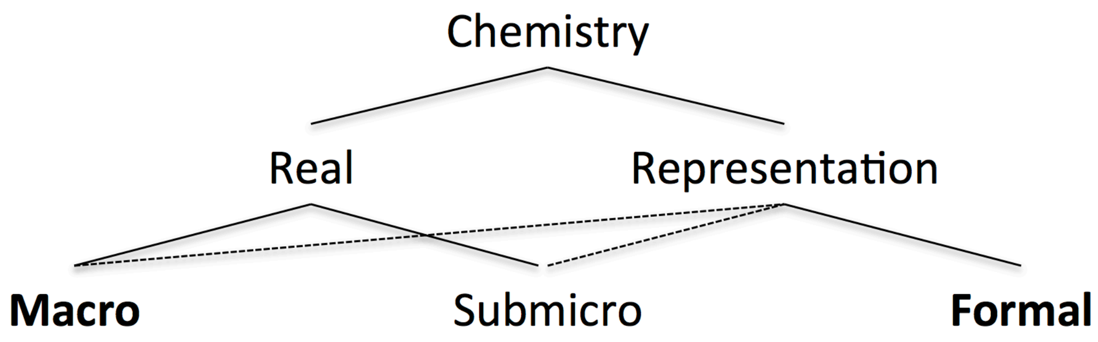


Figure 8. Relationship between reality and representation in chemistry (according to Davidowitz & Chittleborough, 2009, p. 172)

2.2.4 The Role of Representations in Science Education

The triplet relationship is a challenging area in learning chemistry and especially in chemistry because of the key role of chemical formulae and symbols as part of the chemical language. According to Schwartz, Ben-Zvi, and Hofstein (2006) chemistry is an experimental discipline which aims "to explain macroscopic phenomena in terms of the molecular structure of matter" (p.206). Another characteristic of chemistry is the use of the specific language, called "Lingua-Chemica" (Taber, 2009, p. 78). Considering these ideas as part of chemistry literacy the triplet relationship is attracting much attention. Related to the presented framework (see Figure 7) students should complete a hands-on activity in the world as experienced because chemistry is an 'experimental discipline'. They should then explain this phenomenon by using submicroscopic and formal representations to acquire understanding. Understanding chemical concepts like the idea of particulate matter of nature, compounds or chemical bonding involves scientific modelling and hence, scientific representations (Gilbert & Treagust, 2009b).

Explaining macroscopic phenomena at the corresponding explanatory level is a significant challenge in chemistry education (Bucat & Mocerino, 2009). Using different types of representations includes confining attention to language: Water is not polar as well as the water molecule is not polar, but the bonding between an oxygen-atom and a hydrogen-atom in the water molecule is polar. In the context of engaging in authentic science within a realist view (Gilbert, 2004) students should develop scientific models to represent the ‘reality’ of atoms, electrons, etc. in order to be able to explain the related phenomenon (Bucat & Mocerino, 2009). This challenge is well visualized in a ladder as metaphor for the relation between macroscopic and submicroscopic (van Berkel, Pilot, & Bulte, 2009).

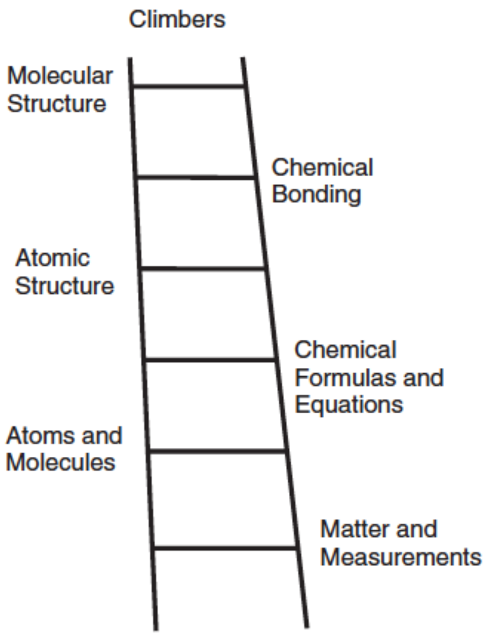


Figure 9. Students’ challenge in understanding the relation between macroscopic and submicroscopic (van Berkel et al., 2009, p. 32)

Students have to climb this ladder during their chemistry school career (van Berkel et al., 2009). While matter and measurements relate to macroscopic entities, and atoms, molecules, atomic structure, chemical bonding and molecular structure to submicroscopic representations, chemical formulas and equations are considered as formal representations. The formal language is a distinctive factor in chemical communication and is part of the specific language. Chemical symbols can represent macroscopic as well as submicroscopic entities (Taber, 2009). Especially in chemical equations, letters are used to symbolize observable physical states such as ‘s’ for solid and ‘Zn’ for zinc atom or for the substance zinc. A chemical equation also describes the interaction of particles. However, a mathematical equation rarely relates to particles (Rappoport & Ashkenazi, 2008). Moreover, the subscript and the stoichiometric coefficient in chemical equations play an important role in understanding a chemical equation. ‘O_2’ represents ‘<O=O>’ or an ‘oxygen molecule’ or the ‘substance oxygen’. The subscript number ‘2’ indicates that it is a diatomic molecule. A stoichiometric coefficient in front of the chemical formula specifies the relation of atoms, molecules, ions, etc. participating in the reaction.

However, understanding science involves more than just one form of representation. The interaction with multiple representations is a challenging area in learning scientific concepts (Ainsworth, 1999, 2006). However, it is widely agreed that multiple representations can support learning science (Kozma, 2000, 2003; Kozma, Russell, Jones, Marx, & Davis, 1996).

2.2.5 Recent Research on Representations in Learning Science

Students’ Difficulties in Understanding Representations

In recent years, much research has focused on students’ understanding the triplet relationship of representations. The results indicate learners’ difficulties (Ben-Zvi et al., 1987; Chittleborough & Treagust, 2007, 2008; Davidowitz & Chittleborough, 2009; Hinton & Nakhleh, 1999; Jaber & BouJaoude, 2012; Kozma & Russell, 1997; Nurrenbern & Pickering, 1987; Pickering, 1990; Rappoport & Ashkenazi, 2008; Tan, Goh, Chia, & Treagust, 2009; Treagust, Chittleborough, & Mamiala, 2003).

As a part of the examination at university, three hundred thirty-one students from five different courses were asked to answer multiple-choice questions regarding traditional conceptual stoichiometric representations of gases as well as traditional mathematical questions on gas laws. Students are able to solve gas laws problems, but they fail in understanding the chemical change of gases at the submicroscopic domain (Nurrenbern & Pickering, 1987). A replication of this study with 101 different students showed similar results. Students have the ability to solve a problem mathematically without deep understanding of submicroscopic reality (Pickering, 1990). Krajcik’s (1991) description of students’ understanding of chemical equations support these results: “Most students master the technique of balancing a chemical equation [… like a] mathematical puzzle […, but] seldom are students challenged to explain the chemical process expressed in the equation" (Krajcik, 1991, p. 119). There is lack of interpretation in the submicroscopic domain.

In Kozma and Russell's (1997) study, ten undergraduate students were videotaped while forming meaningful groups of various representations and transforming one representation into another representation. The results show that students build groups corresponding to common surface characteristics instead of considering underlying concepts and principles. In addition, students demonstrate limited ability to transform different representations, especially transferring animations into another symbol system.

Hinton and Nakhleh (1999) conducted an intensive interview with six students from the first semester of a single chemistry course in order to investigate their conceptual understanding of the stoichiometry of chemical reaction and their use of representations. The results indicate the students' ability to formulate chemical reactions of macroscopic phenomena and to balance chemical equations mathematically. In contrast, students' difficulties lie in representing polyatomic ions at the submicroscopic domain. Moreover, students use submicroscopic terms such as molecule or ion inadequately.

Brosnan and Reynolds (2001) indicate students' difficulties in macro-micro explanations according to their length of time in science education. 82 students from age 11 to 15 were prompted in a first step to decide if a computer-generated sentence makes sense and in a second step to explain its chemical content. Eleven-year old students do not separate macroscopic and submicroscopic entities like substances or atoms. In contrast, most of 17-year old participants are aware of these differences, but it should be noticed that these students were recruited from an advanced chemistry level courses. Students in age between show both: limited macroscopic understanding and the beginning of making difference between macro- and submicroscopic entities.

Rappoport and Ashkenazi (2008) investigated students' use of representations as well as their ability to connect different representations while solving conceptual problems. In a think-aloud protocol interview, ten students from different educational levels were asked about the ideal gas equations in different representation domains. The results demonstrate that students never use submicroscopic representations alone. They are always connected to other types of representations. Furthermore, students focus on describing the variables while explaining the meaning of the mathematical equation of ideal gas law without integrating the different representation types. In general, students prefer macroscopic and formal representations in explaining chemical conceptual problems. The transfer from formal representation to submicroscopic representation is more frequent than the transfer from macroscopic to submicroscopic.

In Singapore, a multiple-choice diagnostic instrument (QADI), which was conducted with 915 students confirms students' difficulty in understanding "the interactions involved in qualitative analysis at the sub-microscopic level as well as the symbolic representations of these interactions" (Tan et al., 2009, p. 139). Another diagnostic test instrument investigated 145 college students' understanding of sugar solution in macroscopic and submicroscopic ways. The results demonstrate their limited comprehension of the particulate nature of matter. Moreover, students are more able to answer verbally presented questions than questions involving submicroscopic visualizations (de Berg, 2012). A paper-and-pencil test in which students were prompted to represent the three states of water confirms their problems in understanding the particulate nature of matter (Pereira & Pestana, 1991).

As a part of a broader intervention study, Jaber and BouJaoude (2012) illustrate students' ability to interpret chemical reactions at the macroscopic domain by describing property changes phenomenologically. In contrast, students show macroscopic/ submicroscopic confusion while explaining a chemical reaction at the submicroscopic level. Furthermore, students' difficulties at the submicroscopic and symbolic level are related to their unsophisticated understanding of the nature and purpose of scientific models.

The overall result of these empirical studies indicates students' lack of ability to relate, connect or transfer the three levels of representations. Moreover, submicroscopic representations, as well as the distinction between 'reality' and its representations cause particular difficulties. Bucat and Mocerino (2009) argue that "students' sense-making operates on representations, rather than on the sub-microscopic 'reality' that they represent" (pp. 25-26).

Promoting Students' Understanding of Representations

In general approaches, constructing external representation is important to promote students' understanding of science. Self-made drawings can support the modelling process (Leenaars, van Joolingen, & Bollen, 2013). Quillin and Thomas (2015) underline the importance to support students to draw. Moreover, drawings are an important tool to learn to represent science and therefore, to enhance understanding of representations (Ainsworth, Prain, & Tytler, 2011).

As a consequence of students' difficulties in understanding the triplet relationship of the three representations, recent research has been conducted to improve the understanding. Instructional approaches were adopted, such as computer-based learning tools to visualize the interaction between atoms, ions and molecules (Kozma, Chin, Russell, & Marx, 2000; Kozma & Russell, 1997). Simulation-based learning environments have the benefit to represent phenomena dynamically in the different representation domains. Consequently, representations influence the modelling process (Löhner, van Joolingen, & Savelsbergh, 2003). An intervention study shows the significant positive influence of integrated, dynamically linked representations on students' learning outcome, compared to non-linked or dynamically linked representations (van der Meij & de Jong, 2006). Another computer-based learning environment focuses on multi representational levels of chemical concepts like Real lab representations, virtual animations and submicroscopic models in the context of chromatography. The results of the evaluation study with 237 undergraduate students suggest the improvement of students' cognitive reasoning skills (Marson & Torres, 2011).

In an action research approach by Justi, Gilbert, and Ferreira (2009), a model-based teaching sequence for chemical equilibrium was used to support activities related to the nature and purpose of scientific models and scientific modelling. 26 students were taught in this way over six lessons. A questionnaire, videotaped classroom observation and audiotaped group discussions during the activities evaluated the teaching sequence. The results indicate that this sequence "enabled the students to demonstrate their capability within and between the three levels of representation" (Justi et al., 2009, p. 304).

A recent study investigated the influence of the order of multiple representations (concrete, abstract) on students' understanding of phase change (Lin, Son, & Rudd, 2016). One hundred-seven students from an introductory psychology course participated in the intervention considering different instructional videos. In a pre-post procedure, students' ability to translate between the triplet relationship of representations (marcoscale, nanoscale, symbolic) was assessed by a paper-pencil-test in order to answer the research question whether the order of different representations has an influence on learning. The instructions follow different directions from concrete to abstract or from abstract to concrete representations. The results show no significant effect between the different groups. There is a tendency that students are more able to answer concrete-to-abstract questions than abstract-to-concrete questions. The difference is significant compared to the pre-test results. This study has shown that the order of different representations involving macroscale, nanoscale and symbolic representations has no influence on students' understanding. Nevertheless, the results show that multiple representations foster students' ability to transfer between representations (Lin et al., 2016).

Therefore, a macro-micro-symbolic teaching approach (Jaber, 2009; Jaber & BouJaoude, 2012) generates considerable interest. This instruction considers the nature of chemical knowledge and modelling in order to enhance students' relational understanding of chemical reaction focusing on the use of and interplay between different representation types. Therefore, this study aimed to answer the research question if

> a student-centered pedagogical approach that: (1) focuses on the interplay between the macro, the micro and the symbolic levels, (2) integrates the use of various schematic representations, and (3) teaches explicitly with and about models, improves students' conceptual understanding of chemical reactions as compared to other student-centered teaching approaches. (Jaber, 2009, p. 9)

This study was conducted in an experimental-control-group design with 46 students who were taught in their normal classes. The intervention took five weeks with four hours of chemistry lessons per week. Several chemical reactions such as the reaction of hydrochloric acid and silver nitrate built the content of the intervention. A pre-post comparison indicates that students from the experimental group can build a better link between the different representation levels as well as a better relational understanding of chemical reaction compared to students from the control group. This study has the limitation of identifying which factor affects the positive development of conceptual understanding. Therefore, research should focus on the "factors such as the interplay between the macro, micro, and symbolic levels, the use of various schematic representations, and explicit teaching with and about models" (Jaber & BouJaoude, 2012, p. 993).

However, the presented research results have addressed the problem of students' understanding and using the different representations. Moreover, they indicate the positive impact of learning instructions on conceptual understanding.

2.2.6 Implication for Learning Science

Treagust and colleagues (2003) demonstrate the role of submicroscopic and symbolic representations in chemical explanations. The authors illustrate the importance of the simultaneous use of symbolic and submicroscopic representations to enhance relational understanding. The relationship between the phenomenon and its explanatory symbolic and submicroscopic representations should be explicitly discussed. In a further case study, the researchers requires students' "practice in the application of multiple representations of chemicals and their interactions" (Chittleborough & Treagust, 2007).

The results of the intervention study from Jaber and BouJaoude (2012) highlight the importance of students' "appreciation of the epistemological and ontological nature underlying the structure of chemical knowledge" (p. 993). Furthermore, metacognitive reasoning can support students in integrating macroscopic, submicroscopic and formal representations to develop relational understanding.

Kozma, Chin, Russell and Marx (2000) conducted an observational study on the use of representations of professional scientists. They concluded that science class should provide the opportunity for making "explicit connections across representations that convey relationships between different representations and between symbolic expressions and the phenomena they represent" (Kozma et al., 2000, p. 136). Accordingly, Kozma (2003) suggests three design principles for the use of representations based on previous empirical research:

- Provide at least one representational system that has features that explicitly correspond to the entities and processes that underlie physical phenomena.
- Have students use multiple, linked representations in the context of collaborative, authentic, laboratory investigations.
- Engage students in collaborative activities in which they generate representations and coordinate the features of representations to confirm and explain the findings of their investigations. (p. 213)

From Hinton and Nakhleh (1999), implications for chemistry education arise that students need the opportunity to use multiple representations to become aware of them. Lin and colleagues (2016) confirm this implication. According to the authors, “for any approach, MR [Multiple Representation] instruction should explicitly teach translation between representations in multiple directions to develop more symmetric understanding and translation ability” (p. 658). Tytler and Hubber (2016) developed the representation construction pedagogy in order to design principles for teaching. These principles include *inter alias* justifying the representational nature of key concepts, demonstrating the need for representations, explicitly discussing representations in order to provide meaningful learning. Students should develop an understanding of a representational need while making sense of macroscopic phenomena. Accordingly, they have to recognise their perceptible limitations. Meaningful learning means to trigger hands-on activity to “allow constant two-way mapping between objects and representations (Tytler & Hubber, 2016, p. 164).

In summary, there remains a need for a learning environment focusing on explicitly discussing and reflecting representations in order to foster students’ awareness of representations.

2.3 Scientific Meta-Knowledge

National standards like the American K-12 framework (NRC, 2012) underline the importance of the nature of science in understanding the characteristics of scientific enterprise. The German educational standards do not explicitly require the support of the nature of science, but teaching the scientific enterprise and modelling (KMK, 2005). These curricular goals include the understanding of the nature of scientific knowledge (Carey & Smith, 1993).

> Scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), and subjective (involves personal background, biases, and/or is theory-laden); necessarily involves human inference, imagination, and creativity (involves the invention of explanations); and is socially and culturally embedded. (Lederman, 2007, p. 833)

McComas, Clough and Amazaroa (1998) confirm his view on the nature of scientific knowledge. To understand scientific knowledge and scientific enterprise White and colleagues (2011) demand students' development of meta-knowledge about science. According to these authors, scientific meta-knowledge includes knowledge *about* scientific models, its representation and theory.

2.3.1 Meta-Modelling Knowledge

Meta-modelling knowledge is defined as knowledge *about* scientific modelling with regard to the nature and purpose of scientific models. This epistemological knowledge relates to understanding how models are built as well as how and why they are used (Schwarz et al., 2009; Schwarz & White, 2005). Moreover, "meta-modelling knowledge focuses on the nature and purposes of models, strengths, and limitations of different models, the evidence-based nature of models, and the importance of change and revision in modelling" (Bamberger & Davis, 2013, p. 215). Therefore, meta-modelling can also be understood "as a technique in which modelling knowledge can be expressed" (Dominguez, Zapata, & Rubio, 1997, p. 319).

Furthermore, Schwarz and colleagues (2009) underline the powerful link between meta-modelling knowledge and the modelling practice. Students should learn to model "as powerful tools and practices for advancing our knowledge about the world" (Schwarz et al., 2009, p. 636). The components of meta-modelling knowledge are summarised in Table 2.

Table 2. Components of meta-modelling knowledge according to Schwarz and White (2005) and Schwarz et al. (2009) based on chapter 2.1.1 (Gilbert & Boulter, 1998; Justi & Gilbert, 2003b)

Component	Content
Nature of models	Representation of non-visible entities (objects, events, processes, ideas) Limited representation Constitution of empirical- or theoretical-based entities Mental representation Generative tools
Purpose of models/ Uniqueness	To predict phenomena To explain phenomena To illustrate/ visualize phenomena in order to enable a person to 'see' non-visible entities To communicate abstract scientific knowledge To think and work scientifically To support creation of new ideas One Model for different purposes (Multiple purpose) Different models for one purpose (Multiple model)
Criteria for evaluating and revising	Relevant to purpose of a model Based on consensus among the scientific community

These dimensions of meta-modelling knowledge are important to understanding scientific models and modelling and enable "students to develop accurate and productive epistemologies of science" (Schwarz & White, 2005, p. 167). Consequently, meta-modelling knowledge plays a key role in learning science.

2.3.2 Meta-Representational Knowledge

According to meta-modelling knowledge, meta-representational knowledge can be defined as knowledge *about* scientific representations (diSessa, 2004; diSessa & Cobb, 2004; diSessa & Sherin, 2000). Further, diSessa and Cobb (2004) require meta-representational competence to „[…] create, critique, and adapt a very wide range of effective scientific representations“ (pp. 88-89). Hence, meta-representational competence can be described as “the full range of capabilities that students (and others) have concerning the construction and use of external representations” (diSessa & Sherin, 2000, p. 385). Gilbert and Eilam (2014) summarise the meta-representational competence as understanding the nature and different modes of external representations like verbal, concrete/ material, visual, gestural or symbolic, to translate different representations, to construct a representation and to solve problems by using suitable representations. Tytler and Hubber (2016) drew a similar conclusion. According to these authors, students should develop

a) “explicit knowledge of representational form and function,
b) knowledge of representational quality and the selective nature of representations, and
c) skills in coordinating multiple representations in problem solving” (Tytler & Hubber, 2016, p. 159).

Although Gilbert (2005) does not directly relate to the term ‘meta-representational’, he considers “metacognition in respect of visualization” (p. 15) as meta-visualization in a similar way compared to meta-representation. Davidowitz and Chittleborough (2009) attach considerable significance to students’ meta-visualization skills in order to understand abstract and difficult submicroscopic representations. Submicroscopic entities demand students’ ability of imagination and visualization (Bucat & Mocerino, 2009). In summary, the conventions of representation, the scope and limitations of representations as well as visualization skills are important to acquire meta-representational competence.

2.3.3 Relation to Metacognition

The nature of the term ‘meta’ might evoke a link to metacognition (cf. diSessa & Sherin, 2000). There is no empirical evidence that there is a link between meta-scientific knowledge and metacognition in general. The structure and kind of knowledge about metacognition evoke a reasonable assumption about this relationship. Furthermore, the development in scientific thinking "[...] might be characterised as the achievement of increasing cognitive control over the coordination of theory and evidence. This achievement, note, is metacognitive in nature because it entails mental operations on entities that are themselves mental operations" (Kuhn & Pearsall, 2000, p. 115). However, the prefix 'meta' has controversially been discussed in terms of metacognition.

> When faced with terms such as metalearning, metamemory, metaattention, metacomprehension, metalinguistics, etc., the dubious reader may wonder why the meta need be added. The addition can be defended if at all, only if it reflects a real change of emphasis - -which we believe it does. (Brown, 1978, p. 84)[1]

According to the origins of metacognition by Flavell (1976, 1979), "metacognition is usually defined as knowledge and cognition about cognitive objects, that is, anything cognitive" (Flavell, 1987, p. 21) and can be summarised as knowledge about one's own thinking (Brown, 1978). Metacognition consists of different dimensions like metacognitive knowledge (Flavell, 1979) and metacognitive regulation considering executive strategies such as planning, monitoring and evaluating thinking processes (Brown, 1978). Flavell (1987) understands any kind of monitoring as a form of metacognition. Referring to Pintrich (2002), planning one's own cognition means to set subgoals, monitoring intends to ask yourself questions while doing an activity and evaluating suggests to subsequently control activity and if necessary to improve processes. Moreover, metacognitive knowledge contains three different subcategories: declarative, conditional and procedural (Jacobs & Paris, 1987). Declarative knowledge includes "what is known in a propositional manner" (Jacobs & Paris, 1987, p.257). Schraw (1998, p. 114) describes the declarative part of metacognition as "knowing about things". Conditional knowledge means knowing

[1] The terms meta-learning, etc. are hyphenated.

[2] The first versions of the 'ThinkerTool Curriculum' focused only on the inquiry processes (White & Frederiksen,

the conditions that influence learning (Jacobs & Paris, 1987) and includes "knowing the "why" and "when" aspects of cognition (Schraw, 1998, p. 114). According to this author procedural knowledge refers to the knowledge how to perform activities and "to an awareness of processes of thinking" (Jacobs & Paris, 1987, p. 259).

Although Flavell (1987) has already emphasised the lack of detailed information about metacognition and its operation, there is still a fuzziness in understanding metacognition (Veenman, 2012).

2.3.4 Relation to Meta-Conceptual Awareness

Meta-conceptual awareness describes individuals' thinking about their own conceptual structures and is an essential factor in learning science (Vosniadou & Ioannides, 1998). In general, "concepts are to be understood as basic units of knowledge that can be accumulated, gradually refined, and combined to form ever richer cognitive structures" (Sfard, 1998, p. 5). In other words, being aware of one's own conceptual structure involves an understanding of the already constructed units of knowledge. Furthermore, concepts are embedded in a wider theoretical framework (Vosniadou, 1994). In addition, "issues of students' ways of conceiving of their own knowledge, issues of strategies for dealing with it, and so on" (diSessa, 2002b, p. 57) are meta-conceptual. Meta-conceptual awareness can be understood as "a process in which the learner explicitly refers to her/his personal stock of information including current or past ideas regarding a concept, presuppositions, experiences, and contextual differences" (Yürük, 2007, p. 313). All these descriptions can be summarised as being aware of, using and applying one's own knowledge about one's conceptual structure. The same metacognitive regulatory skills like planning, monitoring and evaluating with regard to your own conceptual system are needed to increase one's awareness (Schraw, 1998). Meta-conceptual awareness is important to organise and handle one's explanatory framework. Vosniadou and Ioannides (1998) argue that "it is difficult to understand other points of view if you do not even recognise what your own point of view is" (p. 1227). Meta-conceptual awareness is a distinctive factor in avoiding misconceptions. Students should be aware of their naïve theory-building framework in order to restructure it (Vosniadou, 1994). Furthermore, meta-conceptual awareness is central to build a coherent conceptual explanatory framework (Cheng & Brown, 2010). Duit and Treagust (2003) summarise that “students will be able to learn science concepts and principles only if they are aware about the shift of their initial meta-conceptual views towards the meta-conceptual perspectives of science knowledge” (Duit & Treagust, 2003, p. 677). Carey and Smith (1993) share this point of view focusing on gaining meta-conceptual awareness “only by actively constructing scientific understanding and reflecting on this process” (Carey & Smith, 1993, p. 245). Posner, Strike, Hewson, and Gertzog (1982) have already pointed out that students have to be aware of their existing explanatory framework in order to revise their conceptions.

In the context of this research project meta-conceptual awareness refers to chemical concepts rather than a wide variety of constructed concepts in mind. Consequently, using the term of ‘meta-conceptual awareness’ excludes a general awareness of one’s own conceptual structure and includes being aware of chemical concepts like the nature, construction and purpose of chemical concepts. Scientific concepts are “complex, finely configured systems involving named parts and relations” (diSessa, 2002b, p. 58). In chemistry, the particulate nature of matter, chemical change, structure-property relations, energy and the donor-acceptor principle are fundamental concepts (Krajcik, 1991; Niedersächsisches Kultusministerium, 2007, 2009). However, the nature of concepts in chemistry includes three different kinds of knowledge representation (Gabel, Samuel, & Hunn, 1987) called the macroscopic, submicroscopic and formal level (cf. Johnstone, 1982, 1993) Moreover, scientific models and modelling refer to the nature of scientific concepts (Schwarz et al., 2009; Schwarz & White, 2005). Hence, being meta-conceptually aware includes meta-modelling and meta-representational knowledge as well as an understanding of chemical concepts. Krajcik (1991) emphasises that there is a difference between using chemical terms and having a conceptual understanding. Furthermore, students need metacognitive skills like planning, monitoring and evaluating to become aware of (Schraw, 1998).

Table 3 summarises the distinctive components of meta-conceptual awareness in chemistry.

Table 3. Components of meta-conceptual awareness

	Component	Description
1)	**Conceptual knowledge**	Knowing *of* chemical concepts means to have an understanding of the fundamental concepts
2)	**Meta-modelling knowledge**	Knowing *about* chemical concepts means to understand the nature and purpose of scientific models and modelling (Non-visible entities are represented by scientific models; Humans' perception is limited → Models are constructed to predict and explain phenomena → Models are representations)
3)	**Meta-representational knowledge**	Knowing *about* chemical concepts means to understand the nature and purpose of scientific representations (Representations have different purposes; In chemistry, macroscopic, submicroscopic and formal representations are important)
4)	**Procedural knowledge**	How to perform an activity in respect of chemistry means to apply the above presented knowledge while solving chemical problems Students have to plan, monitor and evaluate their thinking processes on the content level

According to Mikelskis-Seifert (2002), a student is meta-conceptually aware when showing knowledge about scientific concepts and their character as well as using and applying this knowledge. Therefore, meta-conceptual awareness consists of the integration between conceptual and procedural knowledge and scientific meta-knowledge as presented in Figure 10.

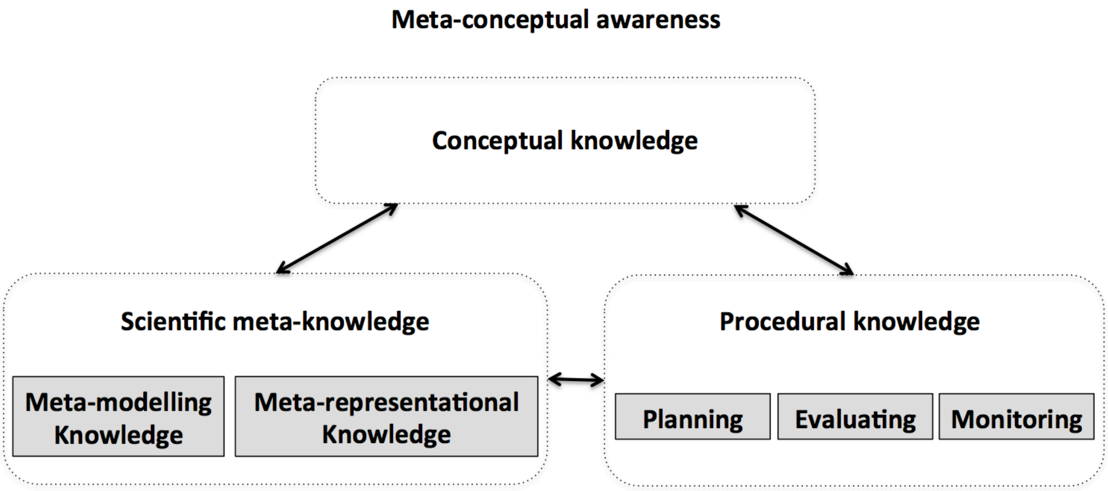


Figure 10. Integration framework of meta-conceptual awareness

2.3.5 Recent Research in Learning Science

2.3.5.1 Meta-Modelling Knowledge

As a consequence of considerable research on students' limited understanding of scientific models and modelling (Grosslight et al., 1991; Harrison & Treagust, 2000a, 2002; Ingham & Gilbert, 1991; Treagust et al., 2002, 2004), a 'Model-Enhanced ThinkerTool Curriculum' has been developed and evaluated (Schwarz & White, 2005; White & Frederiksen, 1998, 2000)[2]. This "inquiry-oriented physics curriculum for middle school students [focuses on learning] about the nature of scientific models [and enhancing] the process of modelling" (Schwarz & White, 2005, p. 165). A model-design software used in this curriculum enables students to create models of force-and-motion phenomena. The model phase of the inquiry cycle supports students in constructing a model and in reflecting the nature of the model. The curriculum was implemented in four seventh-grade classes in San Francisco. Multiple data sources like a pre-post paper-and-pencil test, videotaped classroom observations and student interviews provide answers whether meta-modelling knowledge can improve students' understanding of the nature and process of modelling. The results of the paper-and-pencil test demonstrate students' positive development of modelling knowledge. The correlation between physics knowledge

[2] The first versions of the 'ThinkerTool Curriculum' focused only on the inquiry processes (White & Frederiksen, 1998, 2000)

and knowledge about models suggests a causal relation between them. Furthermore, the results of the interviews indicate students' ability to use scientific models for predicting and explaining phenomena and for multiple purposes like representing abstract ideas (Schwarz & White, 2005). A similar study in the context of condensation illustrates students' ability to evaluate and revise their models when they have been supported in meta-modelling knowledge (Schwarz et al., 2009).

2.3.5.2 Meta-Representational Knowledge

The research study by diSessa, Hammer, Sherin, and Kolpakowski (1991) investigated students' meta-representational competence while learning five sessions about motion. The activity during the sessions focused on generating, critiquing and refining representations. Hence, students learned at a meta-level. The following results are limited to the data source of classroom observation. Consequently, they indicate just the competence of the group instead of the individuals. The authors summarise students' learning progression as followed:

> The students developed their understanding of the construction and interpretation of speed versus time graphs. More important, they did this in a properly meta-representational context in which the purposes of graphing and the general representational criteria they satisfy are salient, and in which graphing is seen as one option among many. (diSessa et al., 1991, pp. 149-150)

Furthermore, the authors suggest that learning at a meta-representational level enables students to use representations in a more flexible and richer sense compared to traditional learning environments (diSessa et al., 1991). In recent research, diSessa (2002a) analysed middle and high school students' ability to judge and critique the quality of representations. This study was embedded in an additional, volunteered course entitled 'the Symbols of Science'. Students were supported in solving the representational tasks in the context of everyday life representations and representations of motion. Besides videotaped classroom observations, three students were retrospectively interviewed about representations produced during the course. The coding of classroom observation indicates rare meta-communication about representations “except when students were explicitly requested to systematise and compare their criteria” (diSessa, 2002a, p. 121). This result indicates students’ existence of meta-conceptual awareness when they are prompted to critique their own knowledge.

2.3.5.3 Meta-Conceptual Awareness

In a clinical interview study, three students from the third grade and three students from sixth grade were individually interviewed four times in order to investigate their explanatory approaches to magnetism. The interview focused on predicting, observing and explaining phenomena about magnetism. Data analysis was based on generating interpretations of non-directly observable events, which were discussed by two researchers. The results emphasise students’ difficulties in awareness of their own explanatory frameworks. Only one student was able to revise and critique her conceptual framework and therefore, showed her meta-conceptual awareness about physics concepts (Cheng & Brown, 2010). Other authors confirm this lack of meta-conceptual awareness (Vosniadou, 1994; Vosniadou & Ioannides, 1998). It must be mentioned that this research has been conducted within the context of physics. As shown in chapter 2.1 models in chemistry education focus on making unobservable entities visible.

In order to enhance students’ understanding of the particle model, a teaching approach about the explicit distinction between the real world and the model world was developed and evaluated (Mikelskis-Seifert, 2002). The teaching approach focuses on the development of meta-conceptual awareness on the experienced and modelled world based on the framework present in Figure 11.

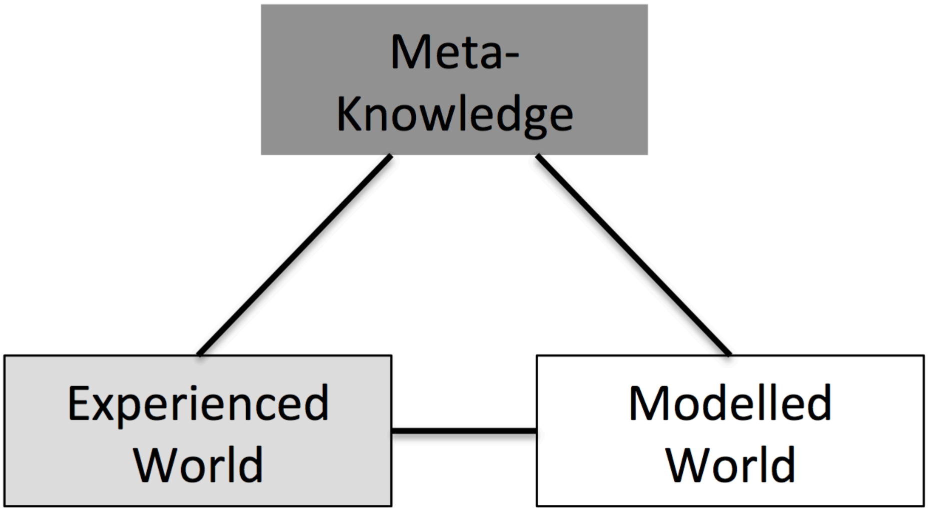


Figure 11. Teaching approach focussing on meta-conceptual awareness (translated from Mikelskis-Seifert & Fischler, 2003b, p. 81)

It enhances students' development of meta-conceptual awareness about the nature of particles focusing on meta-conceptual reasoning about models. Learning about scientific models at a meta-level is a distinctive factor in understanding the nature of models (Mikelskis-Seifert, 2002; Mikelskis-Seifert & Fischler, 2003a). Yürük (2007) and her colleagues (Yürük, 2007; Yürük et al., 2009) investigated the influence of meta-conceptual teaching approaches on students' understanding of force and motion and pre-service biology teachers' understanding of seed plants (Yürük, Selvi, & Yakisan, 2011). In a first approach Yürük (2007) analysed one student's meta-conceptual processes while learning force and motion by meta-conceptual instructions such as concept mapping or journal prompts (Simple questions focusing on reflecting their existing conceptions and writing about their learning of science concepts). This case study indicates the student's development "ranging from simple awareness of her ideas to more sophisticated meta-conceptual processes, such as monitoring and evaluation of ideas" (p. 322). An experimental-control-group study replicates the results of the case study with 45 participants. Students from the experimental group show significantly better conceptual understanding of force and motions compared to students from the control group. A comparable study with 32 pre-service biology teachers confirms the positive impact of meta-conceptual teaching instructions on changing alternative conceptions in the context of flowering plants (Yürük et al., 2011).

Cheng (2012) evaluated meta-conceptual modelling prompts in order to enhance students' revising their already existing explanatory framework. Using prompts in a group-learning situation of magnetism, offers an explicit reflective social process. The results show that meta-conceptual modelling criteria like "Can this model better explain all findings?" (Cheng, 2012, p. 44) help students to reorganise and revise their existing conceptions in order to construct explanatory frameworks scientifically.

2.3.6 Implication for Learning Science

All these research studies result in similar implications for learning science. In general, meta-conceptual awareness is important in learning science (Cheng, 2012; diSessa, 2002a; Mikelskis-Seifert, 2002; Vosniadou, 1994; Vosniadou & Ioannides, 1998; Yürük, 2007; Yürük et al., 2009; Yürük et al., 2011). Increasing students' meta-conceptual awareness requires "learning environments that make it possible for students to express their representations, and belief" (Vosniadou & Ioannides, 1998, p. 1224). According to these authors, group discussions can provide the opportunity to communicate internal representations about phenomena. "It is important to teach science in ways that make children aware that their beliefs and presuppositions are not true facts but theoretical interpretations which are subject to falsification" (Vosniadou, 1994, p. 67). This author demands engaging students in doing authentic science, supporting their verbal communication about phenomena and revising their conceptions. Yürük (2007) and her colleagues (Yürük et al., 2009; Yürük et al., 2011) highlight the importance of meta-conceptual instructions such as expressing existing concepts or writing about learning of science concepts. Becoming aware of one's conceptual structure requires monitoring and evaluating activities about concept learning. Schwarz and White (2005) also illustrate the importance of such activities in the context of scientific modelling. Cheng and Brown (2010) recommend that students need instructional advice to critique and revise their already existing explanatory frameworks to become aware of it. Cheng (2012) suggests that students need to be explicitly prompted by modelling criteria such as internal and external consistency in order to reflect their existing knowledge and revise naïve ideas.

diSessa (2002a) emphasises how rarely students show spontaneous meta-events in their activity and communication, except when they were explicitly prompted in meta-learning. Consequently, instructional support is needed to enhance students' meta-activities. Relating to this result, recent research has been focusing on different kinds of prompts and prompting while learning science and demonstrates prompts as a promising method in enhancing students' ability to learn science (Bannert, 2009; Bannert & Mengelkamp, 2013; Davis, 2003; Davis & Linn, 2000; Marschner, Thillmann, Wirth, & Leutner, 2012; Thillmann, 2007; Thillmann, Künsting, Wirth, & Leutner, 2009; Wirth, 2009; W. X. Zhang, Hsu, Wang, & Ho, 2015). In general, prompts can be defined as suggestions, a recall or a helping tool to activate already existing knowledge, skills or strategies while learning which are not used spontaneously (Bannert, 2009; Bannert & Mengelkamp, 2013; Marschner et al., 2012). Prompts and prompting differ in kind, specificity and timing (Bannert, 2009; Davis, 2003; Davis & Linn, 2000). "They can take the form of questions or sentence-starters to be responded to verbally or in writing" (Davis, 2003, p. 95). Moreover, they are usually "presented by means of short statements asking students at certain times during a learning activity to reflect on specific aspects of the learning topic and/or their own mental activities" (Bannert, 2009, p. 141). Prompts can promote self-explanations (Berthold, Eysink, & Renkl, 2009; Chi, de Leeuw, & LaVancher, 1994) or can support metacognitive controlling in self-regulated inquiry-based learning environments (Marschner et al., 2012; Thillmann, 2007). Instructional prompts can be used "to induce and stimulate cognitive, metacognitive, motivational, volitional, and/or cooperative activities during learning" (Bannert, 2009, p. 140). According to this author, instructional prompts compared to traditional instructional approaches do not provide new information, they should support and stimulate students' knowledge. Prompts are usually used within the learning activity (Thillmann et al., 2009). Presenting prompts while learning in a self-regulated learning environment has a positive impact on the learning outcome compared to prompts used before learning. However, forward prompts directly support the learning activity. Feedback prompts are used to revise past learning behaviour (Wirth, 2009).

2.4 Summary

Scientific models are related to representations "of an idea, an object, an event, a process or a system" (Gilbert & Boulter, 1998, p. 53) as well as a product and methods for a specific aim (Gilbert, Boulter, et al., 2000; Harrison & Treagust, 2002; Oh & Oh, 2011). Humans are not able to apprehend the world directly (Johnson - Laird, 1980; Steinbuch, 1977). Consequently, scientific models are sophisticated instruments to describe, explain and predict the world (Boulter & Buckley, 2000) in order to compensate humans' limited sensory perception. In science education, scientific models are powerful tools to learn and understand science (Gilbert & Boulter, 1998; Schwarz et al., 2009; Schwarz & White, 2005). Recent research has demonstrated students' limited understanding of the nature and purpose of scientific models (Grosslight et al., 1991; Harrison & Treagust, 2000a, 2002; Justi & Gilbert, 2003a; Treagust et al., 2004). Teaching approaches on learning explicitly about models have a positive influence on students' understanding of models and sciences (Gobert et al., 2011; Leisner-Bodenthin, 2006; Mikelskis-Seifert, 2002). Implications for learning science indicate the importance of the nature of scientific knowledge (Justi & Gilbert, 2002a, 2002b), explicit discussions and reflections about the nature of scientific models (Harrison & Treagust, 1996).

Scientific models are closely connected to **scientific representations**. While every scientific model relates to an internal or external representation, a scientific representation does not have to be a scientific model. In chemistry education, macroscopic, submicroscopic and formal representations play a key issue in understanding chemical concepts (Johnstone, 1993, 2000b; Kozma, 2000; Kozma et al., 2000; Kozma & Russell, 1997; Krajcik, 1991). Research has shown that students have difficulties in separating macroscopic and submicroscopic aspects (Jaber & BouJaoude, 2012), understanding chemical equations at the submicroscopic domain (Hinton & Nakhleh, 1999; Krajcik, 1991; Nurrenbern & Pickering, 1987; Pickering, 1990) and transferring between different representations (Kozma & Russell, 1997). An explicit teaching approach focussing on different aspects of representations has a positive influence on students' ability to link between them (Jaber & BouJaoude, 2012). Implications for learning science suggest a simultaneous use of submicroscopic and symbolic representations (Treagust et al., 2003) and explicit discussion of the relation between the phenomenon and its explanatory representations (Chittleborough & Treagust, 2007). The nature of scientific knowledge plays a central role in understanding representations within the context of scientific models (Jaber, 2009).

Scientific meta-knowledge is defined as knowledge about the epistemological nature of scientific knowledge (Carey & Smith, 1993) and involves meta-modelling (Schwarz et al., 2009; Schwarz & White, 2005) as well as meta-representational knowledge (diSessa, 2004; diSessa & Sherin, 2000; Gilbert, 2005). In learning science meta-conceptual awareness as general thinking of one's own conceptual structure attracts widespread interest (Cheng, 2012; Vosniadou, 1994; Vosniadou & Ioannides, 1998; Yürük, 2007; Yürük et al., 2009). Meta-conceptual awareness in respect of chemistry describes one's knowledge of chemical concepts, its nature referring to scientific models (meta-modelling knowledge) and representations (meta-representational knowledge) and using and applying this kind of knowledge (according to Mikelskis-Seifert, 2002). Revising their conceptual framework demands their ability in reflecting on the nature of scientific knowledge. However, recent research has demonstrated students' lack of meta-conceptual awareness (Vosniadou, 1994; Vosniadou & Ioannides, 1998). Explicit teaching approaches considering reasoning about models and their nature increase students' meta-conceptual awareness (Mikelskis-Seifert, 2002; Yürük et al., 2009; Yürük et al., 2011). Implications for learning science demand supporting students in expressing their conceptions (Vosniadou & Ioannides, 1998). Therefore, Cheng and Brown (2010) suggest instructional help.

It can be summarised that researchers have established the importance of meta-events in learning science. However, students rarely show them spontaneously (diSessa, 2002a). Hence, instructional approaches and prompts are used to scaffold students' knowledge (Bannert, 2009; Veenman et al., 2006; Wirth, 2009). Furthermore, it is generally accepted that learning about the nature of scientific models has an influence on learning science (Mikelskis-Seifert, 2002; Schwarz & White, 2005). Understanding chemistry, in particular, involves the macroscopic, submicroscopic and formal domain (Gabel et al., 1987; Johnstone, 1982, 1993, 2000b) and therefore, the modelled nature of submicroscopic and formal representations. While many researchers underline the importance of the triplet relationship, just a few researchers have addressed the influence of knowing explicitly about this relationship on learning chemistry (Jaber & BouJaoude, 2012). Although this approach focuses on teaching the macro-submicro-formal relationship, the study has a lack of clarifying the distinctive influence factor: Is it the use of multiple representations, the interplay between different representation forms, the explicit teaching instruction about scientific models or all together? The problem is to identify the causal relationship between knowledge about scientific representations and conceptual understanding in chemistry.

Therefore, the purpose of this study is to investigate the influence of a meta-conceptual instruction about the triplet relationship of representations on students' understanding of redox reactions and electrochemical processes while doing hands-on activities. According to diSessa's (2002a) findings, prompts should stimulate their communication at a meta-level.

3 Research Design and Methods

In order to fill the presented research gap (see 2.4), this study focuses on the impact of a learning approach in which students are instructed to manage the different representation domains to acquire meta-conceptual awareness. Based on diSessa's (2002a) research findings, instructional prompts are used to enhance communication processes at a meta-level.

3.1 Research Questions and Hypotheses

Therefore, the following research questions arise:

Q1 In what way does knowledge *about* representations and its modelled nature have an influence on students' learning outcome in electrochemistry, if…

- **Q1a they receive a meta-conceptual training before?**
- **Q1b they receive a meta-conceptual training before and prompts during the learning environment?**

On the basis of recent research, it is assumed that students achieve a better conceptual understanding of electrochemistry if they know about the nature of scientific representations and models (H1a). Moreover, the assumption is made that this abstract knowledge about representations and models should be stimulated in order to maintain it (H1b).

Q2 In what way do students communicate their knowledge *about* representations and its modelled nature?

It is expected that students communicate their (newly) acquired knowledge about scientific representations and models rarely (H2). Therefore, it is interesting to analyse the conditions how they communicate their knowledge at a meta-level.

3.2 Methodological Considerations

Quantitative and qualitative research approaches are popular methods in educational research. Their application depends on the related research questions (Döring & Bortz, 2016; Onwuegbuzie & Leech, 2005; Schecker, Parchmann, & Krüger, 2014). "A quantitative research approach is an objective, formal, systematic process in which numerical data are used to quantify or measure phenomena and produce findings" (Carr, 1994, p. 716). Consequently, numerical data is analysed, interpreted and presented. One type of quantitative research focuses on "studies aimed at discovering causal relationships or strength of relationships or differences between groups" (Mertens, 2015, p. 127). In order to realise this research goal, standardised test instruments, a representative sample and controlled conditions are used (Döring & Bortz, 2016). In science education the efficacy of learning and teaching concepts plays an important role. Therefore, intervention studies with a control and an experimental group are conducted to examine causal differences between the groups (Schecker et al., 2014). This kind of research pursues the goal to test theoretically based hypothesis (Döring & Bortz, 2016). Experiments are tools for testing causal hypotheses (Cook, Campbell, & Perracchio, 1990). Moreover, "the key feature common to all experiments is still to deliberately vary something so as to discover what happens to something else later - to discover the effects of presumed causes" (Shadish, Cook, & Campbell, 2002, p. 3). The strength of quantitative research lies in testing theoretical assumptions, providing cause-and-effect relationships and generalising research findings. The weakness lies in understanding the local constituencies and considering all aspects of the phenomena to be investigated (Johnson & Christensen, 2014).

Compared to quantitative approaches, the qualitative research process can be more performed in a more unstructured way with a few cases. The goal is to collect comprehensive data, which can be analysed in an interpretive way (Döring & Bortz, 2016). Benefits of qualitative research methods are to study in-depth complex phenomena while the weakness lies in making quantitative predictions, in a timeconsuming process and in influencing the results easily by the researcher (Johnson & Christensen, 2014).

As a consequence of the strengths and weaknesses of quantitative as well as qualitative research, debates about quantitative and qualitative methodologies take place and mixed-methods have gained popularity (Döring & Bortz, 2016; Johnson, Onwuegbuzie, & Turner, 2007; Leech & Onwuegbuzie, 2009; Onwuegbuzie & Leech, 2005, 2006).

> Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration. (Johnson et al., 2007, p. 123)

In other words, mixed research methods involve quantitative as well as qualitative techniques (Döring & Bortz, 2016). The inclusion of qualitative data can provide explanatory relationships emerging from the quantitative data as well as quantitative data can help to understand the qualitative data (Johnson et al., 2007; Onwuegbuzie & Leech, 2004). As Figure 12 presents, three domains of mixed methods arise; the importance of integrating quantitative data in a qualitative research approach, the equal status and integrating qualitative data in quantitative issues (Johnson et al., 2007).

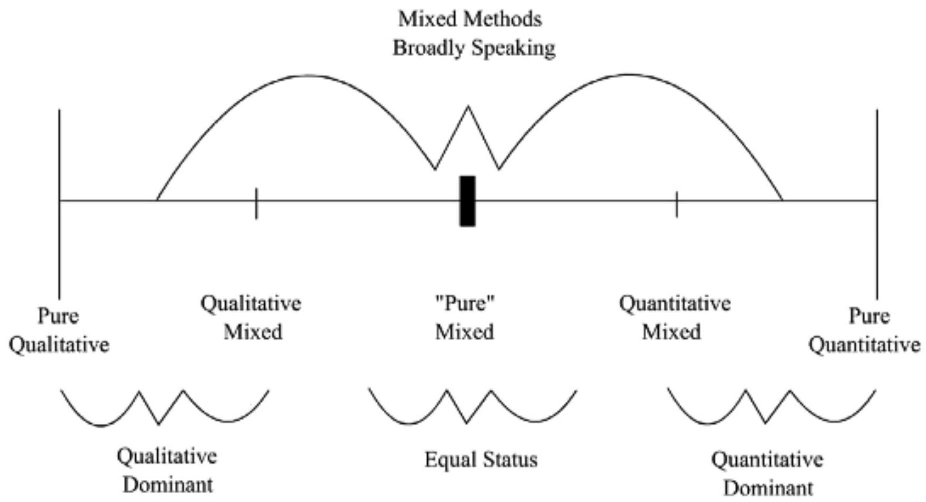


Figure 12. Three major research paradigms (Johnson et al., 2007, p. 124)

In mixed methods research the same quality criteria are used compared to each quantitative and qualitative methods. In addition, the criteria 'mixed methods design quality' describes the quality of the link between quantitative and qualitative data analysis (Döring & Bortz, 2016).

Pilot Study

The significance of empirical research depends on the quality of the overall survey, the quality of the test instruments and the data analysis (Atteslander, 2008). "A pilot or feasibility study is either a small scale implementation of your design or a set of steps taken to ensure quality of future data collection procedures" (Tashakkori & Teddlie, 2009, p. 203). In other words, a pilot study is a 'pre-test', a 'test run' or a 'trying out' (van Teijlingen & Hundley, 2001).

As a consequence, this research study was piloted with 34 students from a secondary school in Osnabrueck in autumn 2013 in order to ensure the quality of the overall survey. All changes caused by the pilot study are described and discussed at each end of the following chapters.

3.3 Design

In order to answer the first research questions and to test the hypotheses, a simple factorial control-group intervention study is conducted. Two experimental groups are needed to identify the effect of the instruction and the instruction combined with prompts compared to the control group. Furthermore, a video study is integrated to answer the second research question as shown in Figure 13. Therefore, this project integrates qualitative methods into a quantitative design.

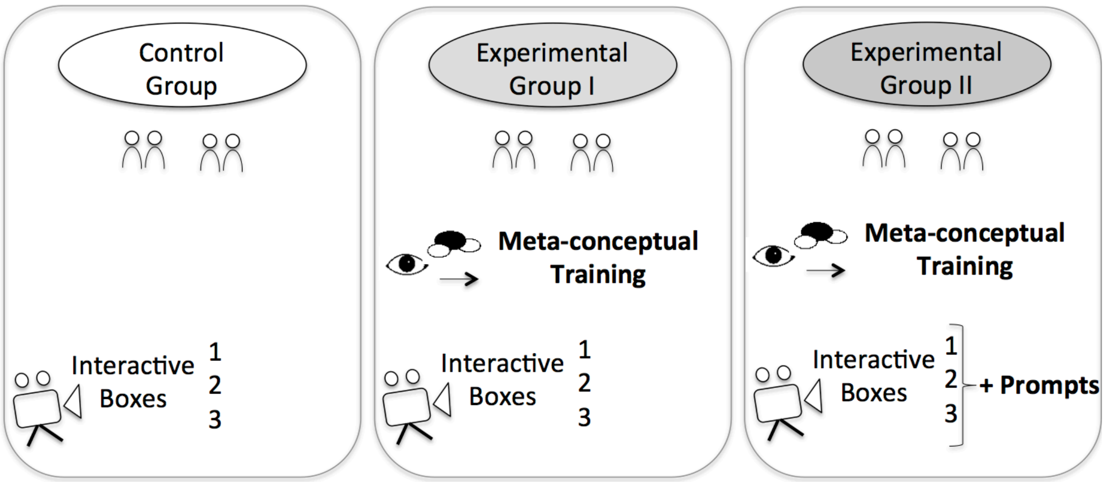


Figure 13. Research design

The independent variable is the knowledge about scientific representations and its modelled nature manipulated by the meta-conceptual training and the prompts. The study is temporally conducted after regular school lessons but inside of the school building. One researcher performs the intervention and students do not learn in their traditional classes. The students gain 15 euros for participating. In order to provide the students with an opportunity to apply and communicate their acquired knowledge, they do three 45-minutes hands-on activities (interactive boxes see chapter 3.6) on two afternoons in one week. This learning environment deals with the subject matter of electrochemistry. Each student chooses a partner freely in order to facilitate communication and cooperation processes. While the first and second experimental group get the instructions, the control group gets a comparable training without focus on meta-conceptual aspects in order to avoid a time-on-task effect (cf. Mackworth, 1968). During the learning environment, the second experimental group gets prompts to stimulate the communication about representations and its modelled nature. The design is evaluated with the help of mixed research methods which are embedded in a quantitative mixed domain (Johnson et al., 2007). The first research question should be answered by analysing students' development in pre-, post- and follow-up-test results relating to their treatment. The second research question requires a more qualitative, interpretative way because communication at a meta-level is a complex phenomenon. Accordingly, video data are collected to provide insights into students' communication.

3.4 Intervention Measures

The independent variable shall be manipulated by a meta-conceptual training and by prompts during the learning environment.

3.4.1 Meta-Conceptual Training

In general, knowledge instruction approaches should consider some conditions. Linn (1995) developed a framework for scaffolding knowledge integration in science education to provide four instructional conditions: identifying learning goals, making thinking visible, making science accessible and providing social support. Knowledge integration means to link and connect scientific ideas. Making thinking visible confirms the view of conceptual change which says that students have to become aware of their own conceptions (Duit & Treagust, 2003; Posner et al., 1982; Vosniadou & Ioannides, 1998). This framework should be integrated into metacognitive instruction principles by Veenman and colleagues (2006) in order to develop the meta-conceptual training:

a) "embedding metacognitive instruction in the content matter to ensure connectivity,
b) informing learners about the usefulness of metacognitive activities to make them exert the initial extra effort, and
c) prolonged training to guarantee the smooth and maintained application of metacognitive activity" (Veenman et al., 2006, p. 9).

These principles are adapted for and implemented in a 60-minutes training focusing on the relationship between the experienced and modelled world (cf. Mikelskis-Seifert, 2002) including submicroscopic and formal representations. In an unpublished bachelor thesis (Flauß, 2013) the training had been developed and evaluated with two students before the pilot study was conducted.

The meta-conceptual training refers to learning strategy research. It should function as a learning aid to help students to explain macroscopic phenomena at the submicroscopic and formal domain. “An effective learning strategy can be defined as a set of processes or steps that can facilitate the acquisition, storage, and/or utilization of information” (Dansereau, 1985, p. 210).

Firstly, the students should observe and explain the presented phenomenon of dissolving sodium chloride in distilled water in the way they have learned in chemistry lessons. The researcher demonstrates the dissolving process by measuring the mass of sodium chloride, water and the solution of both. The dissolving process of sodium chloride is a simple phenomenon and this step is designed to ensure connectivity to students’ prior knowledge.

Secondly, the students learn explicitly about scientific representations and their modelled nature. The relation between the experienced world and the modelled submicroscopic and formal domain is an essential element. According to Krajcik (1991) students develop their knowledge without linking it to their scientific experiences. This link would help students to make sense of scientific knowledge.

Thirdly, the students are required to write their observation and explanation of the presented phenomenon down again but now with the help of a table separated in the experienced and modelled world including the submicroscopic and formal domain as depicted in Figure 14.

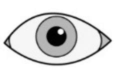
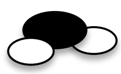
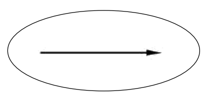
Experienced World	Modelled World	
Macroscopic	Submicroscopic	Formal
		

Figure 14. Central features of the meta-conceptual training

Furthermore, the students are asked to make the relationship between the experienced and the modelled world visible by visually connecting the related statements at the different levels. It should be stressed here, that against the theoretical background of scientific representations, the difference between macroscopic reality and macroscopic representation is not explicitly taught in order to avoid problems and to reduce complexity. On the one hand, this step focuses on identifying the learning goal of the instruction. On the other hand, the repetition of explaining the phenomenon should make students' thinking visible (according to Linn, 1995). Moreover, using the table to explain phenomena should facilitate and improve students' chemical thinking. Therefore, it can be understood as a support strategy (cf. Dansereau, 1985).

Fourthly, the students should apply their instructed knowledge to a new phenomenon 'the combustion of iron'. Applying their knowledge to a new example should demonstrate the fruitfulness of separating the experienced and modelled world. Furthermore, students should recognise the usefulness of this training in order to maintain the application of this knowledge. The last step of the training consists of a summary of all previously presented information. The training is implemented according to the model by the University of Duisburg-Essen (i.a. Fechner, 2009; Neuroth, 2007; Wahser, 2008; Walpuski, 2006). Figure 15 summarises the steps of the meta-conceptual training.

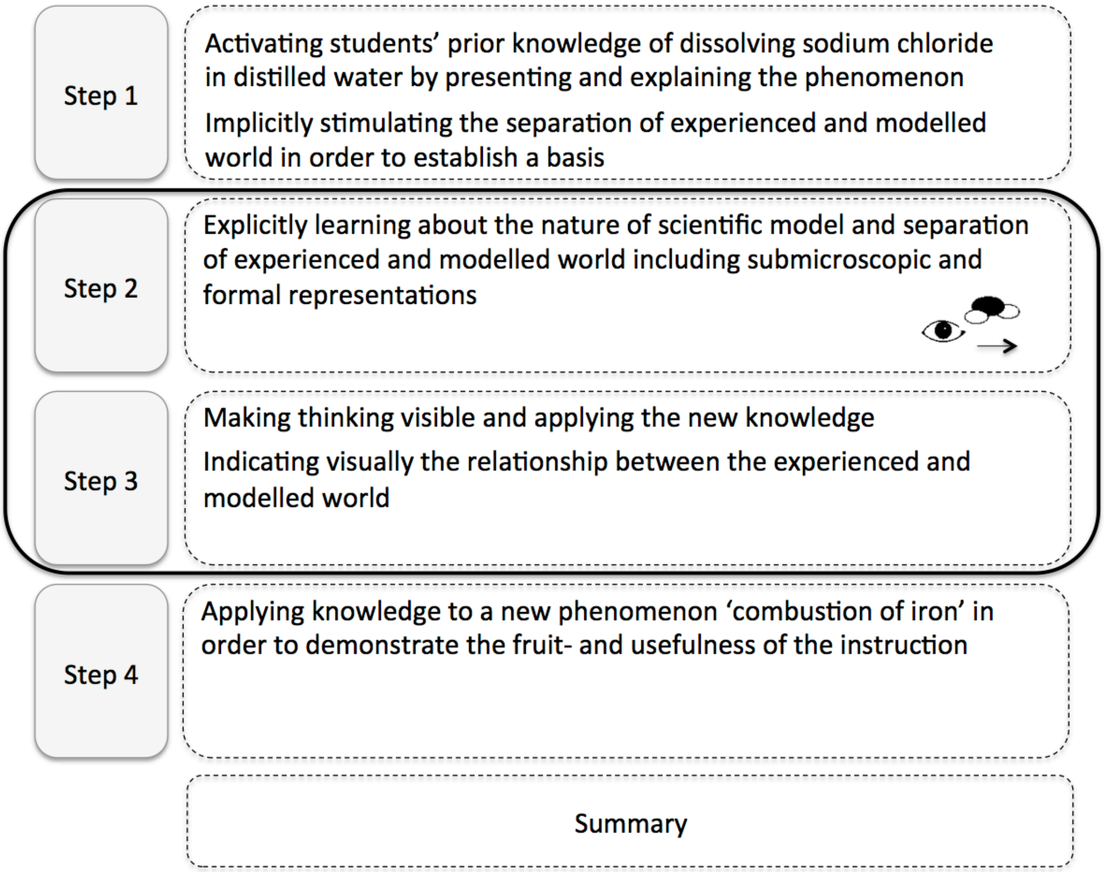


Figure 15. Steps of the meta-conceptual training

3.4.2 Prompts

According to Bannert (2009), instructional prompts are used during the learning environment in order to induce cognitive activity to reflect on the experienced and the modelled world. This additional instruction is meant to stimulate students' communication about scientific representation and its modelled nature because recent research has demonstrated how rarely students show meta-events in their communication spontaneously (diSessa, 2002a). Furthermore, the assumption is made that students need time to integrate their knowledge into their existing knowledge. Two simple prompts in form of a question were developed and evaluated. While the question should stimulate students' knowledge about the different representations explicitly, the symbols should encourage their reflection on the meta-conceptual training implicitly.

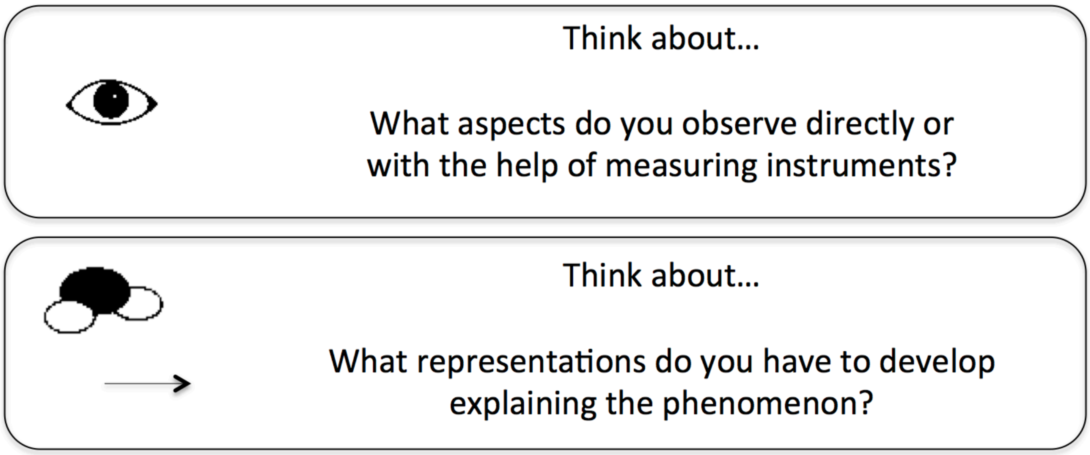


Figure 16. Prompts

The prompts had been developed and were evaluated in an unpublished bachelor thesis (Thomas, 2013). In the pilot study, prompts were used focusing more on the modelling process (e.g., Which models do you have to develop to explain the phenomenon?). This kind of question was too complex and too difficult to understand because students did not receive training on the modelling process. In line with the theoretical background, prompts should stimulate students' existing knowledge (Bannert, 2009; Wirth, 2009).

3.5 Sample

Tenth-grade students aged from 15 to 17 from secondary schools of Lower Saxony were recruited. Within planning this research project a statistical power analysis was conducted with GPower to calculate the sample size. This ANOVA (repeated measures, between factors) was run under the condition of a pre-set statistical power of .8 and a significant level of $\alpha = .05$. To achieve a medium to small effect size f ($f < .25$ according to (Bannert, 2009; Wirth, 2009)), the necessary sample size N should be bigger than 108 related to three measurement times and three groups. As a consequence, three schools were randomly selected in order to pick out 50 students per school and therefore per treatment. To avoid school factors influencing the treatment, the control (CG) and the experimental groups (EGI/II) were distributed as depicted in Figure 17.

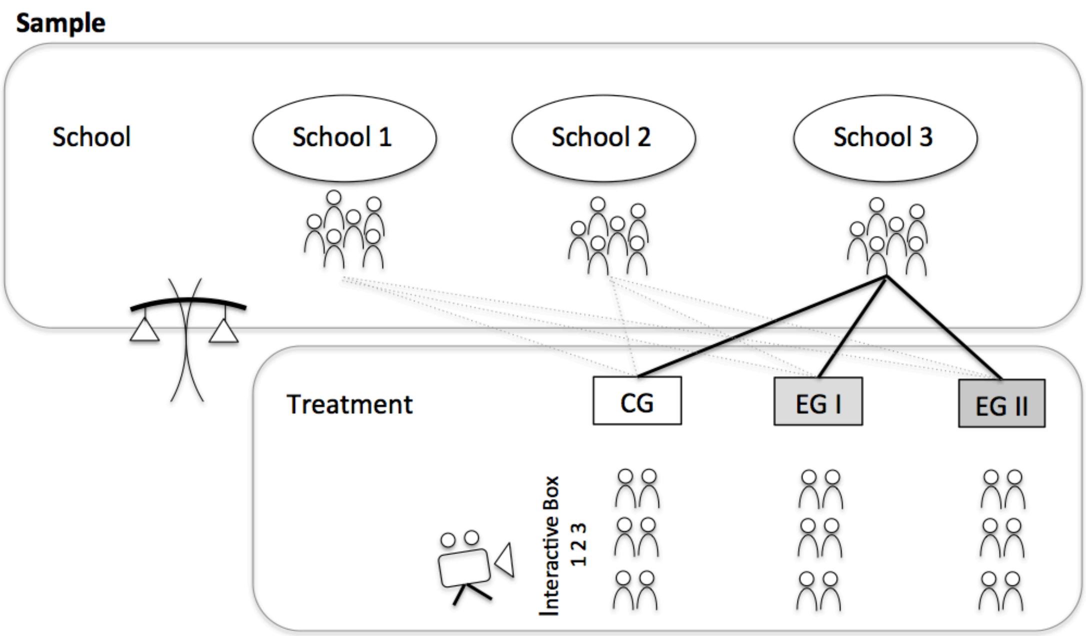


Figure 17. Sample composition

The balance symbolises that students are divided equally into these three groups by balancing prerequisites of students like cognitive abilities, interest and prior knowledge which are collected in the pre-test (for detailed information see chapter 4.1). Furthermore, students work in self-chosen dyads.

3.6 Learning Environment

As mentioned in the chapters before, three hands-on activities are integrated into interactive boxes. After the intervention, students need an authentic learning setting to acquire and apply their chemical knowledge. The control group as well as the experimental groups get the same hands-on activities. Hence, all students get the opportunity to apply their theoretical knowledge on representation in an experimental learning environment, which is defined "as a place where individuals can learn by generating or testing hypotheses in a controlled way" (Sumfleth & Walpuski, 2012, p. 1229). Interactive boxes as experimental learning environment are selected in order to minimise extraneous influences like the teacher variable, because all instructions and materials are offered in the box. In addition, all boxes include information cards to provide necessary knowledge. They are designed according to Rumann (2005) and Walpuski (2006) from the chemistry education group at the University of Duisburg-Essen. Against the model of 'scientific discovery as dual search' (Klahr & Dunbar, 1988), these interactive boxes focus only on the phases 'conducting an experiment' and 'evaluating results' to minimise students' difficulty by reducing the cognitive load. As opposed to the recent boxes, the focus is on explaining the phenomenon in order to give space for self-determined modelling activities.

According to the empirical background, 10^{th}-grade students provide a pool of intuitive knowledge considering different representations. Supporting the use of the different representation domains demands on "focusing on those aspects of a phenomenon under study that require explanation provided through sub-microscopic and symbolic representations" (Justi et al., 2009, p. 288). As a consequence, introductory electrochemistry as content was selected. The electrochemical phenomenon as the galvanic cell requires a deep understanding of submicroscopic entities while visual macroscopic changes are seldom. In particular, students need submicroscopic representations to explain electrochemical phenomena. Furthermore, students have difficulties in understanding electrochemistry (Barral, 1992; de Jong & Treagust, 2002; Garnett & Treagust, 1992; Marohn & Harrison, 2007; Sanger & Greeenbowe, 1997). Hence, explicit instruction about scientific representations provides an authentic supporting strategy.

The first interactive box serves as an introductory session to repeat prior knowledge of redox reactions and the ion concept. The second box focuses on electrochemical processes of the galvanic cell and the third box on a copper/ copper sulphate solution concentration cell (content adapted from Atkins & de Paula, 2006). While students have only 30 minutes to work on the first box, they have 45 minutes for the second and third box. After a pre-set time, students have to stop working on the hands-on activity. The boxes are implemented during the study in the following way as shown in Figure 18.

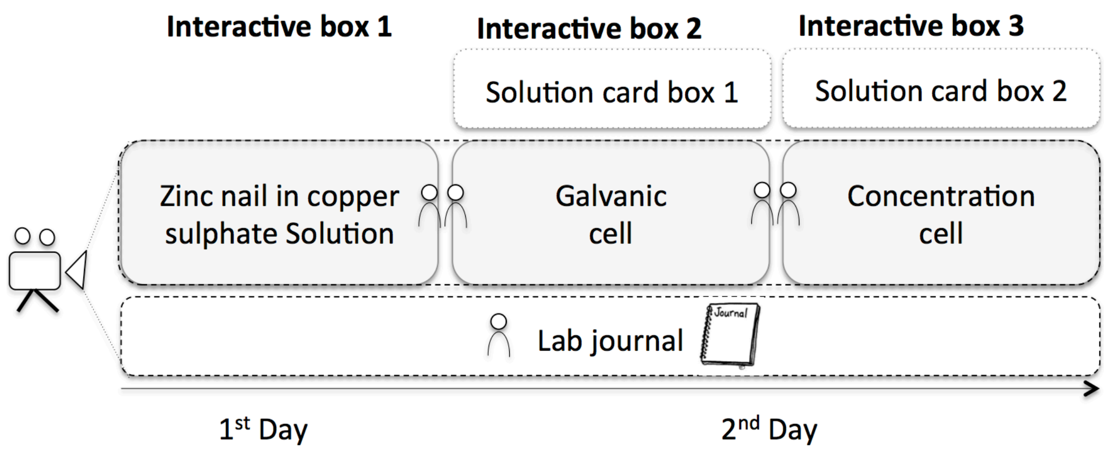


Figure 18. Description of the experimental learning environment

To ensure the same learning conditions the students get a solution card before starting a new interactive box. Furthermore, they are instructed to write a lab journal individually in order to deal with their own conceptions and to provide another data source related to their understanding of scientific representations.

Two main differences in the experimental learning environment have arisen from the pilot study. At first, while performing the pilot study, students of the third treatment got solution cards in form of the table separating the experienced and modelled world including the submicroscopic and formal domain. Secondly, the lab journal of these students was also presented in the same table structure. The problem of these additional learning aids was to clarify the distinctive factors of the third treatment: Do the prompts have the positive influence on learning or the solution cards or the lab journal or all together? In order to investigate these questions more factors should be included in the design. However, this research project should answer the research question in what way the meta-conceptual training in combination with the prompts has an influence on students' conceptual understanding.

4 Test Instruments

As depicted in Figure 19, the intervention is embedded in a pre-, post- and follow-up-test design in order to identify a causal relationship between the independent variable of knowledge about scientific representations and models and the dependent variable of conceptual knowledge of introductory electrochemistry.

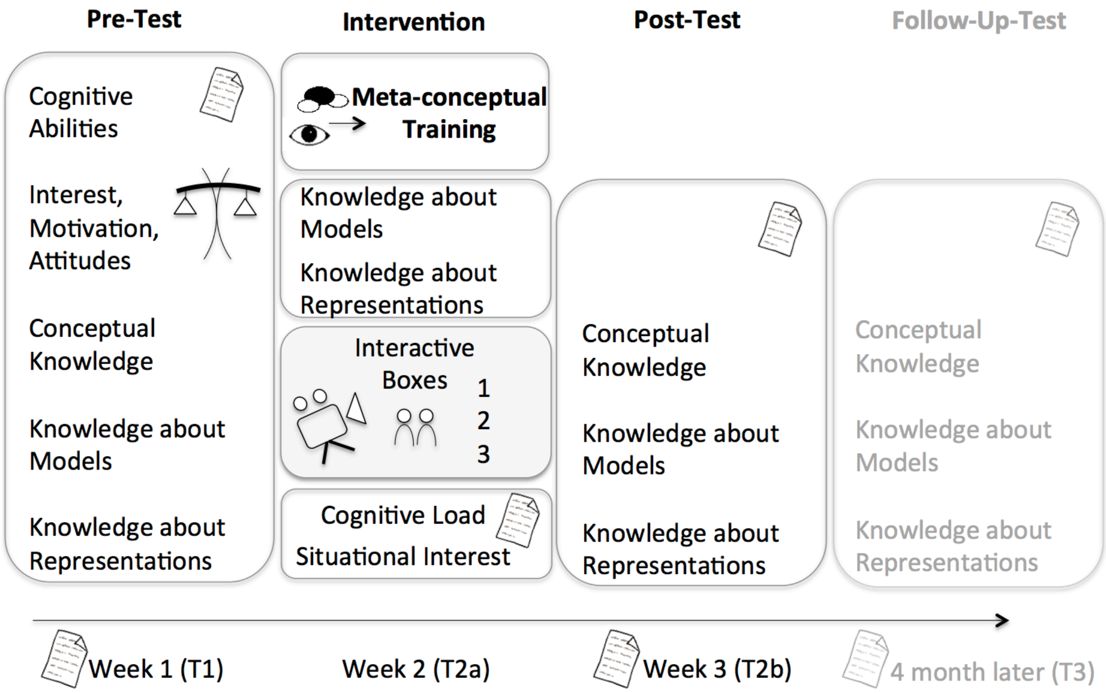


Figure 19. Overview of test instruments

The pre-test data measures students' cognitive abilities, their interest, motivation and attitudes, their conceptual knowledge and knowledge about models and representations. Students' cognitive abilities, attitudes, interest and motivation in chemistry and the first part of conceptual knowledge (recalling chemical knowledge) is used to balance the different treatment groups. Furthermore, indicating the learning outcome of the meta-conceptual training, the test instruments of representations and models are directly conducted after the intervention. In order to ensure the effect of the meta-conceptual training, students have to fill in the questionnaire of knowledge about models and representations after the intervention. Moreover, it can be assumed that additionally learning about representations has an influence on students' cognitive load. "It is pointed out that cognitive load theory deals with learning and problem solving difficulty that is artificial in that it can be manipulated by instructional design" (Sweller, 1994, p. 295). Students' situational interest is measured in order to investigate possible bias. As shown in Figure 19 the follow-up-test will be carefully considered. It was conducted four month later when students had already been at 11^{th} grade. The different test instruments are presented in the following chapters.

4.1 Control Measures

In order to balance the treatment groups and to identify the prerequisites for learning some additional data as control variables is collected.

4.1.1 Cognitive Abilities

The literature review of affect, ability and science achievement (Steinkamp & Maehr, 1983) emphasises a strong relation between cognitive abilities and science achievement. Consequently, to balance the treatment groups the cognitive ability test KFT (Heller & Perleth, 2000) was selected. The test includes three factors, which measure students' verbal (V-test), nonverbal (N-test) and quantitative (Q-test) cognitive abilities. Considering scientific representations, nonverbal cognitive abilities can play a central role. Moreover, verbal cognitive abilities are important in communication processes when knowledge about representations is externalised. Hence, one subscale of the verbal (V2-test/ word-classification) and one of the nonverbal (N2-test/figure analogy) scale were used to minimise the test time. Each subscale includes 25 items with five response choices. The test time is limited to nine minutes for V2-scale and eight minutes for N2-scale. To ensure the consistency of the scales reliability was calculated according to Cronbach (1951). The statistical value of α for the verbal scale (V2) is $\alpha = .67$. This value is exactly the same compared to the standardised sample for the respective ability stream and the same age. As mentioned in Kline (2000), the diversity of psychological abilities can be responsible for α even below $.7$. For the non-verbal scale (N2) an acceptable α-value of $.77$ was calculated.

4.1.2 Attitude, Interest and Motivation

It is generally accepted that students' interest and motivation have a decisive effect on learning outcome (Dweck, 1986; Krapp & Prenzel, 2011; Renninger, Hidi, & Krapp, 1992; Schiefele, 1991). Moreover, students' science-related self-concept has impact on science achievement (Wilkins, 2004; Wilkins, Zembylas, & Travers, 2002). Consequently, these factors play an important role in balancing the treatment groups. To measure students' interest a scale from the 'Test of Science-Related Attitudes' (TOSRA) was administrated (Fraser, 1981). The scale (ES) included eight items asking for students' enjoyment of science lessons. Four items from another scale (SI, TOSRA), referring to the learning environment asked for students' attitude towards scientific inquiry. All items were translated into German, and then to ensure validity, they were translated back into English. In addition, to investigate their subject-related individual interest in chemistry four items of the instrument 'Potsdamer Motivations-Inventars – Mathematik" (Rheinberg & Wendland, 2003) were adapted. Two scales measure students' extrinsic and one scale the intrinsic motivation. In order to control additional factors four more scales were used asking for self-efficacy, self-concept in chemistry, teacher dependent support in chemistry classes and cooperation ability in small groups (Fechner, 2009). All items were rated on a four-point Likert-type scale (0= strongly disagree, 3= strongly agree). Table 4 presents an overview of the different scales.

Table 4. Overview of scales on interest, motivation and attitudes

Scale	Description	Items	Item example
ES	Enjoyment of science lessons	8	I dislike chemistry lessons.
SI	Attitude to scientific inquiry	4	I would prefer to find out why something happens by doing an experiment than by being told.
SAI	Subject-related individual interest in chemistry	4	I am interested in chemical topics.
FGN	Extrinsic-grades	3	To be good in chemistry class is important to get a good grade report.
FBF	Extrinsic- external assessment	3	To be good in chemistry class is important for my parents.
GTA	Intrinsic	3	I have to force me to do chemistry.
Swe	Self-efficacy	3	If I work hard, I am able to answer all questions from my teacher.
Sbk	Self-concept	6	I am able to solve problems without any problems.
Kos	Teacher dependent support in the classroom	4	My chemistry teacher can explain things well.
Koop	Cooperation in small groups	4	I like to cooperate with the students from my group.

A confirmatory factor analysis does not confirm that all items load on the expected scale (see appendix E.I). Especially, items of the scale subject-related individual interest in chemistry’, ‘enjoyment of science lesson’, ‘intrinsic’ and ‘self-concept’ load more on one factor than on four different factors. The correlation analysis of these scales indicates a strong relationship between them ($.80 < r < .88, p < .001$). Nevertheless, the internal consistency estimates of the scales are satisfactory. Hence, the scales remain valid. Two items were removed from the scales to improve their reliability as presented in Table 5.

Table 5. Reliability analysis of scales on attitudes, interest and motivation

Scale	Cronbach’s α (If item deleted)	Deleted item
E	.95	-
I	.75	-
SAI	.79	-
FGN	.87	-
FBF	.69	FBF_75
GTA	.88	-
Swe	.87	-
Sbk	.95	-
Kos	.75	-
Koop	.71	Koop3

4.1.3 Cognitive Load

Two items are used to measure students’ cognitive load which “can be defined as a multidimensional construct representing the load that performing a particular task imposes on the learner’s cognitive system“ (Paas, Tuovinen, Tabbers, & van Gerven, 2003, p. 64). After working on the interactive boxes students were asked to evaluate their cognitive performance on solving a chemical problem. Therefore, the item includes a seven-point Likert-type response format from very low to very high. Rating scales are major technique in measuring cognitive load (Paas et al., 2003).

4.1.4 Situational Interest

In order to investigate whether students work seriously on the hands-on activity and with their partner, 20 items with a four-point Likert-type are conducted after each interactive boxes (measurement time S1, S2, S3). These items can be use to indicate problems within the learning environment. According to Fechner (2009) items are added to investigate students' challenge during the learning environment. These items were obtained from 'Fragebogen zur aktuellen Motivation' (FAM) (Rheinberg, Vollmeyer, & Bruns, 2001). Items related to students' activity-related intrinsic motivation, the success of pair cooperation and their topic-related situational interest are selected from Fechner (2009). According to this author, items on the scale 'cooperation' refer to small group cooperation. Consequently, the scale is adapted to pairs of students. The confirmatory factor analysis indicates that items of the scale 'cooperation' and item of the scale 'activity-related intrinsic motivation' load on one factor (see appendix E.II). There is a significant relationship between both scales, $r = .73, p < .001$). Nevertheless, it makes more sense to interpret the items on two different scales. The reliability analysis supports this interpretation. Table 6 provides an overview of the scales and reliability values.

Table 6. Overview of scales on situational interest

Scale	Description	Items	Cronbach's α
exin	Activity-related intrinsic motivation	6	$.65 < \alpha < .76$
her	Challenge	4	$.52 < \alpha < .72$
koop	Success of pair cooperation	4	$.73 < \alpha < .83$
tosi	Topic-related situational interest	6	$.70 < \alpha < .80$

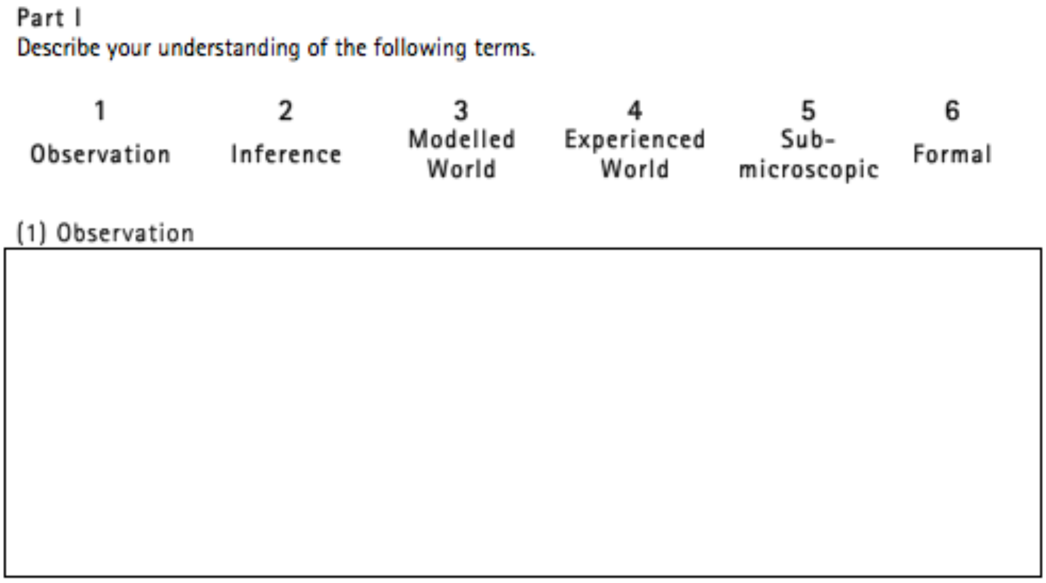
One item 'I am going to tell my parents and friends about the hands-on activities we worked on today' does not refer to any scale and is consequently excluded from further analysis. Students in the 10^{th} grade do not find it relevant to tell their parents about school topics compared to students in seventh grade that participated in the study of Fechner (2009).

4.2 Independent Variables

The intervention aims to enhance the knowledge about scientific representations and models in order to cause an effect on students' conceptual knowledge about redox reactions and electrochemistry.

4.2.1 Understanding about Representation in Science

To ensure the quality and learning success of the intervention a paper-and-pencil test was developed and evaluated focusing on students' understanding of representations. In a first step, students should define the different representation domains 'experienced world', 'modelled world', 'submicroscopic' and 'formal' as well as 'observation' and 'inference' as shown in Figure 20.


Part I
Describe your understanding of the following terms.

1	2	3	4	5	6
Observation	Inference	Modelled World	Experienced World	Sub-microscopic	Formal

(1) Observation

Figure 20. Item example of the understanding about representations

The items were analysed with the help of a coding scheme. Three levels of understanding based on Grosslight and colleagues (1991) were developed. Moreover, two additional codes refer to 'no answer' or 'not classifiable'. Figure 21 shows the three levels of understanding used in the coding scheme. As example the submicroscopic domain is presented. Level 0 reflects a low understanding of submicroscopic representations and level 2 suggest a higher understanding.

However, there is no claim that level 2 reflects a full scientific understanding of submicroscopic representations.

Submicroscopic Domain

Level 0	Is defined as students describe the submicroscopic domain as **representations** of atoms/ particles and their behaviour.

Level 1	Is defined as students describe the submicroscopic domain as representations of atoms/ particles and their behaviour. Furthermore, students describe the **existence** of atoms/ ions/ molecules/ particles and define the representations of them as **modelled nature**.

Level 2	Is defined as students describe the submicroscopic domain as representations of atoms/ particles and their behaviour. Furthermore, students describe the existence of atoms/ ions/ molecules/ particles and define the representations of them as modelled nature. Moreover, students describe the submicroscopic domain as a concrete visualization of the **mental model**.

Figure 21. Examples from the coding scheme of understanding about representations

The test instrument was coded with the help of the statistic software SPSS® and 10% was double-coded by another researcher. In general, kappa is "a chance-adjusted measure of agreement between two observers" (Byrt, Bishop, & Carlin, 1993, p. 423). The value of Cohen's kappa is calculated as follows.

$$\kappa = \frac{p_0 - p_e}{1 - p_e}$$

p_0 is the relative agreement and p_e is the chance-corrected relative agreement. To measure the intercoder agreement of a polytomous rating scale (each coder can choose level 0 to level 2), weighted kappa coefficient was calculated (Cohen, 1968; Wirtz & Kutschmann, 2007). Weighted kappa "consider the various kinds of disagreement as representing differing amounts of disagreement” (Cohen, 1968, p. 218). Table 7 presents the results of double coding.

Table 7. Agreement matrix of coding levels of understanding

		Coder 2					Σ
		0	1	2	No answer	Not classifiable	
Coder 1	0	89	2	0	0	3	94
	1	9	99	1	0	0	109
	2	1	2	10	0	0	13
	No answer	0	0	0	36	0	36
	Not classifiable	2	0	0	0	25	27
	Σ	101	103	11	36	28	288

The researcher achieve to 90% agreement, which is equivalent to $\kappa_W = .82$ and therefore, an almost perfect agreement.

In a second step, twelve chemical statements like “Sodium-ions are positive metal-ions” are presented in order to assign them to a related representation domain. Multiple responses are allowed, but are limited to three references at a maximum. Furthermore, they have to response whether they are sure or unsure in their choice and highlight the most important term as shown in Figure 22.

Assign the numbers of the following terms to the statements in the table below.

1	2	3	4	5	6
Observation	Inference	Modelled World	Experienced World	Sub-microscopic	Formal

You can choose one to three terms per row. Highlight the most important term. If you are unsure with your choice of term, please highlight this.

1. 2g of sodium chloride are in the beaker.	
2. Sodium-ions are positive metal-ions.	

Figure 22. Item example of knowledge about representations

The internal consistency of the association scale varies considerably between the different measurement times. While the pre-test reliability is too low ($\alpha = .51$), post-test reliability values reach high scores ($\alpha_{T2a} = .87$; $\alpha_{T2b} = .80$). The difference can arise from real changes in students' abilities, which may have occurred because of the intervention (cf. Kline, 2000). In addition, Cronbach's alpha shows an acceptable internal consistency of the follow-up data ($\alpha_{T3} = .75$).

Compared to the pilot study, the open items of defining the different terms were added for ensuring students' understanding of the terms and therefore, for evaluating the association tasks. Moreover, the association task had been refined. In the pilot study students associated single words like chloride-ion to a representation domain. This approach had a limited relevance.

4.2.2 Understanding about Models in Science

To investigate students' understanding of models in science, nine items of the pencil-and-paper questionnaire, called *SUMS* (Treagust et al., 2002), are selected in line with the content of the meta-conceptual training (3.4.1). Hence, items of the scales 'Models as exact replicas' (ER), 'Models as explanatory tools' (ET) and 'Uses of scientific models' (USM) are used to identify students' development of scientific understanding of models. In addition, to improve content validity, one item from Beerenwinkel (2007) and four items from Mikelskis-Seifert (2002) were partly modified. In the original instruments the items were used to test students' knowledge about the particle nature of matter model. Consequently, the term 'particle nature of matter' was replaced with 'particle at the submicroscopic domain. However, these items form the scale 'Submicroscopic domain' (Mod). In contrast to the original instruments, students have to respond on a four-point Likert-type scale instead of a five-point Likert-type to force students to make a decision. They have only the response options of: strongly disagree (0), disagree (1), agree (2) and strongly agree (3). Some items have been reversed before doing data analysis. To identify the factors, the principal component analysis technique with varimax rotation was used. Because of the specific term 'particle at the submicroscopic level', which students learned during the intervention, data from measurement time T2a is used. Moreover, the Kaiser-Meyer-Olkin (KMO) value confirms that the sampling adequacy at measurement time T2a better suits (KMO of .58 compared to KMO of .72) (Hutcheson & Sofroniou, 1999). Four factors are extracted (see Table 8). The retained factors explain 56.31% of variance.

Table 8. Factor loadings of model items for principal component analysis with varimax rotation

	Component			
Item number and description	1	2	3	4
Because of the existence of 'particle at the submicroscopic level' you can explore their appearance sooner or later. (SMod03)	.75			
'Particle at the submicroscopic level' needs to be close to the real thing. (SMod02)	.66			
'Particle at the submicroscopic level' is a model conception. (SMod04)	.66			
The model conception 'particle at the submicroscopic level' is an exact replica. (SMod01)	.61			-.40
The conception we have of 'particle at the submicroscopic level' is a human invention to explain specific phenomena. (AMod05)	.59			
A model needs to be close to the real thing by being very exact, so nobody can disprove it. (ER3)		.84		
A model should be an exact replica. (ER1)		.80		
A models needs to be close to the real thing. (ER2)		.78		
Models are used to help formulate ideas and theories about scientific events. (USM1)			.77	
Models are used to make and test predictions about a scientific event. (USM3)			.72	
Models are used to explain scientific phenomena. (ET3)			***.57***	
Models show a smaller scale size of something. (ER8)				**.74**
Models help to create a picture in your mind of the scientific happening. (ET2)				.58
Models are used to physically or visually represent something. (ET1)				.49

Extraction method: Principal component analysis, rotation method: Varimax with Kaiser normalisation, factor loadings less than .4 omitted.

Compared to the original instrument *SUMS*, item 6 (ET3) loads on scale USM (factor 3) rather than to ET (factor 4). Consequently, the scale 'Uses of scientific models' describes item 6 more adequately. Item 9 has a high factor loading on ET (factor 4). Nevertheless, the scientific content-related interpretation does not make sense. The definition of a model as a smaller scale of something does not fit to the latent variable 'Models as explanatory tools'. The reliability analysis confirms this assumption (see Table 9).

Table 9. Reliability analysis of scales on models at different measurement times

Scale (item number)		Cronbach's α T1	T2a	T2b	T3
Mod	(1,2,3,4,5)	**.45**	.71	.67	.74
ER	(1,4,8)	.54	**.78**	.74	.60
ET	(2,3,9)	**.11**	**.39**	**.04**	**-.14**
	(2,3)	**.56**	**.42**	**.28**	**.48**
USM	(5,6,7)	.62	.60	**.67**	.64

The scale 'Models as explanatory tools' will not be considered in further data analysis because of too low internal consistency. A reason for this low internal consistency can be the small number of items (Hammond, 2006). The differences of reliability values at different measurement times can be explained by students' low prior knowledge (T1). An explanation for the unacceptable low reliability of the scale 'Mod' at measurement time T1 is the use of the specific term 'Particle at the submicroscopic domain' which is rarely known to students.

In summary, to investigate students' understanding of scientific models eleven items referring to the three scales 'Models as exact replicas' (ER), 'Uses of scientific models' (USM) and 'Submicroscopic domain (Mod) are administrated.

Compared to the pilot study, just one item had been deleted and another one was added in order to reach higher reliability values. Both items refer to 'Models as exact replicas' – scale. The item 'Everything about a model should be able to tell what it represents' was replaced with the item 'Models show a smaller scale size of something', which refers directly to the meta-conceptual training.

4.3 Dependent Variable

"An understanding of chemistry requires students to integrate and link fundamental chemical concepts" (Krajcik, 1991, p. 117). According to this author, chemical terms have to be linked to build conceptual understanding. In other words, recalling terms is not synonymous with understanding. Based on German educational standards chemical understanding includes the ability to predict and explain scientific phenomena (KMK, 2005). However, explaining and predicting phenomena scientifically requires scientific knowledge (OECD, 2013). Consequently, conceptual knowledge requires students' ability to recall and apply chemical knowledge as Figure 23 demonstrates.

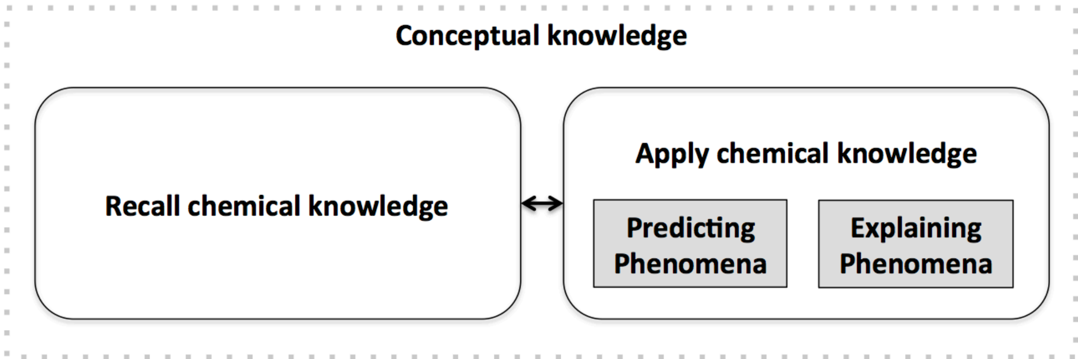


Figure 23. Operationalization of conceptual knowledge

According to the operationalization, this paper-and-pencil questionnaire consists of two different parts. Fifteen closed multiple-choice items referring to recall chemical knowledge. Additionally, seven two-tier-items adapted from Chandrasegaran, Treagust, and Mamiala (2007) refer to predicting and explaining phenomena. They are selected to investigate students' understanding and development of ions, redox reaction and electrochemical processes. The closed items are selected from the study by Marohn (1999) and Ropohl (2010). In addition, six closed items were developed to adapt the instrument to the experimental learning environment. All multiple-choice items have four response options with only one correct answer. The same questionnaire was used at all measurement times.

Part I

In Figure 24 a multiple-choice item of the first part of the test instrument is presented.

3 Redox reactions are...

- ☐ Neutralisation reactions.
- ☐ Electron transfer reactions.
- ☐ Proton transfer reactions.
- ☐ Electron pair transfer reactions.

FTC_3

Figure 24. Example of a multiple-choice-item (recalling chemical knowledge)

The reliability of the questionnaire is acceptable as shown in Table 10.

Table 10. Reliability analysis of multiple-choice items (Part I)

Cronbach's α (Scale variance if item 4 deleted)		
T1	T2b	T3
.66 (.68)	.63 (.65)	.64 (.66)

Item 4 correlates negatively on the scale at the first and third measurement time. Consequently, item number 4 is excluded from further analysis.

Compared to the pilot study five items are added in order to thoroughly investigate students' understanding of electrochemical processes.

Part II

The items in part II were adapted from Chandrasegaran, Treagust, and Mamiala (2007). In science education two-tier multiple-choice tests are used as a diagnostic tool to investigate students' alternative conceptions. In the first step, students have to justify their choice. Two-tier items aim "to assess students' knowledge of a scientific concept for tier 1 and their reasoning about this concept for tier 2" (Fulmer, Chu, Treagust, & Neumann, 2015, p. 1). Consequently, they have the benefit to get students' interpretation behind their response as well as their reasoning process (Gurel, Eryilmaz, & McDermott, 2015). Against the test instrument from Chandrasegaran, Treagust, and Mamiala (2007), items are developed and evaluated focusing on students' explanation of a possible observation because these items aim at investigating students' conceptual knowledge as the item example shows.

1 You put a piece of iron into a copper sulphate solution.

What do you observe?

- ☐ Iron dissolves.
- ☐ Iron does not change.
- ☐ A blue coloured layer covers iron.
- ☐ A copper coloured layer covers iron.

Explain your observation...

a) ...in written form!

b) ...visually! FTC_tt2

Figure 25. Example of a two-tier-item (predicting and explaining chemical knowledge)

According to the definition of scientific knowledge by the OECD (2013), students should predict and explain scientific phenomena. Seven items relate to the following content shown in Table 11.

Table 11. Overview of the chemical content

Content	Item number
Redox reaction	tt3, tt5
Reaction of precipitation	tt2, tt6
Galvanic cell	tt4, tt7, tt8

Predicting and explaining scientific phenomena might to be close to real and authentic science. An open response format is chosen for explaining the observation. In addition, students are prompted to answer in text and with the help of visualizations to give space for self-constructed drawings. Moreover, this procedure provides the opportunity to use multiple representations. Open-ended items have the disadvantage that students do not have to give detailed response (Reja, Manfreda, Hlebec, & Vehovar, 2003). This problem was also identified in the presented study. In a first analysis approach, a coding scheme was developed including 244 scientifically correct statements (see appendix D.II). The items were analysed with the help of the statistic software SPSS ®. For each item, the coder had to agree if the student used scientifically correct statements (1), or not (0). Around 10% of the answers are double coded to determine interrater agreement. While the percentage agreement is 99%, the kappa coefficient is $\kappa = .80$.

Table 12. Agreement matrix of coding scientifically correct statements

		Coder 2		
		0	1	Σ
Coder 1	0	**10037**	46	10083
	1	32	**161**	193
	Σ	10069	207	**10276**

A reason for comparable low kappa is the unequal distribution of codes which affects the value of Cohen's kappa. In particular, the problem is caused if a code is seldom used. Feinstein and Cicchetti (1990) define this problem as first kappa paradox: "A low value despite high values of p_0 will occur only if the marginal totals are highly symmetrically unbalanced" (p. 546).

Nevertheless, students responded rarely to the open-ended items. Hence, the detailed coding scheme was not suitable in order to investigate partial understanding. Consequently, the partial credit model is selected to analyse the data (Masters, 1988). Three levels of understanding are defined to measure students' achievement.

Table 13. Categories of the partial credit model

Category	Description	Step
0	Unable to solve	Step 1
1	Able to solve multiple-choice item	Step 2
2	Able to develop explanatory approach	

The partial credit model is an item response model which distinguishes separable person and item parameters (Masters & Wright, 1997). While the classic test theory points to the existence of a true score (Moosbrugger & Kelava, 2008; Novick, 1966; van der Linden & Hambleton, 1997), the item response theory, "also known as latent trait theory, is model-based measurement in which trait level estimates depend on both persons' responses and on the properties of the items that were administered" (Embretson & Reise, 2000, p. 13). Accordingly, the partial credit model can estimate a person's ability more precisely (Masters, 1988). The detailed coding scheme is used to identify students' explanatory approach. One correct statement for each item means students have an explanatory approach.

The following equation describes person n scoring x on item i where β_n is the ability of person n. Based on the categories, x reaches values from 0 to 2 per each item. In sum, seven items are analysed.

$$\pi_{xni} = \frac{exp \sum_{j=0}^{x} (\beta_n - \beta_{ij})}{\sum_{k=0}^{m_i} exp \sum_{j=0}^{k} (\beta_n - \delta_{ij})} \qquad x = 0,1,2_i$$

with notational convenience $\sum_{j=0}^{0} (\beta_n - \delta_{ij}) \equiv 0$.

δ_{ik} $(k = 1,2)$ is defined as the individual step difficulty (Masters, 1982, p. 158).

Table 14. Scores for a two-step item i of person n

Person n	Performance level			Score
	0	1	2	x_{ni}
1	$\xrightarrow{First\ step:\ \delta_{i1}}$		$\xrightarrow{Second\ step:\ \delta_{i2}}$	x_{1i}
…	$\xrightarrow{First\ step:\ \delta_{i1}}$		$\xrightarrow{Second\ step:\ \delta_{i2}}$	…
111	$\xrightarrow{First\ step:\ \delta_{i1}}$		$\xrightarrow{Second\ step:\ \delta_{i2}}$	x_{111i}

The data of the pre-, post- and follow-up test is analysed with the help of the software ConQuest®. As regression model, students' cognitive abilities (V2-, N2-scores) are taken. The goodness of fit statistic shows satisfactory results. According to Bond and Fox (2015), if the weighted-mean-square value reaches the expected value E of 1, the goodness of fit of the model is perfect. The values at the pre-test are between $0.94 \leq MNSQ \leq 1.07$. Five items (tt2, tt3, tt4, tt7) have an overfit (larger variance in responses than in the model) and two items (tt5, tt8) have an underfit (lower variance in responses than in the model). At the post-test the values are between $0.96 \leq MNSQ \leq 1.0$. While the first item (tt2) perfectly fits, three items (tt4, tt6, tt7) have an overfit and three (tt3, tt5, tt8) an underfit. At the follow-up-test the values are between $0.89 \leq MNSQ \leq 1.08$. While two items have an overfit (tt6, tt7), five items (tt2, tt3, tt4, tt5, tt8) have an underfit. Moreover, "the standardized fit statistic indicates 'how likely' is that amount of misfit" (Bond & Fox, 2015, p. 67). t-values are accepted between $-2 \leq t \leq +2$. All t-values range between $-0.7 \leq t \leq +0.6$ at the pre-, post- and follow-up-test. Consequently, it can be assumed that the model fits and students' cognitive abilities reflect the latent trait.

The person separation reliability analysis shown in Table 15 indicates a too low value at the pre- test ($<$ .5), a poor value ($>$ .5) at the post-test but an acceptable value at the follow-up-test. However, the reliability values of the item separation are excellent as the following table shows. The values can be interpreted like the Cronbach's alpha coefficient (Bond & Fox, 2015).

Table 15. Item and person separation reliability

	Reliability value		
	T1	T2b	T3
Item separation	.95	.98	.93
Person separation	.38	.54	.71

The results of Rasch analysis are depicted in a Wright map in Figure 26. Individual student's performance (0.2 students are represented by an 'X') on the items (indicated by the item number) are presented. The results are shown on the logit scale "which is the measurement unit common to both person ability and item difficulty" (Bond & Fox, 2015, p. 67). The Wright map of pre-test results indicates that the items are too difficult for the students (1=tt2, 2=tt3, 3=tt4, 4=tt5, 6=tt7, 7=tt8).

```
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--------------------------------------------------------------------------------------
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======================================================================================
Each 'X' represents    0.2 cases
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Figure 26. Pre-test: item-person analysis wright map

The Wright map of post-test results show that students can solve more easily the items.

Figure 27. Post-test: Item-person analysis wright map

In the pilot study one additional item was used to investigate students' understanding of the oxygen transfer. To avoid confusion of the different chemical concepts, this item was deleted. Furthermore, the three items about the galvanic cells were too complex. Accordingly, schematic representations of the galvanic cell were added in order to reduce complexity by visualizations. In the pilot study students responded in a detailed way. As a consequence, students' difficulties could not have been anticipated.

4.4 Video Analysis

Before conducting video research, the researcher should consider issues of selection, technology, ethics and analysis (Derry et al., 2010). The selection process depends on the research question. Hence, the video analysis of this research project aims at answering in which situations and how students communicate their knowledge about scientific representations and its the modelled nature (see 3.1). Moreover, video data is a powerful data source to triangulate it with the quantitative data. Therefore, students were videotaped while doing scientific hands-on activities. Moreover, to focus on students' communication, video cameras are located in front of one pair to offer a small but focalised perspective. An additional microphone on the table should provide good audible quality. According to ethical considerations, students are anonymised in order to protect their rights. Video data provide a promising source to analyse students' communication processes and allow a unique iterative process (Jacobs, Kawanka, & Stigler, 1999) as shown in Figure 28.

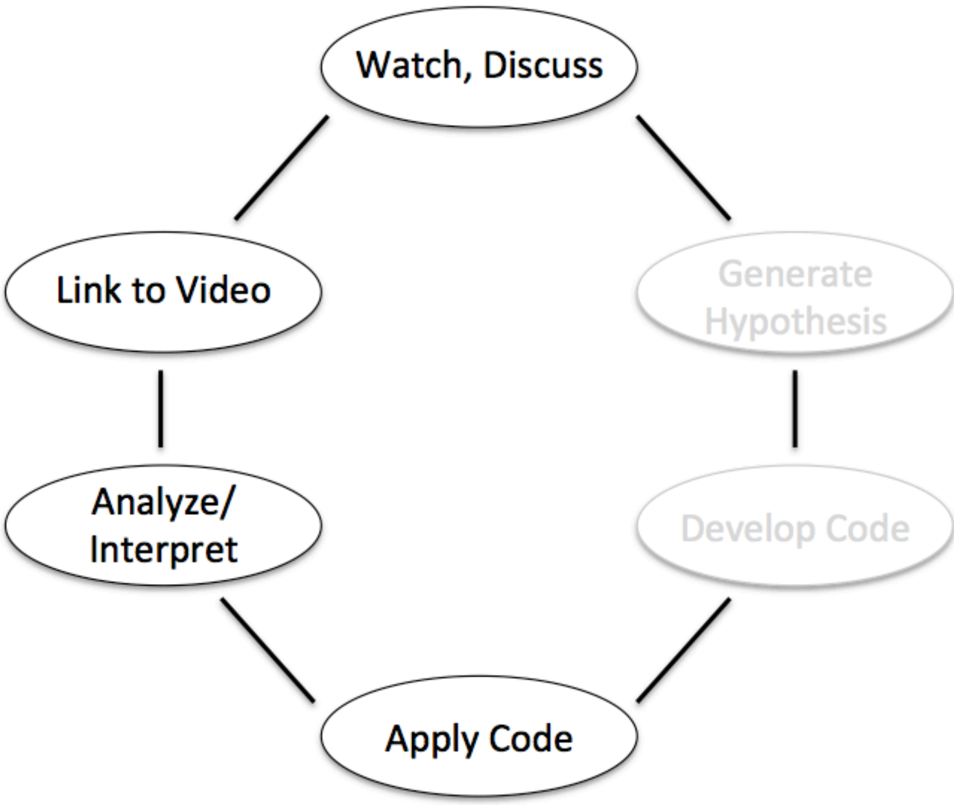

Figure 28. Cycle of coding and analysis of video data (Jacobs et al., 1999, p. 719)

This coding and analysis circle is more appropriate to explore video data in a more inductive approach. Hence, the aspects 'generating hypotheses' and 'developing codes' play no important role within this deductive analysing approach. Consequently, the coding variables are developed in line with the theoretical background.

Coding Variables

The first dimension of the coding scheme includes just surface structure to control students' inquiry activities. The second dimension describes the meta-conceptual awareness according to the theoretical background (see chapter 2.3.4 and appendix D.III).

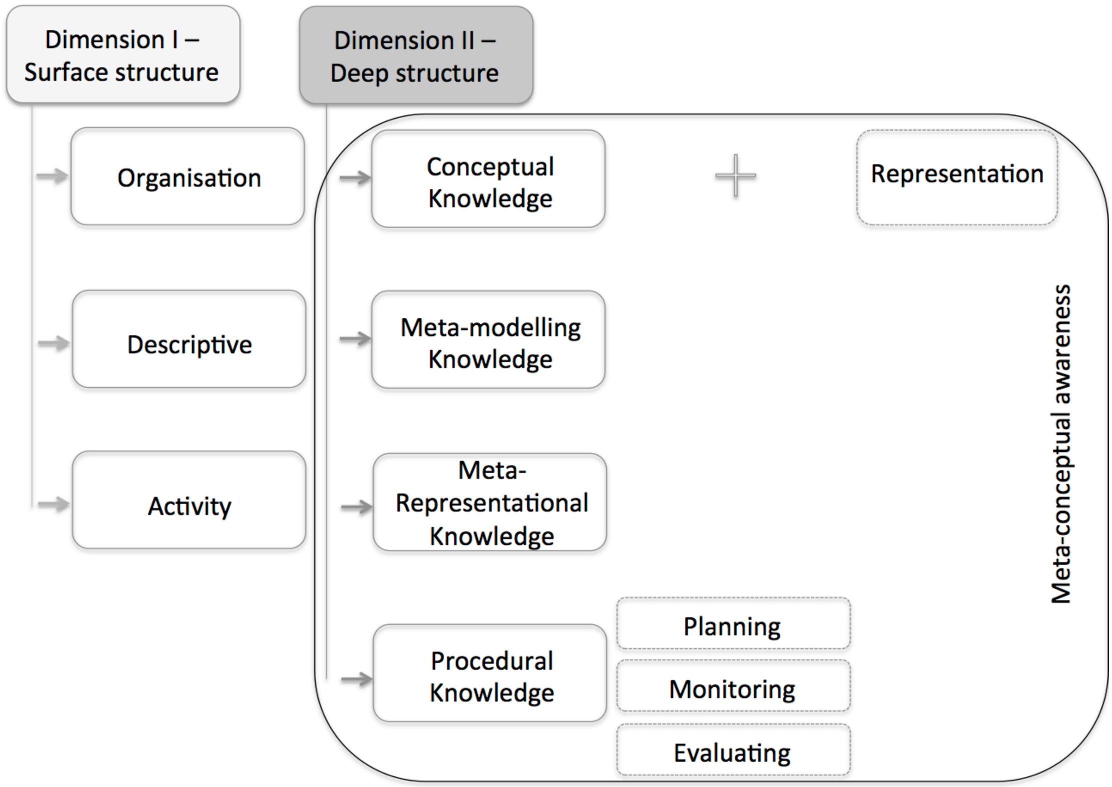

Figure 29. Coding scheme for video analysis

Macro-level coding aims to provide an overview of students' activities. Moreover, it controls the processes between pre- and post-test. Deep structure codes are based on meta-conceptual awareness. In the first approach, meta-modelling knowledge (see Table 2) and meta-representational knowledge (see Table 3) were coded in a more detailed way. However, students rarely spoke about scientific knowledge at a meta-level. Accordingly, all codes according to the different aspects of models and representations were summarised in meta-modelling knowledge and meta-representational knowledge. Conceptual knowledge refers to students' understanding of chemical concepts. This kind of knowledge is coded in addition to the representation domain: macroscopic, submicroscopic and formal. Based on the empirical studies presented in chapter 2.2.5 students have difficulties in understanding the different representations. Therefore, it can be assumed that students do not use the representation separately. Additional codes were defined relating to mixing representations. Table 16 shows an overview of the representation domains.

Table 16. Representation domains

Domain	Code	Description/ Example
Experienced	Rep_ EW	Is defined as students use a statement, which refers to macroscopic aspects that are "directly" accessible to the senses/ [06:58.8-06:59.8] LGGY39/Box1: "That's red."
Submicroscopic	Rep_SL	Is defined as students use a statement, which refers to submicroscopic aspects like atoms or molecules/ [26:46.0-26:48.2] LGGY39/Box1: "Oxygen atom has minus two electrons."
Formal	Rep_FL	Is defined as students use a statement, which refers to chemical formulae language like Fe or Cu/ [13:33.3-13:35.3] JKGY20/Box1: "SO_4^{2-} or not"
Submicroscopic/formal	Rep_ SLFL	Is defined as students use submicroscopic and formal aspects in one statement/ [27:40.1-27:46.7] LGGY39/Box1: "Cu^{2+} gives two electrons
Experienced and modelled world	Rep_ EWMW	Is defined as students use macroscopic, submicroscopic and formal aspects in one statement/ [20:37.2-20:43.7] JKGY20/Box3: "That $2e^-$ are going that way and give it away to copper"
Experienced /formal	Rep_ EWFL	Is defined as students use macroscopic and formal aspects in one statement/ [09:47.0-09:48.7] LGGY38/Box2: "Red is +"]
Experienced/sub-microscopic	Rep_ EWSL	Is defined as students use macroscopic and submicroscopic aspects in one statement/ [06:58.8-06:59.8] LGGY39/Box1: "Zinc nail was reduced

The video data of the pilot study support students' difficulty in separating different representation domains. For example, "you know that oxygen is charged partial negatively" [2:15-2:17 RGO07/Box 1]. This statement is coded as conceptual knowledge in combination with mixing the experienced and submicroscopic domain. Improving this statement to a scientifically correct one, it must be: "You know that the oxygen **atom** in a **water molecule** is charged partial negatively." Oxygen is a macroscopic accessible entity, which cannot be charged. Furthermore, students' procedural knowledge is coded with regard to planning, monitoring and evaluating activities. Planning activities are not related to the inquiry process such as planning how to perform a hand-on activity. They include processes with regard to scientific meta-knowledge such as planning how to externalise their knowledge (e.g., "This? You can write it down related to the formal domain" [Lggy03/Box1 18:02.4-18:04.9]).

Sample

For this video study six cameras were available. The video sample is composed of two videotaped pairs of students per treatment per school. While at the second and third school the research project took place during two afternoons, the sample from the first school was divided into two groups participating separately on two afternoons. Consequently, 24 pairs of students could be videotaped.

Data Analysis

The video data was coded in an event-based way with the help of the software Maxqda®. The limitation of Maxqda® is that the communication and activities of only one student can be coded per video. Hence, every video is implemented in the program two times. To ensure quality in the process, an independent interrater coded 20% of the video material. The challenge of double coding was to identify events at the same time compared to the first coder and then to use the same codes. The results are shown as percentage agreement. Therefore, all coded events of both coders were tabular compared with the help of Maxqda ®. Finding an event, finding the same in- and out-points of an event and the same code for an event influence the agreement of both coders. Considering these factors the percentage agreement is 80%. Cohen’s kappa is not calculated because of a non-square matrix.

Moreover, the video data is analysed with the help of qualitative content analysis (Mayring, 2010). A deductive approach is applied relating to the theoretical framework (Derry et al., 2010). Furthermore, the analysed data is quantified with the help of SPSS®. In a first step, video data from the pilot study is coded in order to test and adapt the coding scheme as well as to train the interrater.

4.5 Lab Journal Analysis

The lab journal provides an additional data source in order to analyse students' conceptual understanding as well as their understanding about and use of representations. Therefore, the lab journal analysis consists of three parts presented in Figure 30.

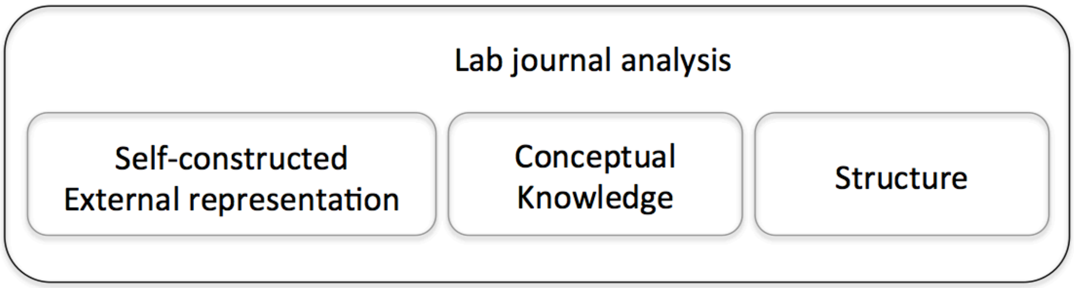

Figure 30. Overview of the coding scheme of the lab journal

In an unpublished bachelor thesis (Lampe, 2016) students' self-constructed external representations were investigated. Drawings are a key tool to learn science or to communicate about science (Ainsworth et al., 2011). A drawing can be defined "as a learner-generated external visual representation depicting any type of content, whether structure, relationship, or process, created in static two dimensions in any medium" (Quillin & Thomas, 2015, p. 2). According to these authors, drawing is the process of externalising one's internal and mental representation. Based on content analysis with an inductive approach (Mayring, 2010), students' explanatory drawings were analysed. Lampe (2016) developed a coding scheme focusing on analysing the different kinds of macroscopic, submicroscopic and formal representations (see appendix D.IV.i). The data was analysed with the help of Maxqda® as depicted in Figure 31.

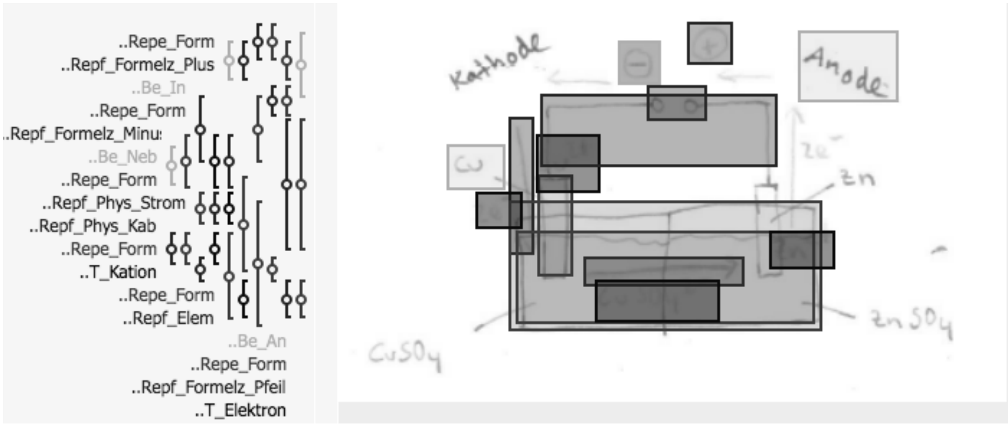

Figure 31. Screen shot of drawing analysis with Maxqda®

In the context of this bachelor thesis, another researcher coded 20% of students' external representations. The percentage agreement is roughly 80%. Cohen's kappa is not calculated because of a non-square matrix.

Moreover, students' explanatory approaches are investigated. Therefore, a detailed coding scheme of chemistry-related statements is formulated per each interactive box (see appendix D.IV.ii). For each interactive box, the coder had to agree if the student used scientifically correct statements (1), or not (0). Another researcher coded 20% of lab journals with the help of the level of expectations. The agreement matrix is presented below.

Table 17. Agreement matrix of coding conceptual statements

		Coder 2		
		0	1	Σ
Coder 1	0	**1505**	43	1548
	1	34	**156**	190
	Σ	1539	199	**1738**

Although the percentage agreement is 95,6%, Cohen's kappa remains comparatively small with $\kappa = .78$. One reason is the unequal distribution of codes. Coder 1 and 2 agreed in 1505 cases that students did not apply conceptual knowledge. Only in 156 cases, however, students showed conceptual knowledge.

In the last step, the structure of the lab journal is analysed in order to answer the question if the students apply their knowledge of the meta-conceptual training. This analysis focuses on identifying the specific terms such as ‘Experienced world’ or ‘Modelled world’. Furthermore, every statement is coded in addition to the representation domain presented in Table 16. Another researcher coded 20% of the lab journals. Calculating Cohen’s kappa causes two problems:

1. Both coders have to find independently the events such as students use a table to structure their lab journal.
2. If the two coders do not find the same events a non-square matrix results and it is impossible to calculate Cohen’s kappa.

Coder 1 and 2 found different numbers of events but in 934 cases they found the same events. Accordingly, the percentage agreement is calculated and reaches 94,9%. Coder 1 found 30 different events than coder 2 who found 20 other events than coder 1. Figure 32 presents an example of the structure and representation domain analysis.

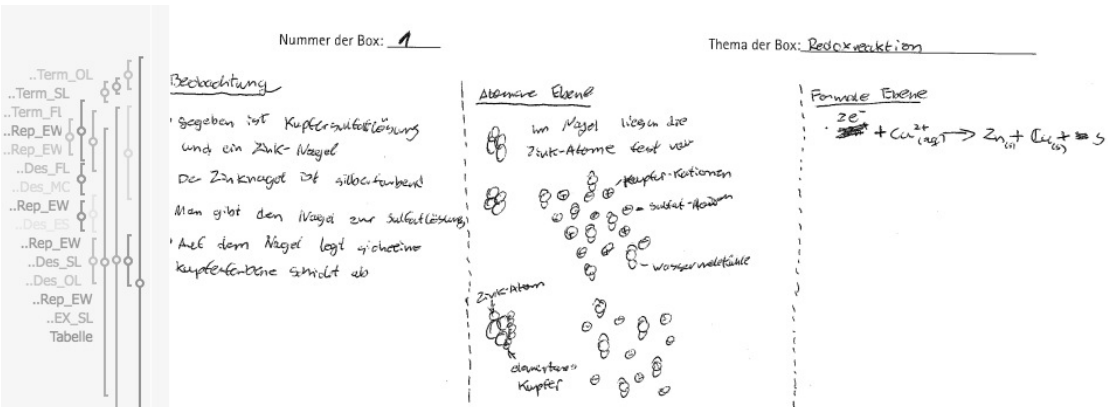

Figure 32. Screen shot of the structure and the representation domain analysis with Maxqda®

5 Results

5.1 Descriptives

Sample

One hundred thirty-six students were recruited from three secondary schools in Lower Saxony, Germany. The final sample of students was reduced to 111 because of illness or other reasons for quitting the project. Consequently, 111 students participated in pre- and post-test as well as in the three sessions of interactive boxes. Table 18 describes the sample.

Table 18. Overview of the sample

School	Final sample *N*	Gender [%]		Age
		Female	Male	
1	50	42	58	15.9
2	39	62	38	16.1
3	22	64	36	15.7
Σ Total	111	53	47	15.9

Students had achieved grades in chemistry ranging from 1 to 5 while the possible grades range from excellent (grade 1) to failed (grade 6). The average grade was $M = 2.74$ $(SD = 1.04)$ with 58.5% of students being at grades 2 and 3 but almost 26.1% at grade 4. Grades in physics show similar values ranging from 1 to 5 and an average grade of $M = 2.59$ $(SD = 1.03)$ with 66.6% at grades 2 and 3 and just 12.6% at grade 4.

Less students participated in the follow-up-test. Due to German educational system reasons, many students change to specialized secondary schools or leave school after 10^{th} grade or do not anymore participate in chemistry classes. Consequently, only 60% of the sample participated in the follow-up-test: 21 students of the control group, 26 students of the first experimental group and 22 students of the second experimental group. However, the one-way ANOVA demonstrates non-significant differences between the groups in participating in chemistry classes.

Cognitive Abilities

The data of the verbal- and non-verbal-test is non-normally distributed as the Kolmogorov-Smirnov test demonstrates and as Figure 33 and Figure 34 show.

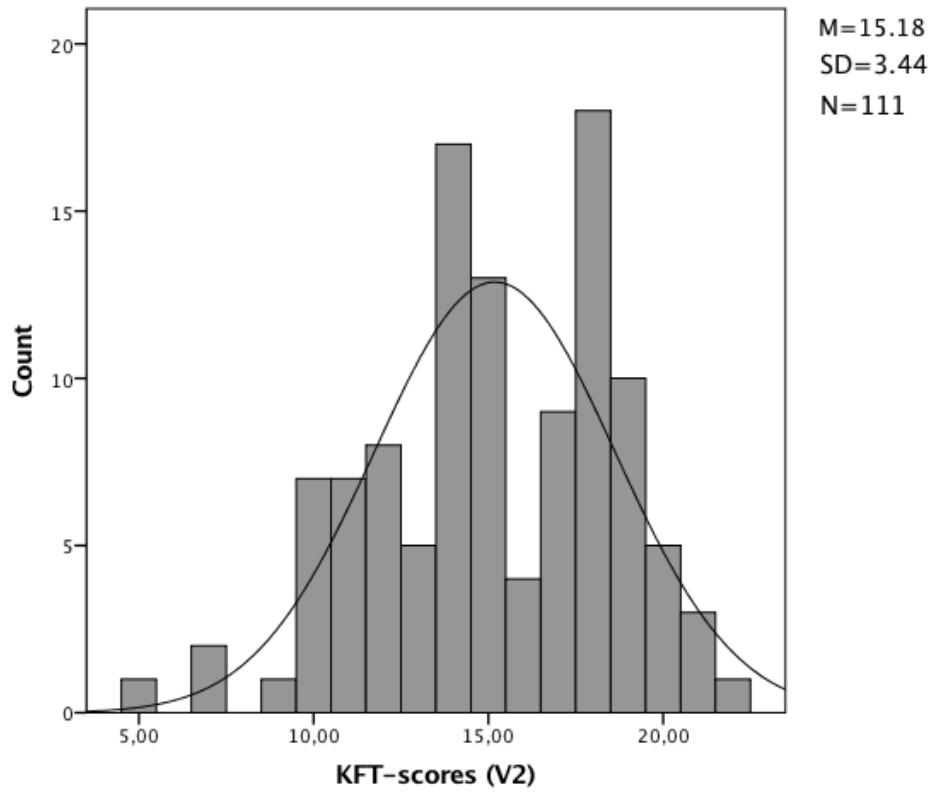

Figure 33. Histogram of KFT-scores V2

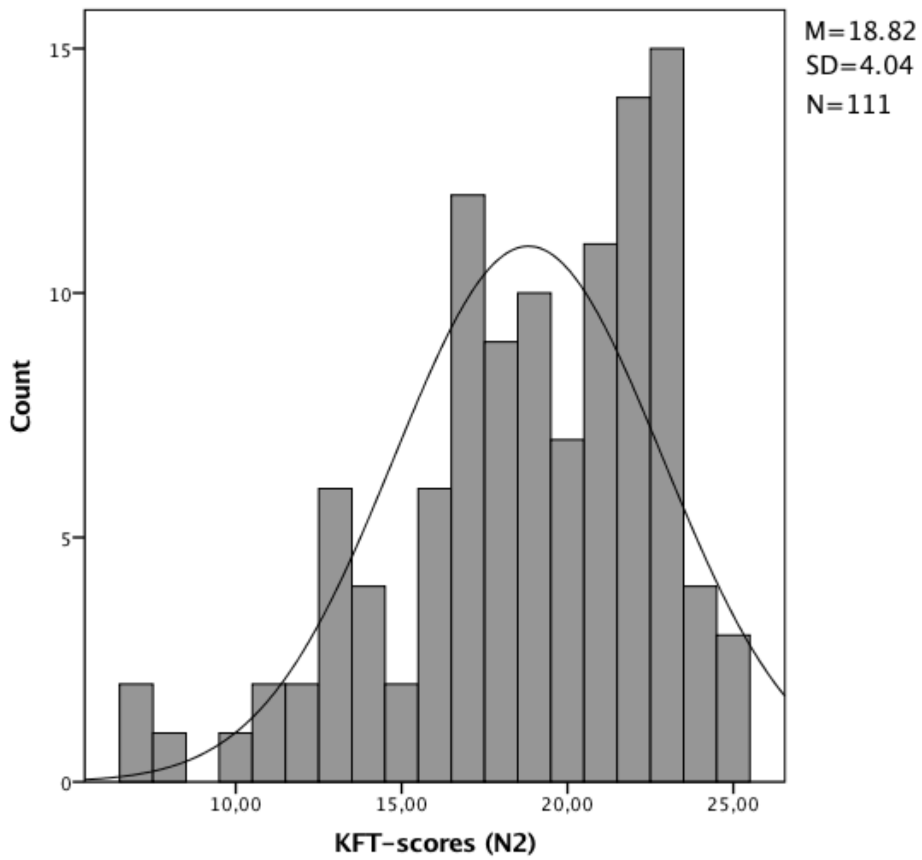

Figure 34. Histogram of KFT-scores (N2)

The data of the verbal- and non-verbal-test has a negative value of skewness $S_{V2} = -.39$ $(SE = .23)$ and $S_{N2} = -.82$ $(SE = .23)$ which "indicates that the tail on the left side of the distribution is longer than the right side and the bulk of the values lie to the right of the mean" (Kim, 2013, pp. 52-53). There is a very significant negative skew of the non-verbal data shown by z-scores greater than 1.96 (cf. Field, 2005). Based on non-normally distributed data, a nonparametric test should be used. However, nonparametric test statistics are not as powerful as parametric test statistics (de Vaus, 2002). Nevertheless, according to this author, a parametric test can safely be used for non-normally distributed data for larger samples (100 or more).

While the mean values of the verbal-scale (V2) remain constant over the different schools, the mean values of the non-verbal scale (N2) seem to differ as depicted in Figure 35.

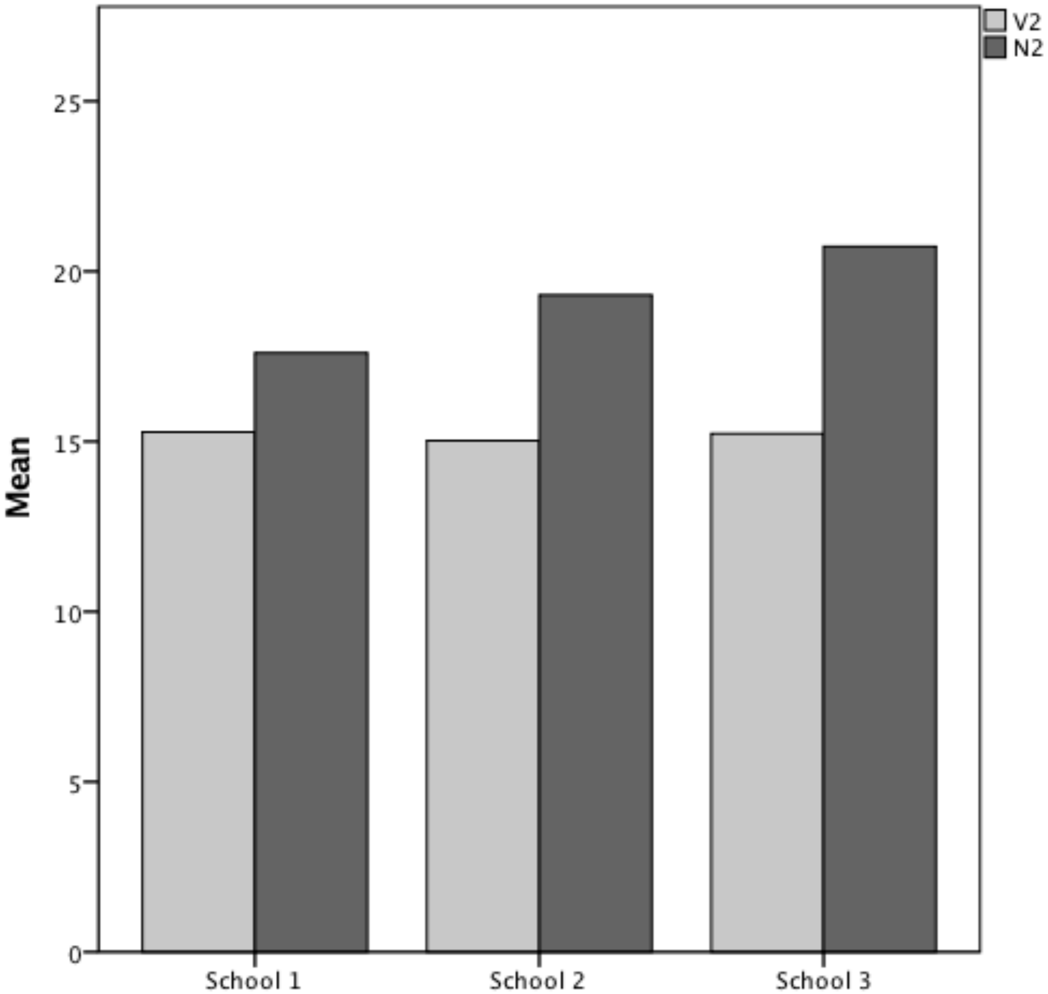

Figure 35. Overview of mean scores of cognitive abilities (V2-verbal; N2-non-verbal)

Students consistently showed lower cognitive abilities in the V2-test compared to the N2-test. The analysis of variance, called ANOVA, tests whether group means of the different schools differ. There is only a significant difference in the mean values of the data of the non-verbal-test, $F(2{,}110) = 5.42, p < .01, \omega = .27$. The Scheffé post-hoc test illustrates significant differences of students' non-verbal abilities between the first ($M = 17.6, SD = 4.12$) and third school ($M = 20.73, SD = 3.48$).

Attitudes, Interest and Motivation

All students show low subject-related individual interest in chemistry ($M = 1.4, SD = 0.65$). Students from the three schools differ only significantly on the scale 'extrinsic-grades', $F(2{,}109) = 4.78, p = .01, \omega = 0.25$. The Scheffé post-hoc test indicates the significant difference on the scale 'extrinsic-grades' between the second $(M = 1.36, SD = 0.74)$ and third school $(M = 2.22, SD = 0.69)$. The significant difference of students' self-concept $(t(109) = 3.62, p < .001, d = 0.35)$ between male $(M = 1.93, SD = 0.83)$ and female students $(M = 1.34, SD = 0.75)$ is in line with previous empirical research (Wang, Oliver, & Staver, 2008).

Balancing of Treatment

In order to balance the treatments, data on students' attitudes, interest and motivation as well as their cognitive abilities and their prior content knowledge was collected. The pre-test data had been analysed before the intervention phase started. Because of the high drop out rate after the pre-test at the third school (caused by the world championship finals) students from this school were spontaneously divided into treatment groups. Accordingly, the condition of equal division within the treatment was not satisfied.

Attitudes, Interest, Motivation. A one-way ANOVA shows significant differences on the scale self-concept between the groups, $F_{sbk}(2,110) = 3.71, p < .05, \omega = .22$.

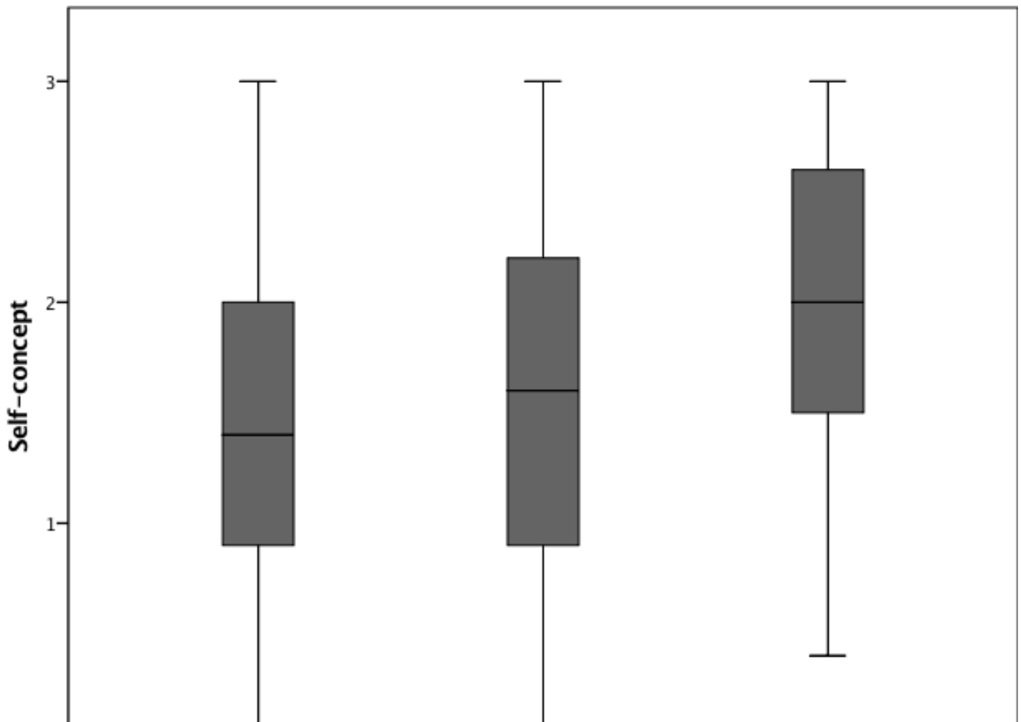

Figure 36. Difference of the self-concept over the treatment

As Figure 36 highlights, the significant difference is between the control ($M = 1.44, SD = 0.82$) and the second experimental group ($M = 1.93, SD = 0.68$). Consequently, this difference will be considered in further analyses.

Cognitive Abilities. There were no significant effects of the treatment group on the cognitive abilities scales (V2, N2).

Prior Content Knowledge. Prior content knowledge of science has a positive influence on achievement (Hewson, 1982; Tobias, 1994). Hence, the treatment is divided into three equal groups based on test scores of recalling chemical knowledge (Part I). A one-way ANOVA shows a non-significant difference of scores between the groups.

In summary, the three treatment groups are equally distributed on cognitive abilities and recalling chemical knowledge. However, students' self-concept in chemistry varies significantly between the control and the second experimental group. As a consequence, it is included as a covariate in further analyses considering between-group differences.

Video Sample

The final video sample is composed of 48 students participating in all sessions: eleven pairs of male students, one female group of three students, seven pairs of female students, four mixed pairs and one female student who changed the partner. Due to unacceptable audible quality the data of three students was excluded from the video analysis. Consequently, the total sample available for video analysis includes 45 students as depicted in Figure 37.

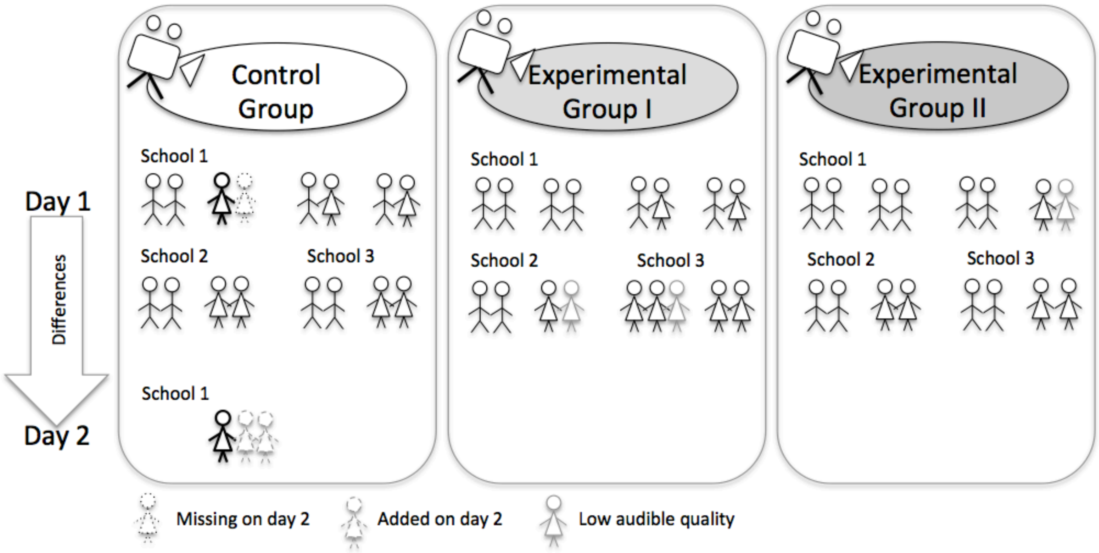

Figure 37. Distribution of video sample

However, one student did not participate in the post-test. The video material consists of 135 videos with a mean length of about 25 minutes. 20 girls (44,4%) and 25 boys (55,6%) were videotaped. Students from the video sample do not differ in their self-concept as the Kruskall-Wallis-test demonstrate, $H(2) = 2.57, p = .276$.

5.2 Learning Effects

5.2.1 Experimental Learning Environment

Independent from the meta-conceptual training, all students should acquire conceptual knowledge while learning in the experimental learning environment. It can be assumed that working with the interactive boxes has a positive influence on students' conceptual knowledge as it depicted Figure 38.

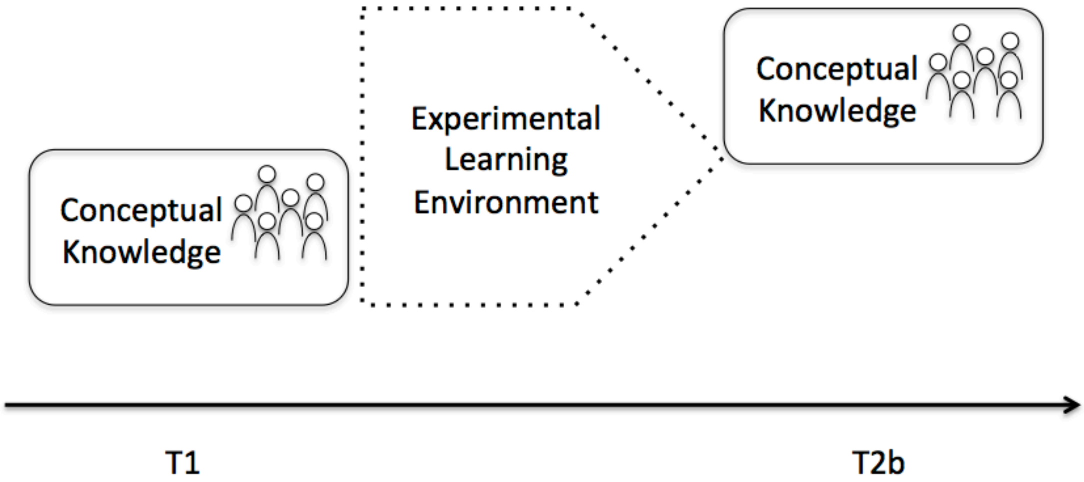

Figure 38. Assumption of the effect of the learning environment on students' conceptual knowledge

At first, a Kolmogorov-Smirnov test was conducted in order to investigate whether the distribution among the test scores (Part I) is normal. The results of this test confirm that the deviations from normality are significant at both measurement times, $T1$: $D(110) = 0.12, p < .01$; T2: $D(110) = 0.1, p < .05$. However, a t-test was run because of the large sample size. The results show that all students have acquired chemical knowledge, $t(110) = 12.84, p < .001, d = 1.2$. The observed effect is large. It can be summarised that the students achieved significantly higher scores on the post-test ($M_{T1} = 6.1, SD_{T1} = 2.68$; $M_{T2b} = 9.39, SD_{T2b} = 2.49$) as depicted in Figure 39.

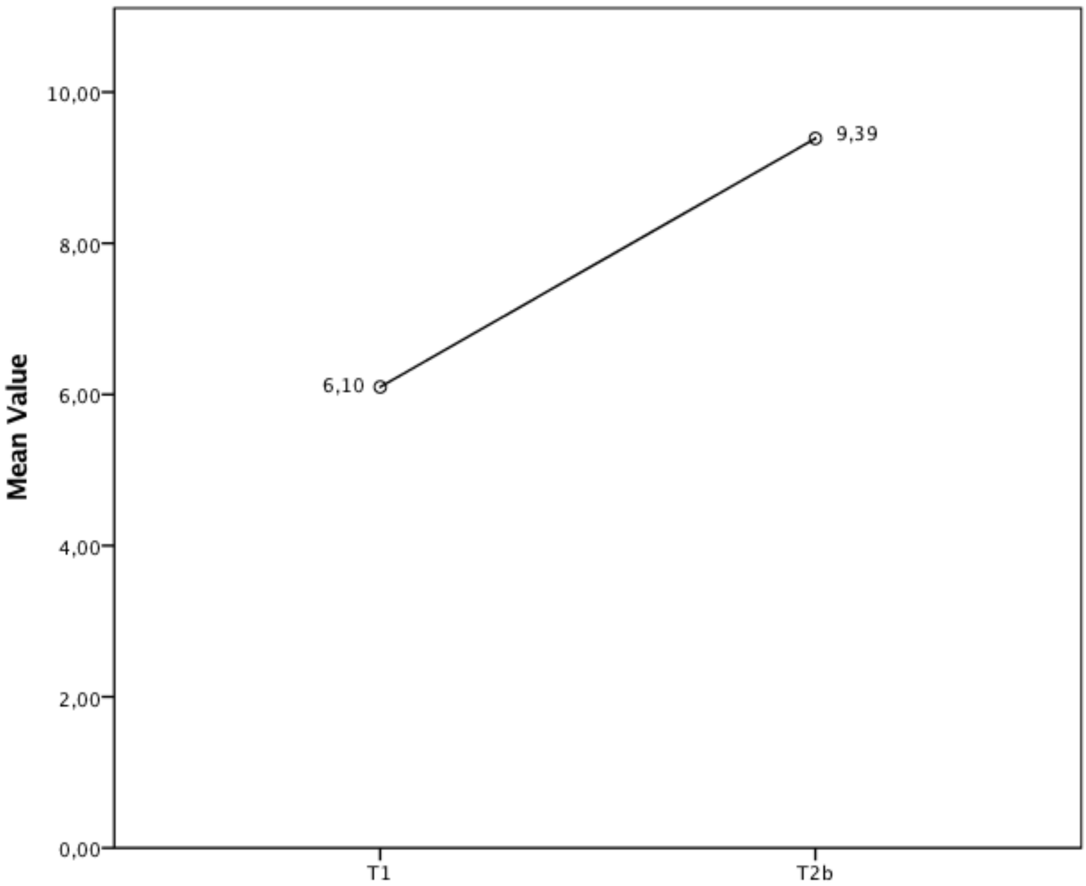

Figure 39. Comparison of students' pre- and post-test results

Students' test scores on predicting and applying chemical knowledge (Part II) has increased from pre- to post-test, $t(110) = 10.27, p < .001, d = .97$. On average, students achieved 2.1 points ($SD = 1.88$) in the pre-test and 3.96 points ($SD = 1.89$) in the post-test, while the maximum of test scores could be 21 points.

In sum, the experimental learning environment has a positive influence on students' ability to recall, predict and apply chemical knowledge.

Situational Interest

After working on the interactive boxes students were asked to evaluate the challenge, cooperation within the pair, topic-related situational interest and intrinsic motivation. The descriptive results of the mean values are presented in Table 19.

Table 19. Descriptive results of situational interest

Scale	Measurement Time	Sample	Mean (0=strongly disagree; 3=strongly agree)	Standard Deviation
her	S1	107	2.06	.57
	S2	111	1.85	.53
	S3	111	1.81	.62
koop	S1	107	2.36	.52
	S2	111	2.32	.49
	S3	111	2.24	.63
tosi	S1	107	**1.53**	.48
	S2	111	**1.30**	.52
	S3	111	**1.27**	.54
exin	S1	107	2.27	.50
	S2	111	2.06	.43
	S3	111	2.04	.48

This table illustrates also the low mean value (in bold) of students' topic-related situational interest. The mean values of the scale 'cooperation' do not significantly differ between the measurement times. The mean values of the other scales decrease from the first to third measurement time. A simple explanation for students' reduction of interest lies in the declining effect of novelty of the interactive boxes.

Cognitive Load

The cognitive load differs significantly between the first ($M = 2.25, SE = 0.1$) and second measurement time ($M = 3.01, SE = 0.1$), $t(110) = -6.28, p < .001, d = 0.6$, and the first and the third measurement time ($M = 3.02, SE = 1.19$), $t(110) = -5.95, p < .001, d = 0.56$. These effects are large and represent a substantive finding (cf. Field, 2005).

There is a significant difference between the treatment groups in their cognitive load ('Performing an exercise') at the second measurement time, $F(2,108) = 6.02, p < .01, r = .32$. The first ($M = 3.28, SD = 1.21$) and second experimental group

($M = 4.27, SD = 0.93$) differ significantly ($p = .002$) in evaluating their cognitive load while the control group does not significantly differ ($M = 3.87, SD = 1.47$).

5.2.2 Meta-conceptual Training

It can be assumed that the meta-conceptual training increases students' understanding about models and representations as shown in Figure 40.

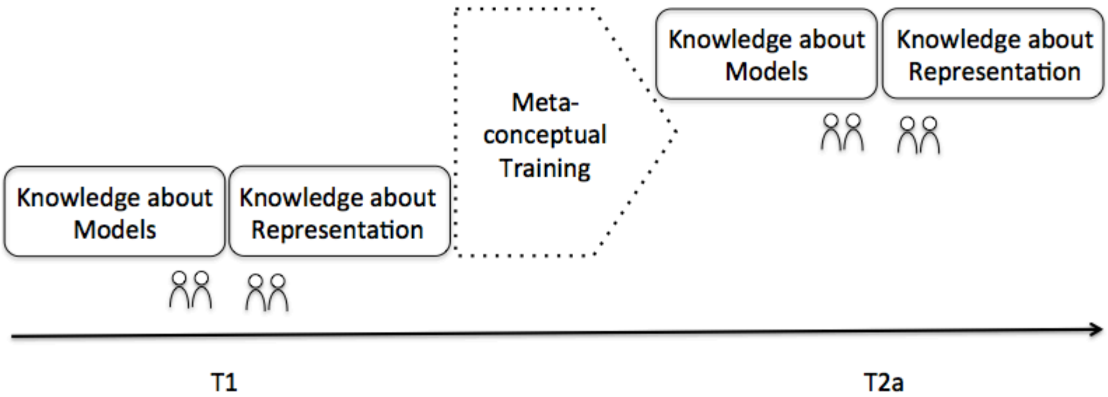

Figure 40. Assumption of the influence of the meta-conceptual training on knowledge about models and representations

Knowledge about Representations

Firstly, students' development in classifying chemical statements was analysed. For students from the experimental groups, scores of knowledge about representations were significantly higher on the post-test (T2a: $\boldsymbol{M = 5.34, SD = 3.66}$) than on the pre-test (T1: $\boldsymbol{M = 2.18, SD = 1.97}$) as the results of the Wilcoxon signed-rank test indicates. The Wilcoxon signed-rank test was performed because of non-normally distributed data and a smaller sample size than 100 students. Table 20 illustrates the z-scores, the exact significance and the effect size r that is calculated as follows:

$$r = \frac{Z}{\sqrt{N}}$$ *N* is the number of total observations

Table 20. Test statistics[a] of Wilcoxon signed-rank test (knowledge about representations)

	Rep(T2a)-Rep(T1)
Z	-5.828[b]
Asymp. Sig. (2-tailed)	<.001
r	-.68

a Wilcoxon Test, b Based on negative ranks,

Secondly, students recommended their classifications with regard to their belief of their own choice. Less than 10 percentages of such choices were related to a feeling of uncertainty at measurement time T2a. This result indicates a reasonable certainty in students' answers.

Comparing the control group with the experimental groups, illustrate a significant influence of the treatment on the development of knowledge about representations as the repeated-measures ANOVA shows, $F(1{,}109) = 20.03, p < .001, \eta^2 = .16$. Partial eta square indicates a medium effect.

Comparing the control group with the first and the second experimental group over the three measurement times (T1, T2a, T2b), demonstrates still a significant impact of the treatment on the development of knowledge about representations, $F(4{,}216) = 9.24, p < .001, \eta^2 = .15$.

Knowledge about Models

The results of the Wilcoxon signed-rank test indicate a positive influence of the training on students' knowledge about scientific models on all scales as

Table 21 demonstrates.

Table 21. Test statistics[a] of Wilcoxon signed-rank test (knowledge about models)

	ER(T2a)-ER(T1)	Mod(T2a)-Mod(T1)	USM(T2a)-USM(T1)
Z	-5.103[b]	-5.616[b]	-2.161[c]
Asymp. Sig. (2-tailed)	<.001	<.001	.031
r	-.42	-.47	-.18

a Wilcoxon Test, b Based on positive ranks, c Based on negative ranks

Nevertheless, the training stimulates less the stage in the development of using scientific models. The results demonstrate a significant difference between the mean values from the pre-test ($Mod\colon M = 1.53, SD = 0.5; USM\colon M = 1.91, SD = 0.63; ER\colon M = 1.29, SD = 0.66$) to the post-test (T2a: $Mod\colon M = 1.11, SD = 0.61; USM\colon M = 2.09, SD = 0.57; ER\colon M = 0.73, SD = 0.61$). While the effect sizes from the differences on the scale ER and Mod are medium to large, there is just a small to medium change on the USM scale (cf. Field, 2005).

Comparing the control group with the experimental groups, illustrate a significant influence of the treatment on the development of knowledge about models on the scale 'Mod', $F(1{,}105) = 16.87, p < .001, \eta^2 = .14$ and on the scale 'ER', $F(1{,}105) = 12.3, p < .01, \eta^2 = .11$. Students from the different treatment groups do not significantly differ in their knowledge about models on the scale 'USM', $F(1{,}105) = 1.84, p = .178, \eta^2 = .02$.

Comparing the control group with the first and the second experimental group over the three measurement times (T1, T2a, T2b), demonstrates still a significant impact of the treatment on the development of knowledge about models on the scale 'Mod', $F(4{,}208) = 5.83, p < .001, \eta^2 = .1$ and on the scale 'ER', $F(4{,}208) = 3.28, p < .05, \eta^2 = .06$. Students from the different treatment groups do not significantly differ in their knowledge about models on the scale 'USM', $F(4{,}208) = 1.67, p = .159, \eta^2 = .06$.

5.3 Conceptual Knowledge

In order to answer the first research question,

> **in what way does knowledge *about* representation and its modelled nature have an influence on students' learning outcome in electrochemistry, if…**
>
> **Q1a they receive a meta-conceptual training before?**
>
> **Q1b they receive a meta-conceptual training before and prompts during the learning environment?**

the development of students' conceptual knowledge (Part I, Part II) is analysed according to their corresponding group. Pre- and post-test comparison tested whether conceptual development has occurred between the groups. It is assumed that students from the experimental groups achieve higher test scores compared to students from the control group. Moreover, the second experimental group should see a significant increase in test scores compared to the first experimental group as depicted in Figure 41.

Part I

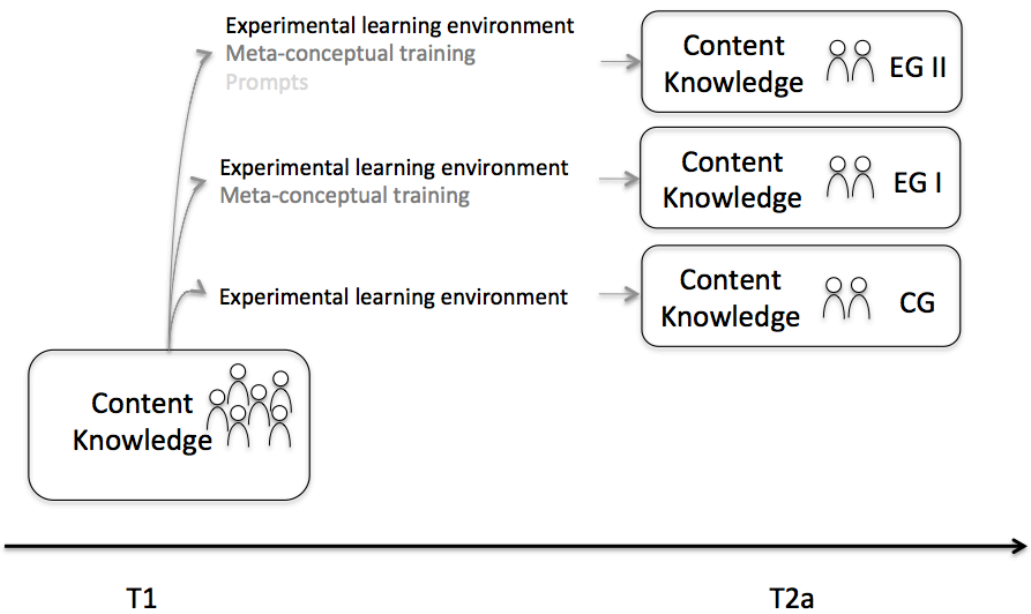

Figure 41. Assumption of the development of students' content knowledge between the groups

The results of balancing the treatment groups show significant differences in students' chemistry-related self-concept (see chapter 5.1). It is assumed that students' self-concept is "a mediating variable that facilitates the attainment of other desired outcomes, such as achievement […] in school" (Marsh, 1990, p. 78). A positive and strong self-concept is important for scientific understanding (Nieswandt, 2007, p. 908). The bivariate correlation analysis supports the positive relationship between students' chemistry-related self-concept and their post-test scores in content knowledge, $r = .39, p < .001$. Moreover, there is a positive relation between the self-concept and the pre-test scores, $r = .25, p < .001$.

To clarify the influence of the self-concept on the treatment and on the content knowledge development a repeated-measures ANOVA and a repeated-measures ANCOVA were run.

Without Covariate: Repeated-Measures ANOVA

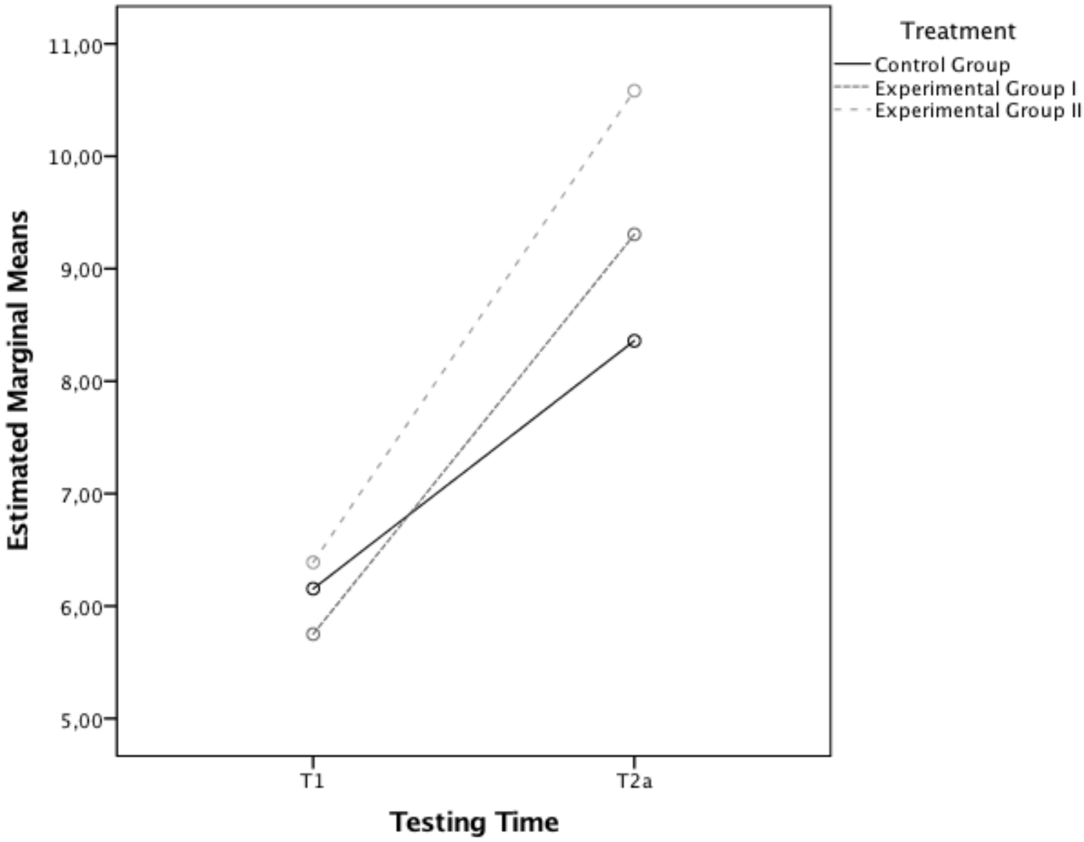

Figure 42. Pre-post-comparison between the treatment groups

The time elapsed has a significant influence on students' content knowledge, $F(1{,}108) = 182.35$, $p < .001, \eta^2 = 0.63$. There is also a significant interaction of the treatment group on the development of content knowledge (from pre-test to post-test), $F(2{,}108) = 5.82, p < .01, \eta^2 = 0.096$. Consequently, the intervention has a medium effect on students' development of content knowledge. The post-hoc analysis demonstrates a significant difference ($p < .05$) between the mean scores of the second experimental group ($M = 10.6, SD = 2.0$) and the control group ($M = 8.4, SD = 1.9$). However, the first experimental group ($M = 9.3, SD = 3.0$) does not significantly differ from the control and second experimental group.

With covariate: Repeated-Measures ANCOVA

To investigate the influence of students' chemistry-related self-concept on the development of content knowledge over the treatment, a repeated measures ANCOVA is calculated. Students' chemistry related self-concept is the covariate. "Then ANCOVA is ideally suited to remove the bias of [this] variable" (Field, 2005, p. 364).

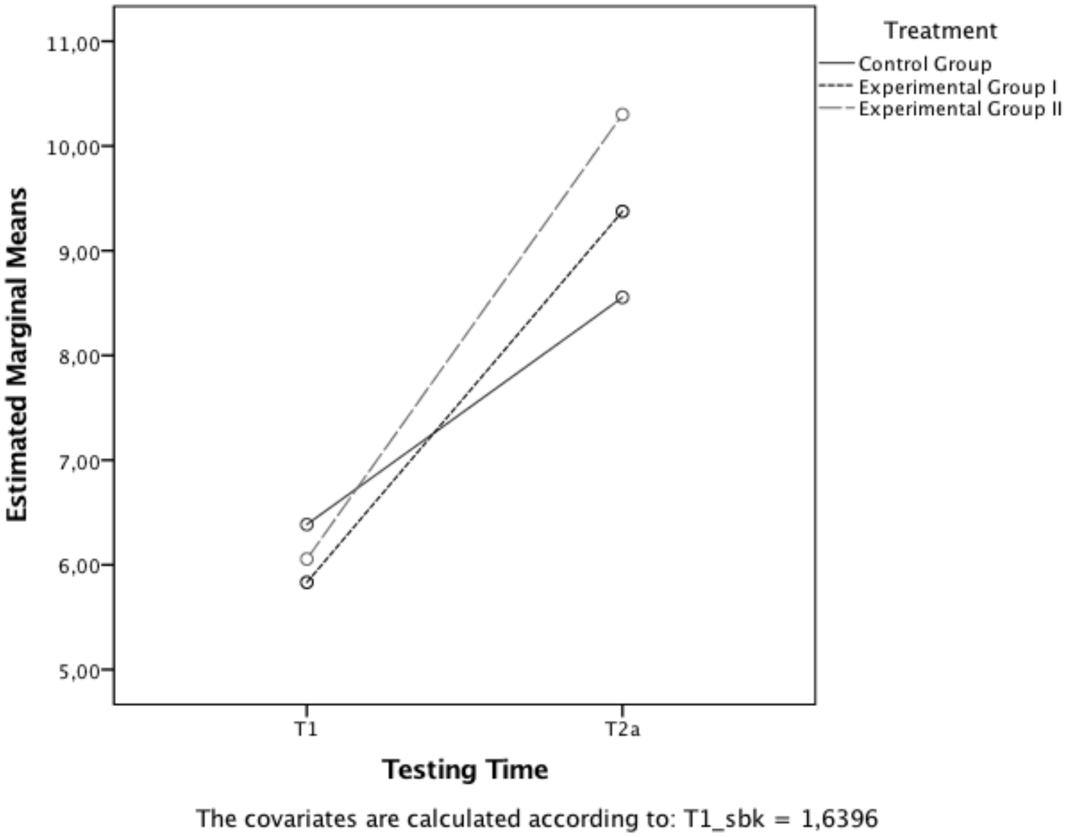

Figure 43. Pre-post-comparison between the treatment groups (with covariate)

There is a significant interaction of the treatment group on the development of content knowledge (from pre-test to post-test), $F(2,107) = 5.92, p < .01, \eta^2 = 0.10$. Consequently, the intervention has still a medium effect on students' development of content knowledge which is higher than without covariate (0.1>0.096). There is no significant interaction of the self-concept and the development of content knowledge, $F(1,107) = 0.32, p = .572, \eta^2 = 0.003$. Post-hoc analyses cannot be calculated because of the covariate.

In sum, the results of the repeated-measures ANOVA and ANCOVA show a significant difference of the interaction between the treatment groups and the development of content knowledge with a medium effect size.

Follow-up test

A repeated-measures ANCOVA was calculated. The graph of students' content knowledge in a pre-post-follow-up comparison according to their treatment is presented in Figure 44.

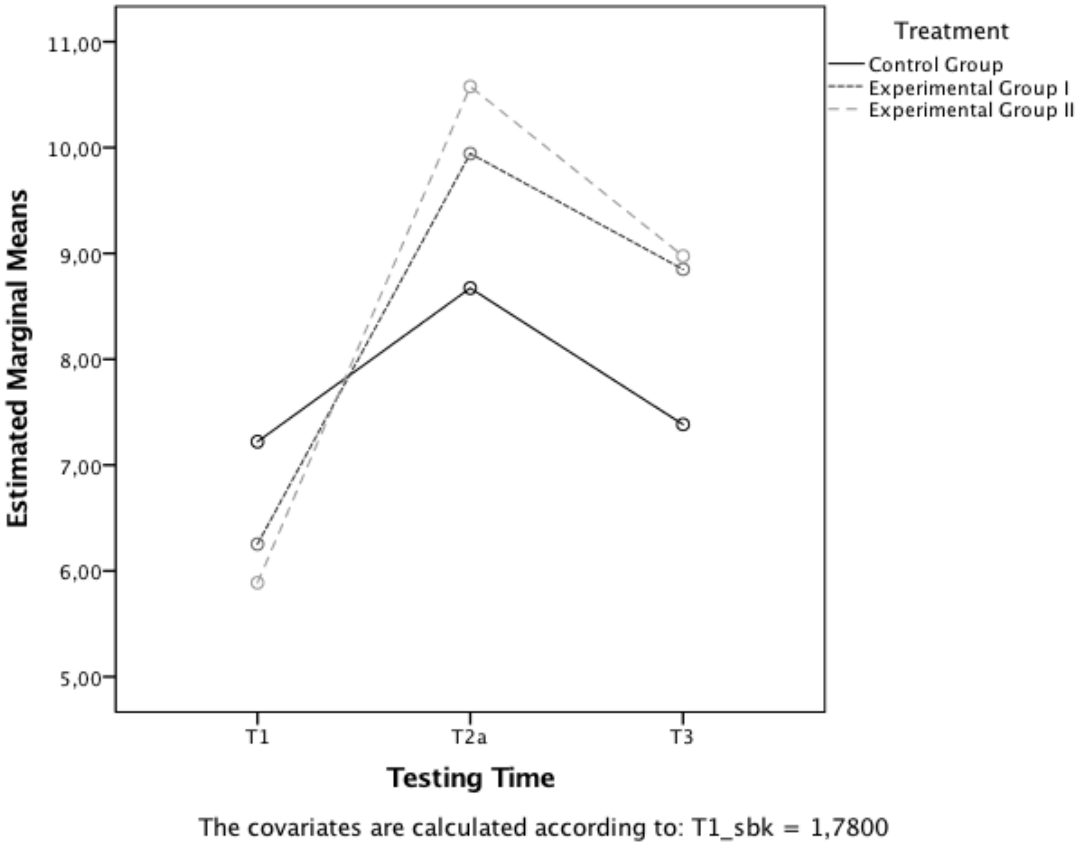

Figure 44. Pre-post-follow-up test comparison between the treatment groups

Firstly, the Mauchly's test was calculated in order to test the sphericity. The test is not significant. Consequently, sphericity is given. Secondly, there is a significant interaction of the treatment group and students' content knowledge development, $F(4,132) = 5.07, p < .01, \eta^2 = 0.13$. This effect is medium.

Part II

The second part of the test instrument measures students' ability to predict chemical phenomena and to apply chemical content knowledge. Items' difficulties are too high as the Wright map has illustrated (see chapter 4.3). Students responded rarely at the different measurement times as Table 22 demonstrates.

Table 22. Count of answers in percentage

	Item number						
	tt2	tt3	tt4	tt5	tt6	tt7	tt8
T1	49	59	37	24	27	9	26
T2b	84	62	61	45	59	30	54
T3	64	57	33	30	33	14	27

The repeated-measures ANCOVA shows no significant difference between the treatment groups.

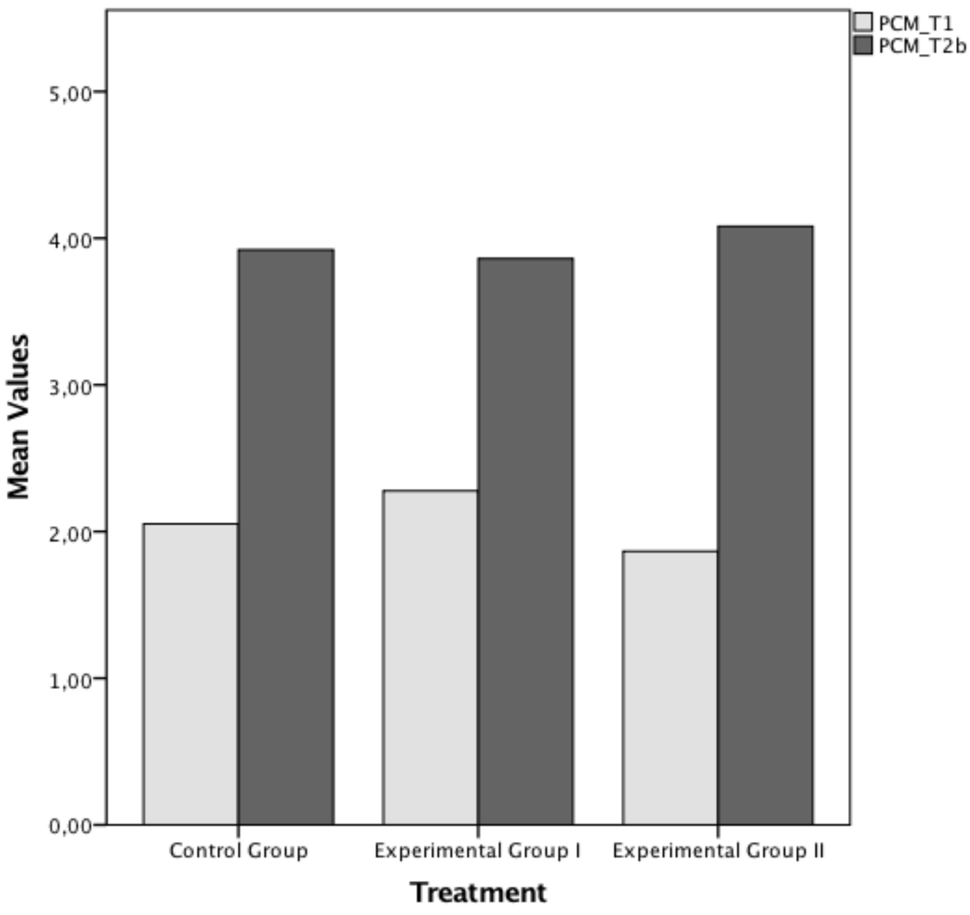

Figure 45. Pre-post-comparison of conceptual knowledge (Part II) between the treatments

In sum, there is a significant influence of the treatment on students' content knowledge development (Part I). The self-concept as covariate increases the effect. However, there is no significant effect of the treatment on their development in predicting and applying chemical knowledge. Consequently, the hypothesis (H1a, H1b) can be partially confirmed.

5.4 Video Analysis

DiSessa (2002a) underlines students' rare communication of meta-events. In order to support students' communication about scientific models and representations the second experimental group got additional prompts. The video analysis should answer the question

> **in what way do students communicate their knowledge *about* representations and its modelled nature.**

The video analysis provides a closer and deeper look at the learning process in between (Derry et al., 2010). In order to answer this question, the video analysis is based on the following framework presented in chapter 2.3.4.

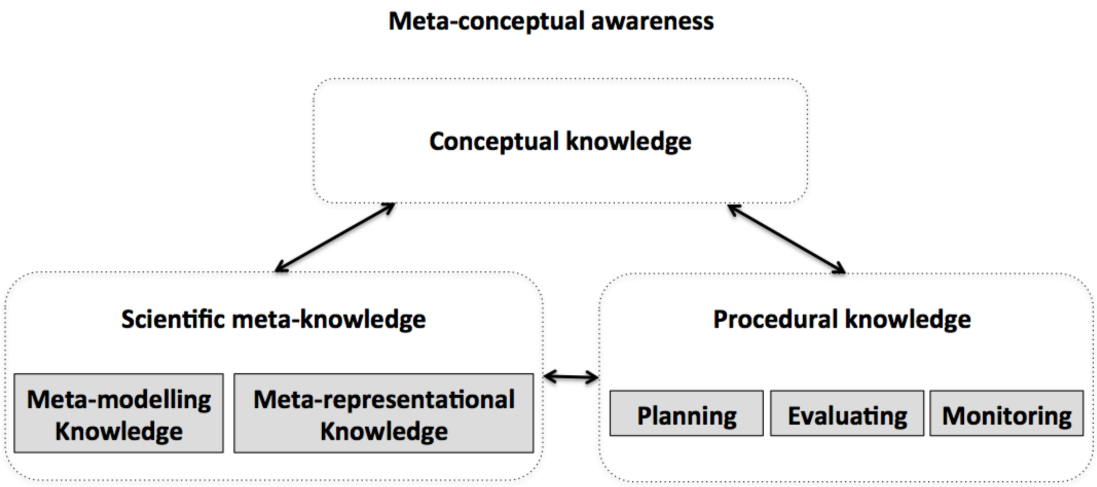

Figure 46. Overview of meta-conceptual awareness (see p. 45)

Videotaped students are equally distributed among all treatments with *n*(CG)=15, *n*(EGI)=15 and *n*(EGII)=15. Furthermore, there are no significant differences in the pre-test results of their cognitive abilities (V2, N2), the different scales of interest and motivation and their conceptual knowledge (Part I).

Table 23 gives an overview of coded situations per treatment. Codes of the surface structure and of the deep structure are presented.

Table 23. Count of codings per treatment group

Surface structure		CG	EG I	EG II
Off-topic		107	125	122
Descriptive		342	359	379
	Planning	5	5	12
Hands-on activity	Designing	59	54	40
	Performing	231	190	188
Deep Structure		CG	EG I	EG II
Conceptual knowledge		251	215	303
Meta-representational knowledge		0	6	11
Meta-modelling knowledge		0	0	0
	Planning	58	115	135
Procedural knowledge	Monitoring	24	37	66
	Evaluating	0	3	1

This table illustrates that students of the different treatment groups are involved in similar activities at the surface structure. The difference of performing hands-on activities results from two students [Lggy38/39] of the control group who performed the hands-on activity of the first interactive boxes 15 times. Moreover, all students talk in many situations about non-chemistry related topics.

Conceptual Knowledge

The mean number of coded conceptual knowledge statements per student over the three sessions is *M*=17.11, *SD*=13.34 with regard to enormous range from zero to 67. Nevertheless, all students communicate their chemical conceptual knowledge less in the last session, *M*=2.62, *SD*=3.99. The Kruskall-Wallis-test shows no significant differences in communicating conceptual knowledge between the treatment groups at each of the three sessions, $H_1(2) = 0.41, p = .814$; $H_2(2) = 1.87, p = .392$; $H_3(2) = 2.34, p = .31$ and in sum of all three sessions, $H_{sum}(2) = 1.36, p = .506$.

Table 24. Coded conceptual knowledge statements per treatment group

	CG	EG I	EG II
Mean *M*	16.8 (*SD*=12.8)	14.3 (*SD*=11.1)	20.2 (*SD*=15.9)

Nevertheless, there is a slight tendency that students of the second experimental group show more concept-related statements compared to students of the other groups. In addition, the representation domains are connected to the conceptual statements. Students used most commonly experienced, submicroscopic and mixing experienced and submicroscopic based statements as the following pie chart shows.

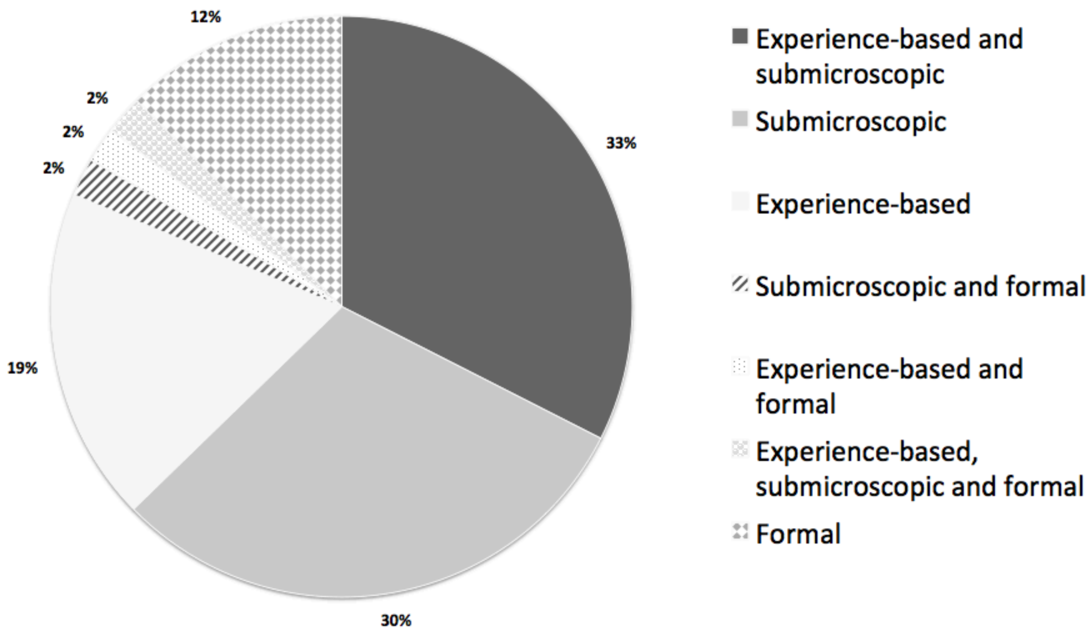

Figure 47. Pie chart of representations related to conceptual knowledge statements

In order to compare the different treatment groups, Table 25 shows the conceptual knowledge statements at the different representation domains in percentage terms.

Table 25. Representation domains of the coded conceptual knowledge statements over all sessions

		EW	**SD**	FD	EWSD	EWFD	EWMW	SDFD
Control	Count	50	**66**	28	85	5	6	9
Group	Percentage	20%	**27%**	11%	34%	2%	2%	4%
Experimental	Count	28	**52**	29	82	6	3	1
Group I	Percentage	14%	**26%**	14%	41%	3%	1%	1%
Experimental	Count	62	**110**	37	78	4	7	6
Group II	Percentage	21%	**36%**	12%	26%	1%	2%	2%

Comparing only conceptual knowledge statements at the submicroscopic domain [in bold] demonstrates a difference between the treatment groups during the second session (CG:22; EGI: 20; EG II:52), $H(2) = 5.08, p = 0.079$. The post-hoc test highlights a significant difference ($p = .05$) between the control and the second experimental group ($U = 68, r = -.35$).

Scientific Meta-Knowledge

In only 17 situations students from the experimental groups communicate their knowledge about representations. The second experimental group communicated more meta-representational statements than the first experimental group. The majority of situations arose in the first session. However, the experimental groups do not communicate any kind of knowledge about models. Students from the control group do not communicate any kind of knowledge about models or representations.

Procedural Knowledge

Students over all treatments were involved in planning activities. These activities refer to students' ability to plan the externalisation of their knowledge of representations instead of planning the inquiry process. For example, one student talked to his partner and said, "think about the different representations" (UEGY48/ Box1 13:20.3-13:22.5). The planning activities decreased over the three sessions as Figure 48 demonstrates.

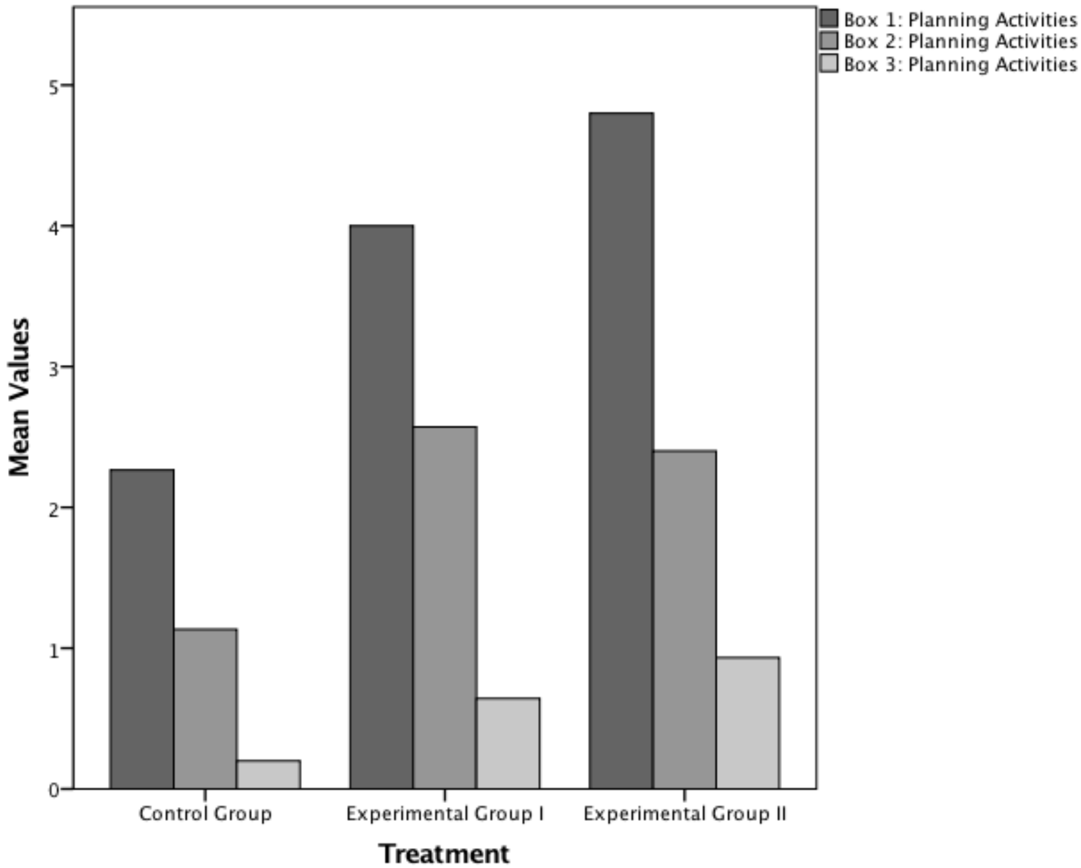

Figure 48. Planning activities over the three sessions

Students' statements on evaluating their knowledge are rarely found compared to situations of planning and monitoring activities as Table 26 shows.

Table 26. Count of procedural activities

	Planning	Monitoring	Evaluating
Control Group	58	24	0
Experimental Group I	115	37	3
Experimental Group II	135	66	1

The sum of planning and monitoring activities over the three sessions differ significantly between the treatment groups as the Kruskal-Wallis test shows, $H_{pl}(2) = 6.79, p < .05$; $H_{mo}(2) = 6.77, p < .05$. The Kruskal-Wallis test was performed because of non-normally distributed data and a smaller sample size than 100 students. The treatment groups significantly affected counts of planning activities. However, there are only significant differences in planning activities between the control and first experimental group $(U = 55, r = -.41)$ as well as between the control and the second experimental group ($U = 58.5, r = -.41$). Moreover, students from the control and second experimental group differ significantly in monitoring activities ($U = 53.5, r = -.45$). In addition, the count of students' planning activities during the first session is significantly related to the count of their conceptual knowledge related statements, $\tau = .26, p < .05$. It can account for 7% of the variation in conceptual knowledge scores. Kendall's tau is more accurate for small data (Field, 2005). Moreover, there is a positive relationship between the count of planning activities and the count of monitoring activities during the first session, $\tau = .49, p < .001$. Therefore, planning activities can account for 24% of the variation in the count of monitoring activities. However, the count of monitoring activities is significantly correlated with the count of conceptual knowledge related statements, $\tau = .28, p < .05$. Table 27 presents the correlation matrix of the relation between procedural and conceptual knowledge.

Table 27. Correlation matrix of the video data analysis of the first interactive box

		(1)	(2)	(3)	(4)
(1)	Planning		$.49^{**}$	$.26^{*}$	$.26^{*}$
(2)	Monitoring			.24	$.28^{*}$
(3)	Evaluating				$.29^{*}$
(4)	Conceptual Knowledge				

* The correlation is significant at a level of 0.05 (both sides).

** The correlation is significant at a level of 0.01 (both sides).

The correlation matrix provides the assumption that there is a relation between students' procedural knowledge about representations and their development of content knowledge. The correlation analysis of this assumption is not significant as Table 28 shows. Procedural activities are summed up over the three sessions.

Table 28. Correlation matrix of the video data analysis of all boxes

		(1)	(2)	(3)	(4)
(1)	Planning		$.43^{**}$	.2	.06
(2)	Monitoring			$.29^{*}$	.11
(3)	Evaluating				.19
(4)	Development (Recalling chemical knowledge)				

Importantly, situations of the second experimental group, where students use prompts, were analysed in order to investigate the influence of prompts on students following activities and communication processes. With the help of Maxqda® the temporal distances from the code 'prompt' to other codes revealing with meta-conceptual awareness are analysed.

Table 29 shows the counts of activities after using the prompts.

Table 29. Counts of activities in short distance to the used code 'prompt'

	EW	MW	SD	FD	Meta-representational	Planning	Monitoring	Evaluating
Prompt	5	2	5	5	7	21	2	0

Consequently, the prompts stimulated students to talk about the different representations domains like the experienced world or the submicroscopic domain. Furthermore, students communicated their meta-representational knowledge in seven situations. The most common consequence of focussing on the prompts is planning the next steps of knowledge representation and externalisation. For example, the student JKG08 pays attention on the prompts and recognises: "This part [He points his finger at the prompt], we have not done this. We only have the formal domain. We need the submicroscopic domain and the modelled world" (Box 1: 17:46.7-17:56.7).

In sum, students communicate rarely their scientific meta-knowledge. The video analysis indicates that students from the second experimental group show more planning activities than the control group. There is no significant difference in communicating the conceptual knowledge, but the second experimental group communicates their knowledge more at the submicroscopic domain than the control group while the second session. However, the correlation analysis indicates no significant relation between the development of conceptual knowledge and procedural knowledge (planning, monitoring, evaluating). As a consequence, chapter

5.6 provides the integration of the different data types to clarify the effect of the meta-conceptual training.

5.5 Lab Journal Analysis

The lab journals provide considerable insight into students' learning process between the different measurement times. Furthermore, students' written or visual explanations and their understanding about representations can support their test scores and their learning success. As it was presented in chapter 4.5 the analysis includes the following elements.

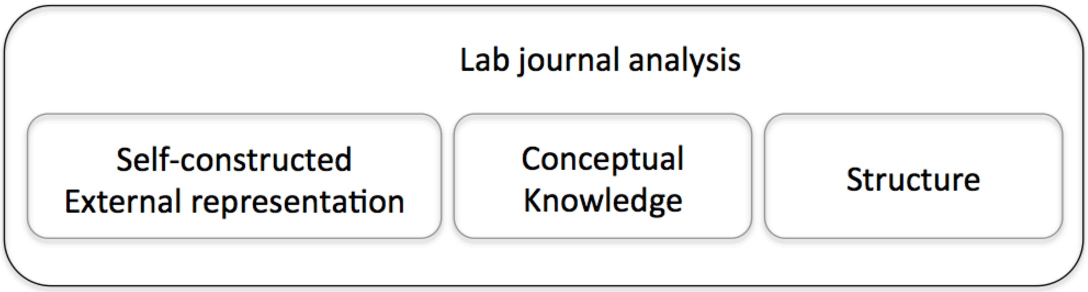

Figure 49. Lab journal analysis (see p.97)

Self-Constructed External Representations (Drawings)

In an unpublished bachelor thesis (Lampe, 2016) 59 drawings were analysed according to the use of the different representation domains. At first, it must be underlined that the majority of students from the experimental groups made drawings from chemical processes and only five students from the control group. Moreover, only students from the experimental groups (EG I: 6, EG II: 16) visualized the chemical content including submicroscopic entities. Lampe (2016) summed up that all representation domains are equally used in students' drawings. Furthermore, they use the different representation domains in the same drawing without differentiating between the phenomenon and the modelled representation as Figure 50 demonstrates.

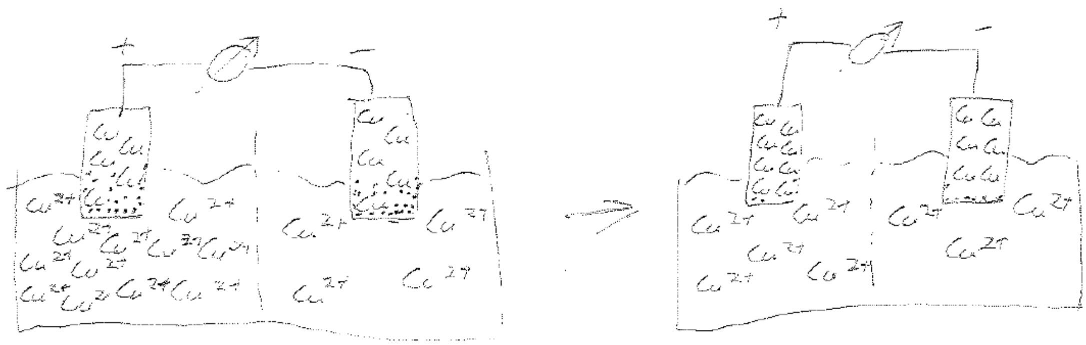

Figure 50. Student's drawing of a concentration cell (UEGY64)

Conceptual Knowledge

The coding scheme includes 17 possible statements to investigate students' understanding of the phenomenon 'The zinc nail in a copper sulphate solution'. The mean number of coded conceptual knowledge statements per student is *M*=4.21, *SD*=3.1. The majority of students were able to explain the oxidation of the zinc atoms and the reduction of the copper cations. However, students focused on the educts, zinc atoms and copper cations. The products of the reaction, zinc cations and copper atoms were neglected. The mean number of coded statements per student decreases from session 1 to session 3. As a consequence of the first interactive box, about half of the students put the zinc plate in the copper sulphate solution and the copper plate in the zinc sulphate solution. This experimental setup caused problems in explaining the voltage. The average number of conceptual statements is 1.27 (*SD*=1.83). Nevertheless, explaining the Daniell element brought similar problems. The mean number of coded conceptual knowledge statements per student is *M*=1.19, *SD*=1.74. The chemical content of the third interactive box causes considerable difficulties. 27 students were able to explain the phenomenon of a concentration cell by the reduction of copper cations of the higher concentrated solution. However, only 20 students could explain that copper atoms of the lower concentrated cell are oxidized. Students from the different treatment groups do not significantly differ in their conceptual statements.

Structure

Six students from the first and five students from the second experimental group used the table (see Figure 14) to structure their lab journal. Consequently, there is no significant difference between the first and second experimental group in using this learning aid. Three students from the second experimental group connected the content of the different representation domains with the help of circles as Figure 51 shows.

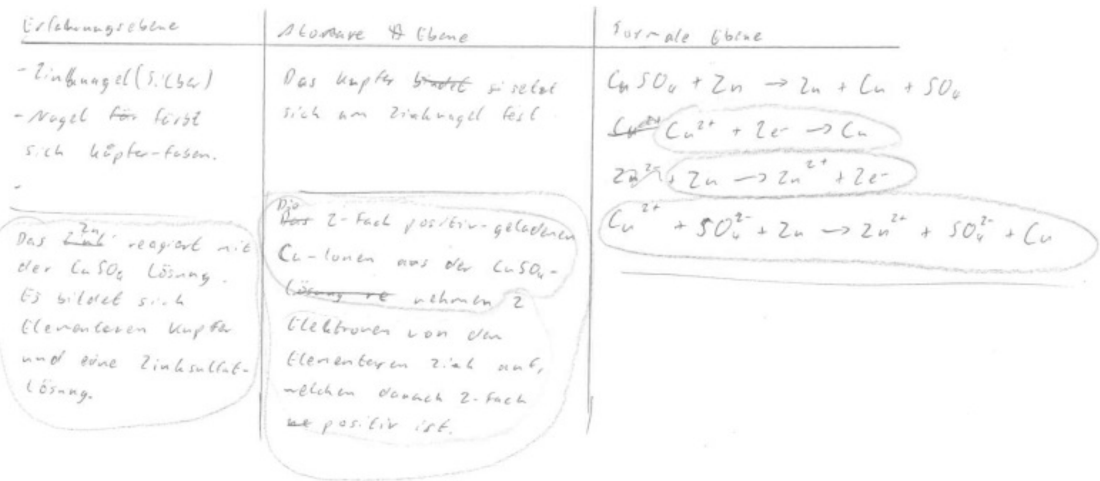

Figure 51. The lab journal of UEGY02

To compare the lab journal structure of the different treatment groups, the lab journal of the first interactive box is analysed. Students extensively wrote on the content of the first interactive box compared to the second and third box.

More than 80% of the students from the control group used the terms ‘observation’ and ‘inference’ in organising their lab journal. Moreover, the majority of the students from the experimental groups applied these terms in their lab journal, too. Nevertheless, seven students from the experimental groups used the term ‘observation’ as well as ‘experienced world’, 10 students used the term ‘experienced world’ to structure their lab journal. Furthermore, 19 students from the experimental groups successfully combined the terms ‘inference’ with ‘submicroscopic domain’ or ‘formal domain’.

In addition, students' conceptual statements are connected to the different representation domains. All students most commonly used experience based statements like in the example "Copper forms a layer around the zinc nail" [UEGY02/Box1]. There is a significant difference in using statements at the formal domain, $F(2{,}107) = 8.43, p < .001, \omega = .34$. Students from the second experimental group ($M = 2.19, SD = 1.17$) used significantly more formal statements than the control group ($M = 0.95, SD = 1.16$) as the Bonferroni post-hoc test demonstrates.

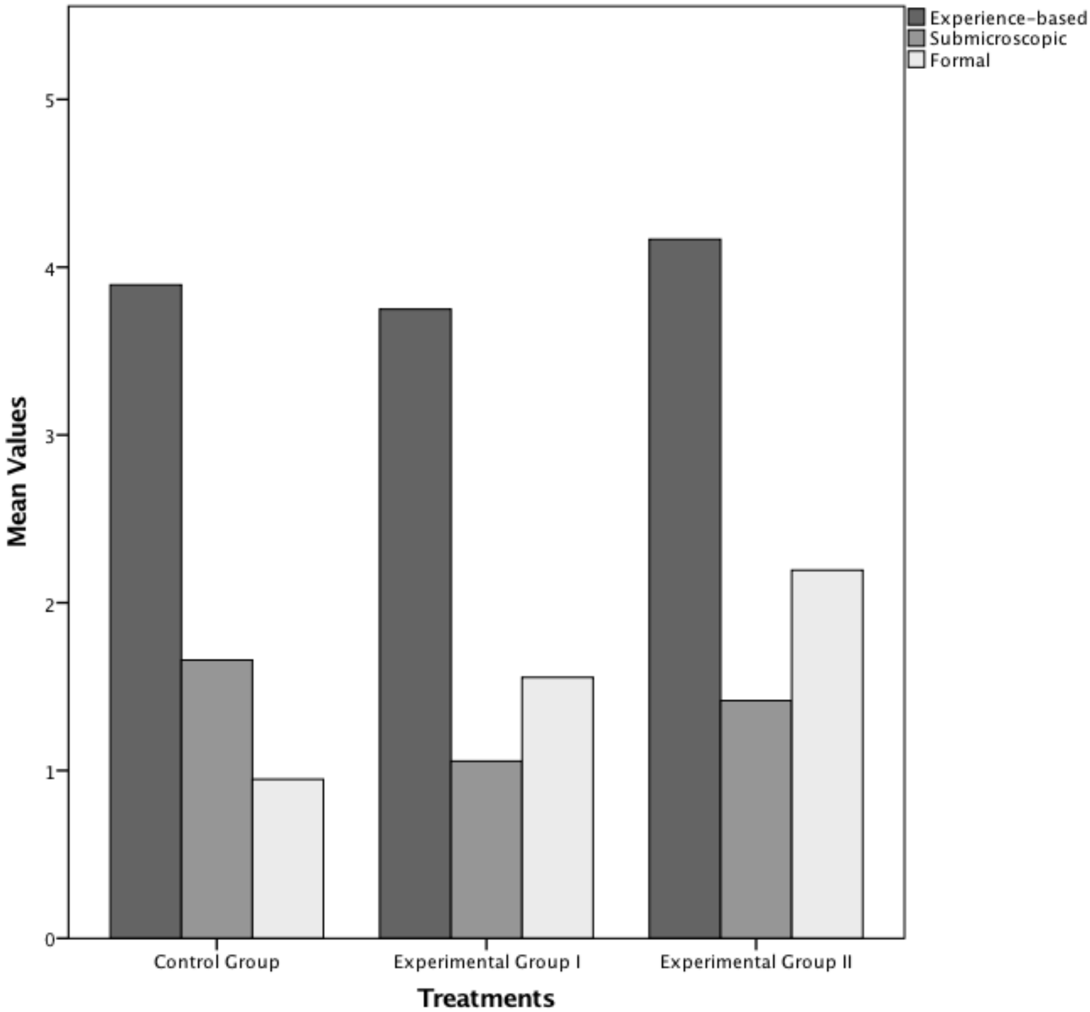

Figure 52. Representation domains in the lab journal

In sum, all students showed preference to experience based statement followed by submicroscopic and formal statements. Moreover, students most frequently mixed the experience based and the submicroscopic domain like in the example "Copper is reduced" [LGGY39/Box1]. The frequency distribution can be extracted from the pie chart.

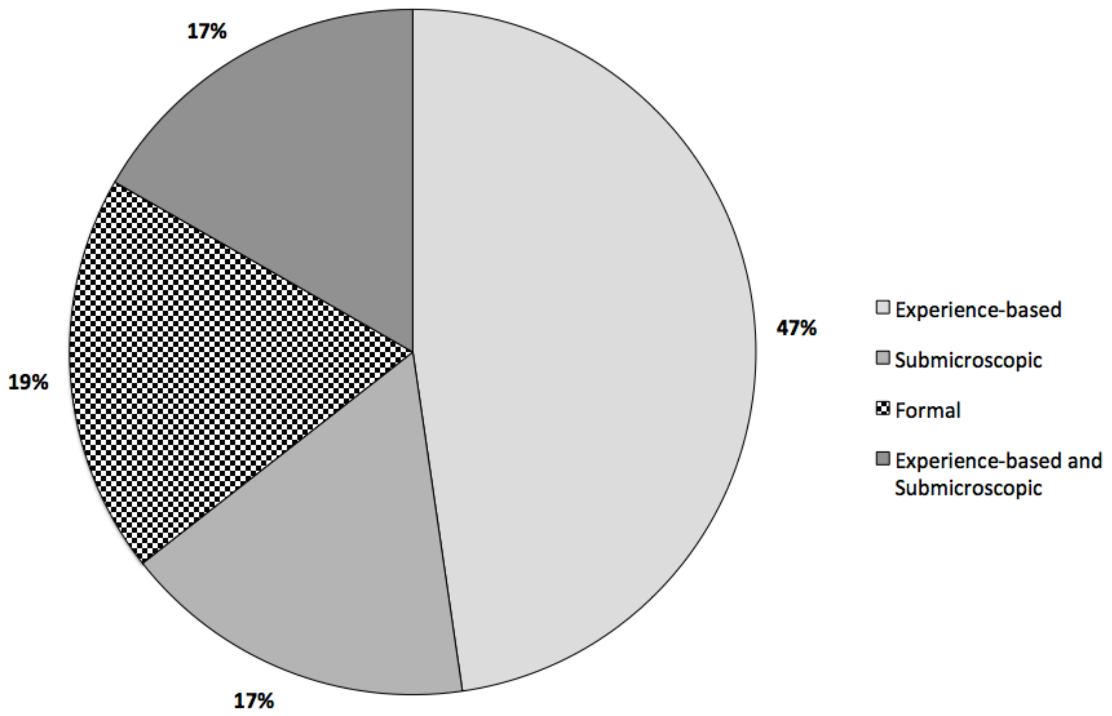

Figure 53. Pie chart of the representation domains

5.6 Data Integration

Mayring (2001) describes the integration of qualitative and quantitative data analysis on different levels. He understands the integration on an individual level as "the creation of types and the inductive generalisation of cases" (p. 1). This method allows discussing quantitative results on the personal level and therefore, an in-depth understanding of a phenomenon like in case study research (cf. Cavaye, 1996; Yin, 1994).

In order to get a better understanding of the influence of the meta-conceptual training on learning outcome, the data of three students from the second experimental group were analysed focussing on the different data sources. These students were selected because of their above average knowledge achievement in the pre-post test comparison compared to the whole distribution.

UEGY 48

This student achieved a learning progress from 36% in the pre-test to 93% in the post-test. His cognitive abilities are slightly above the average of the whole sample distribution. The results of the video analysis demonstrate his increased activities in planning and monitoring. Moreover, he communicated his meta-knowledge about representations in two situations. Nevertheless, his activities and representational related statements markedly decreased from the first to the third interactive box as the following table shows.

Table 30. Counts of statements (UEGY48)

	Conceptual Knowledge	Meta-Representational	Planning	Monitoring	Evaluating
Box 1	5	2	6	4	0
Box 2	0	0	4	2	0
Box 3	0	0	0	0	0

The following transcript should highlight his way of thinking and arguing.

Table 31. Transcripts of communication processes (UEGY48/ Box 1)

Id	Time	Transcript	Code
UEGY48	7:59.6-8:01.8	[While writing the lab journal]: Do you write ‚observation' or ‚experienced world'?	Term_OL Term_EW
UEGY64	8:01.8-8:02.6	I write ‚observation'.	Term_OL
UEGY48	8:02.6-8:05.6	I write ‚experienced world' […]	Term_EW
UEGY64	8:05.6-8:10.2	Hm… But I think the experienced world… Yes, ok. Basically, it is the same.	Meta-Representational
[Teacher reminds students to use the prompts]			Prompts
UEGY64	9:12.1-9:15.2	I called it observation.	Term_OL
UEGY48	9:15.2-10:22.8	Yes, but is the experienced world. That's a difference […].	Meta-Representational
[…]			
UEGY64	13:21.3-13:26.6	Remember the representation domains. I can also draw it [the reaction equation] on the modelled domain.	
UEGY48	13:26.6-13:30.0	But write ‚the formal domain', now, when you link.	Pl_EX_FL
UEGY64	13:30.0-13:32.0	But that is the modelled world.	Meta-Representational
UEGY48	13:32.0-13:40.6	Yes, but the … [He points his finger at the two symbols on the prompt]. The modelled world is divided into formal and submicroscopic domain… Yes, we should not write inference, but formal domain.	Meta-Representational
UEGY64	13:40.6-13:43.4	[He points his finger at his lab journal]: That is the modelled world and this is the formal domain. I can write it [the terms] down.	M_control_EX_FL
UEGY48	13:43.4-13:47.0	Yes, you should replace this term [He points his finger at the ‚chemical equation'].	
UEGY64	13:47.0-13:49.7	But here [He points his finger at his lab journal], I will explain the…	P_EX_SL
UEGY48	13:49.7-13:50.7	The submicroscopic domain?	Term_SL
UEGY64	13:50.7-13:52.2	Yes.	
UEGY48	13:52.2-13:54.0	I don't understand your problem.	

This transcript emphasises UEGY 48’s way of thinking. He thinks about the different terms and the differences between the new terms and the old terms (observation, inference). His communication process shows his dispute concerning the representation domains. However, his line of arguments is strong and plausible. Consequently, he does not understand UEGY64 in his way of arguing.

His lab journal underlines his communication process.

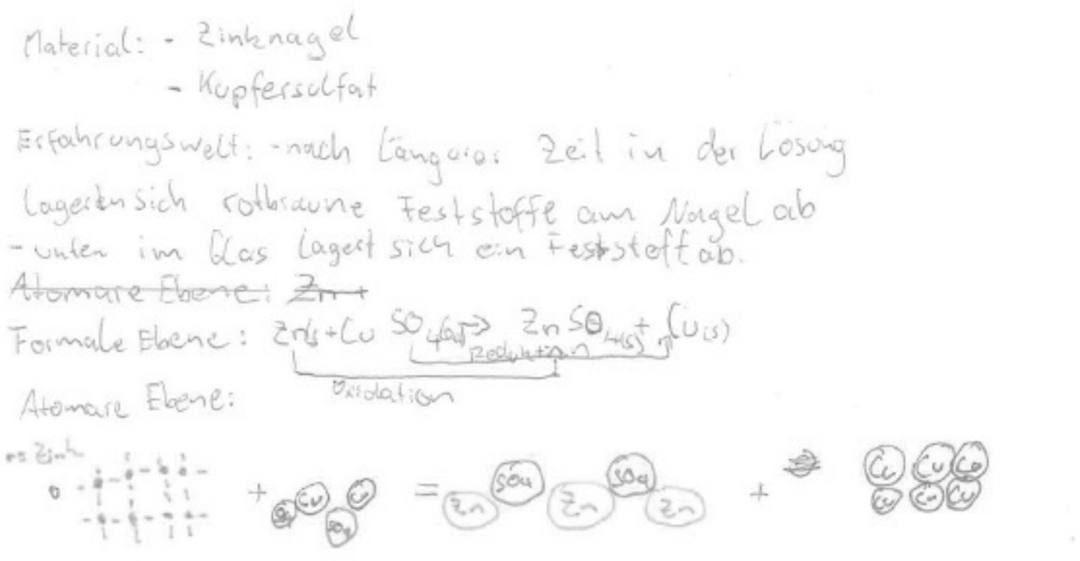

Figure 54. UEGY48's lab journal (Box 1)

He differentiated between the representation domains ‘Experienced World’, ‘Formal Domain’ and ‘Submicroscopic Domain’. His use of written language reflects his communication regarding the different representation domains. Moreover, he drew the chemical equation with the help of particles. The open items of applying chemical knowledge (Part II) do not reflect his awareness of the different representation domains. There, he responded, “Iron oxidizes” instead of “Iron atoms oxidize”.

In conclusion, this student applied the knowledge of the different representation domains he had acquired in the meta-conceptual training. The video analysis underlines this result. He planned and monitored his knowledge about representations while working with the interactive boxes. The training stimulated his knowledge about scientific models but he could not apply this knowledge during the three sessions.

UEGY 26

This student achieved a learning progress from 50% in the pre-test to 79% in the post-test. His cognitive abilities are above the average of the whole sample distribution. In sum, he gained 41 test score points out of 50 possible points. Compared to UEGY48 he showed similarly increased activities in planning and monitoring. Nevertheless, he did not explicitly communicate his meta-knowledge about representations.

Table 32. Counts of statements (UEGY26)

	Conceptual Knowledge	Meta-representational	Planning	Monitoring	Evaluating
Box 1	7	0	11	4	0
Box 2	10	0	5	2	0
Box 3	0	0	2	0	0

The following transcript emphasises his awareness about the different representation domains.

Table 33. Transcripts of communication processes (UEGY26/ Box 1)

Id	Time	Transcript	Code
UEGY27	4:56.8-5:00.0	Now, the observation… observing.	Term_OL
UEGY26	5:00.0-5:05.0	Consequently, the eye [He points his finger at the prompt and read aloud].	Term_EW, Prompt
[...]			
UEGY27	10:31.5-10:48.9	Submicroscopic domain […]. The nail… the atoms are solid, right? Zinc atoms are solid.	Term_SL
UEGY26	10:48.9-10:53.3	Zinc atoms, what?	
UEGY27	10:53.3-10:55.1	Yes, are solid.	
UEGY26	10:55.1-10:57.7	Yes, but you have to write it down here [he points his finger at the experienced world].	M_SL

This part of the transcript highlights his ability to monitor the chemical content belonging to the different representation domains. He seriously considered the statement of his partner "The atoms are solid" and reminded him of the different representation domains by showing the prompts.

The lab journal reflects his way of thinking. He adapted the different representation domains in organizing the chemical content as Figure 55 highlights.

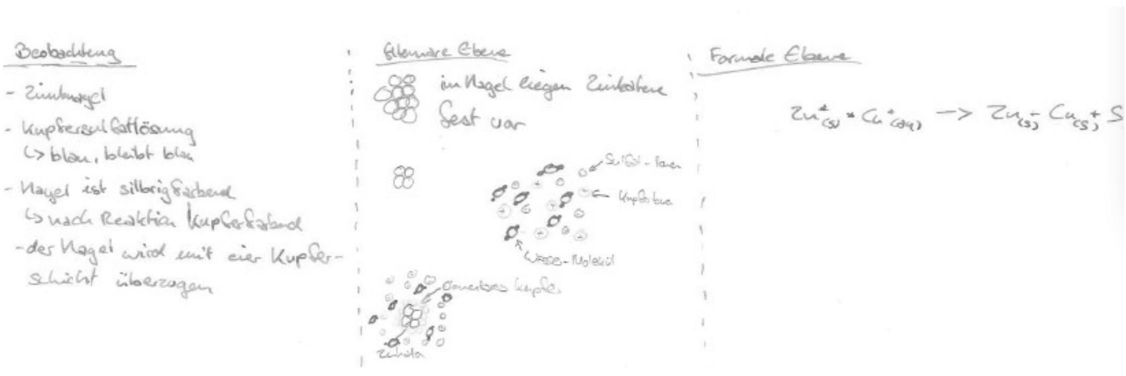

Figure 55. UEGY26's lab journal (Box 1)

The column of the submicroscopic domain underlines his way of arguing. Instead of understanding “solid” as a material characteristic, he understood “solid” as fixed arranged in the metal lattice. In the post-test of applying chemical knowledge (Part II) he tried to adopt his knowledge about the different representation domains. He wrote: “The iron plate oxidizes and copper ions reduces.” This statement emphasises that his framework for applying the representation domain to the chemical content is not fully established.

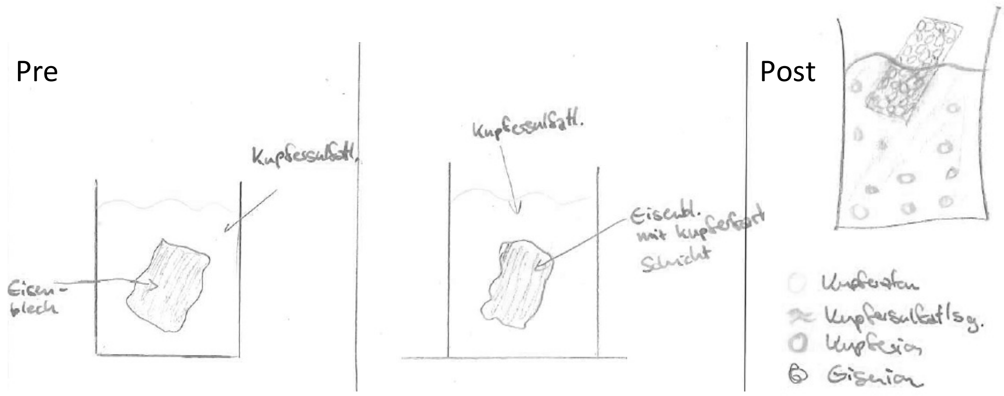

Figure 56. Visualization in the pre-post-test comparison (UEGY26)

Nevertheless, he visualized his conception in the pre-test as well as in the post-test as presented in Figure 56. In the pre-test he drew only the phenomenon on the experience based domain. In the post-test his visualization includes the scientifically correct use of particles like copper ions and iron ions. However, this student does not distinguish between the experienced and the modelled world, because he drew the beaker and the metal plate including particles. It must be underlined that he developed his representational skills compared to the pre-test.

In conclusion, this student applied his knowledge about representations particularly with regard to his visualizations.

UEGY 51

This student achieved a learning progress from 57% in the pre-test to 93% in the post-test. His verbal cognitive abilities are below the average of the whole sample distribution, but his non-verbal cognitive abilities are above the average. Compared to UEGY48 and UEGY26, he showed similarly increased activities in planning and monitoring, but he frequently communicated his conceptual knowledge as the following table shows.

Table 34. Counts of statements (UEGY26)

	Conceptual Knowledge	Meta-representational	Planning	Monitoring	Evaluating
Box 1	11	1	7	6	0
Box 2	33	0	4	1	0
Box 3	23	0	2	1	0

The following part of the transcript highlights his ability to think about the chemical content on different representation domains.

Table 35. Transcripts of communication processes (UEGY51/ Box 1)

Id	Time	Transcript	Code
UEGY51	11:05.9-11:32.2	CuSO4 is l, yes because…, no that's aq. It is dissolved in water as you can see. Now, you know that. That was the formal domain… Right?	CK, Rep_Fl M_EX_FL
UEGY54	11:32.2-11:35.3	That's the…	
UEGY51	11:35.3-11:37.1	Yes?	
UEGY54	11:37.1-11:41.4	That's the… You have the experienced…	Term_EW
UEGY51	11:41.4-11:46.1	No that's the formal… Of course, that's the formal domain.	M_EX_FL
UEGY54	11:46.1-11:47.7	Yes.	
[…]			
UEGY51	15:13.7-15:16.1	Ok, now we have [to write] the observation, the formal and what do we have to do now? Hm…	PL_EX_OL, PL_EX_FL, PL_EX_GEN
UEGY54	15:16.1-15:18.1	The submicroscopic	Term_SL
UEGY51	15:18.1-15:20.6	Now, we have to…	
UEGY54	15:20.6-15:21.2	To draw a model.	
UEGY51	15:21.2-15:25.0	Yes, that's easy. You draw a solid substance as a nail and cations and anions around the nail. That's easy.	PL_EX_SL

This student considered the different representation domains by monitoring the chemical content of them. His lab journal underlines his differing view on the representation domains as the below figure demonstrates.

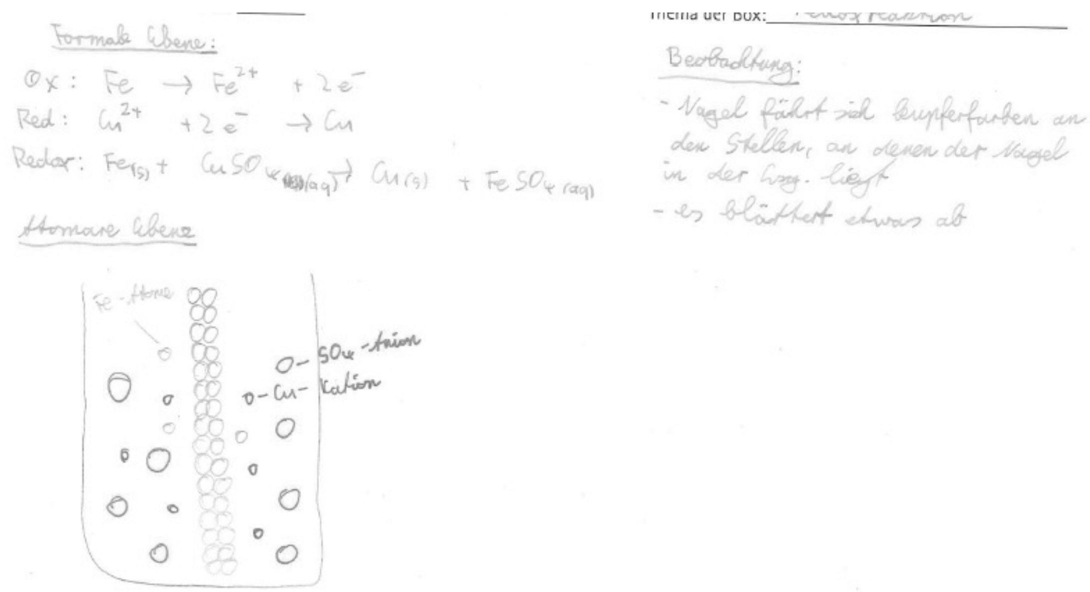

Figure 57. UEGY54's lab journal (Box 1)

He visualized the submicroscopic domain by drawing the particles. However, the drawing is scientifically incorrect. Nevertheless, the ability to draw chemical processes is absolutely high level. In the post-test of conceptual knowledge (Part II) he tried to apply his knowledge of the different representation domains. Consequently, he carefully formulated the chemical content related to the specific representation domain. For example, he articulated that silver ions accept the electrons, instead of saying the substance silver accepts the electrons.

In summary, the three students applied their knowledge of representations. Moreover, they planned and monitored their knowledge. According to Ainsworth et al. (2011) students need representational skills to visualize scientific phenomena. Drawing enhances conceptual understanding and requires an interactive engagement with science. These students all had in common that they all tried to visualize the chemical processes on the submicroscopic domain.

6 Discussion

The aim of the study was to enhance students' conceptual understanding of electrochemistry with the help of meta-conceptual instruction. This study focussed on answering the following research question.

In what way does knowledge about representations and its modelled nature have an influence on students' learning outcome in electrochemistry, if…

> they receive a meta-conceptual training before?
> they receive a meta-conceptual training before and prompts during the learning environment?

The results of the pre-post-test comparison of students' conceptual knowledge support the hypothesis (H1a) that students achieve a better conceptual understanding of electrochemistry if they know about the nature of scientific representations and models. The meta-conceptual training considerably influenced students' understanding about representations and models as the pre-post comparison of these test scores demonstrates. Nevertheless, this hypothesis cannot be completely confirmed. The intervention has a significant effect on the development of their ability to recall chemical knowledge (Part I) but not in predicting and applying chemical knowledge (Part II). The Wright map of the pre- and post-test results (Part II) demonstrates students' difficulty with these items (see Figure 26, Figure 27). There is no significant effect of the intervention on predicting and applying chemical knowledge. Moreover, this problem causes a general limitation to this study. This test instrument is convenient to verify the effect of the meta-conceptual training on learning outcome. In the pilot study, the students participated in the study during regular school lessons. This could be a reason why they, in contrast to students from the main study, have completed fill in the blank questionnaires. Krajcik (1991) emphasises that there is a difference between using chemical terms and having conceptual understanding. Thus, recalling chemical knowledge does not necessarily mean having conceptual understanding. However, it can be assumed that the significant difference between the treatments arose from the meta-conceptual training in combination with the prompts, because the control and the second experimental group differ significantly. Therefore, the hypothesis saying that the abstract knowledge about representations should be stimulated in order to maintain it (H1b) may be accepted. Nevertheless, the items of recalling chemical knowledge confirm the positive influence of the meta-conceptual training in combination with the prompts on students' achievement.

Moreover, this research study deals with the question

> in what way do students communicate their knowledge about representations and its modelled nature.

The video analysis demonstrates that the students never communicate their knowledge about scientific models. It can be assumed that the meta-conceptual training has an immediate but short-term effect on students' understanding of scientific models as the pre-post-test comparison in this questionnaire demonstrates. The period of this training seems to be too short and limited considering the integration of the knowledge about scientific models. Furthermore, the training particularly focused on the table as a learning aid considering the different representation domains. Only one scientific text highlights the nature and purpose of scientific models. As Gobert and colleagues (2011) underlined, students need explicit instructions addressing scientific modelling in order to engage their understanding about the nature of scientific models. In addition, Schwartz and colleagues (2009) summarise that students should be prompted to reflect on the nature of scientific models. The prompts used in this study include questions dealing with the different representation domains and exclude scientific models. Consequently, students' communication on scientific models is not at all surprising. Moreover, diSessa (2002a) underlines students' rare communication at a meta-level. The video analysis confirms this rare communication. However, prompts were used to stimulate their communication at a meta-level. The video data indicates an influence of using prompts on engaging in planning activities. In addition, students differ significantly in their planning activities. The significant difference is between the control and the second experimental group. There is a positive relationship between planning activities and coded conceptual knowledge statements. Moreover, the video analysis displays a tendency among the second experimental group to demonstrate more conceptual knowledge. However, this difference is not significant. There is a significant difference in expressing conceptual statements at the submicroscopic representation domain between the control and the second experimental group. Johnstone (1982) emphasised "that trained chemists jump freely from level to level in a series of mental gymnastics [but] it is eventually very hard to separate these levels" (p. 377). On the one hand, this citation in combination with the significant difference reflects students' meta-conceptual awareness because they seem to be aware of clearly differentiating between the chemical content and the related representation domain. According to Bucat and Mocerino (2009) different types of representations command attention on the chemical language. Therefore, it can be assumed that the meta-conceptual training in combination with the prompts has a positive impact on precisely communicating chemical knowledge. On the other hand, students' communication illustrates their difficulty of separating the different representation domains as Johnstone (1982) has already highlighted. They communicate their conceptual knowledge while mixing the different representation domains. This outcome confirms the result by Brosnan and Reynolds' (2001) study, who found out that students have problems in separating the macroscopic and submicroscopic domain.

The lab journal analysis provides additional information supporting the results from the questionnaire and the video analysis. The lab journals demonstrate that students construct external representations. The majority of students from the experimental groups tried to visualize the chemical processes including particles. Students from the control group only visualized the phenomenon at the experienced based domain. It can be assumed that students from the experimental groups have developed a representational need while making sense of macroscopic phenomena.

This representational need is in line with the study by Tytler and Hubber (2016). Chemistry as a visual science demands students' ability of imagination and visualization (Bucat & Mocerino, 2009). Visualization plays a key role in learning science (Wu & P. Shah, 2004). According to these authors, students need multiple representations and a visible connection between them to understand chemical concepts. Thus, students' representational abilities are important for learning science. Moreover, students' drawings confirm the results of Rappoport and Ashkenazi (2008) showing that students never use submicroscopic representations alone. However, the drawings demonstrate students' increased engagement in submicroscopic visualization when they are instructed. In sum, the meta-conceptual training seems to be an effective learning aid to interpret and to construct the submicroscopic domain. The control group confirms the research by Krajcik (1991) which says that there is a lack of interpretation at the submicroscopic domain.

7 Conclusion and Implications

Recent research has demonstrated students' difficulties in understanding the triplet relationship of representations (Chittleborough & Treagust, 2007; Rappoport & Ashkenazi, 2008; Tan et al., 2009; Treagust et al., 2003). In chemistry education, macroscopic, submicroscopic and formal representations are a key issue for understanding chemical concepts (Johnstone, 1982, 1993). Chemistry lessons often focus on the macroscopic and formal domain without considering involved particles. Accordingly, the submicroscopic domain seems to be a black hole (Johnstone, 1993) and the interpretation of submicroscopic entities is neglected (Krajcik, 1991; Rappoport & Ashkenazi, 2008). The overall result of the empirical research indicates students' lack of the ability to relate, connect or transfer the three representation domains. Consequently, researchers claim an explicit discussion of the relation between the phenomenon and its explanatory representations (Chittleborough & Treagust, 2007; Jaber & BouJaoude, 2012). All these representations are important to build a solid, conceptual understanding (Kozma, 2003; Kozma & Russell, 1997).

Understanding scientific representations requires knowledge of their modelled nature. Scientific models are an essential element in fields of learning and understanding science (Giere, 1988; Gilbert & Boulter, 1998; Gilbert & Osborne, 1980; Gilbert, 1991). They are sophisticated instruments to describe, explain and predict the world (Boulter & Buckley, 2000). Empirical research has demonstrated students' limited understanding of the nature and purpose of scientific models (Grosslight et al., 1991; Harrison & Treagust, 2000a, 2002; Treagust et al., 2004). Students consider models as exact copies and visual representation of real targets (Treagust et al., 2002). However, scientific models are powerful tools to learn science (Schwarz et al., 2009; Schwarz & White, 2005). Explicit teaching approaches on scientific models have a positive influence on students' understanding models and scientific concepts (Gobert et al., 2011; Leisner-Bodenthin, 2006; Mikelskis-Seifert, 2002).

It may be assumed that scientific meta-knowledge as knowledge about the epistemological nature of scientific knowledge (Carey & Smith, 1993) can build a bridge between representations and models. Moreover, meta-conceptual awareness as general thinking of one's own conceptual structure attracts widespread interest (Cheng, 2012; Vosniadou, 1994; Vosniadou & Ioannides, 1998; Yürük, 2007; Yürük et al., 2009). Meta-conceptual awareness in respect to chemistry describes one's own knowledge of chemical concepts. This knowledge refers to the nature of scientific models (meta-modelling knowledge) and representations (meta-representational knowledge). Moreover, students have meta-conceptual awareness when they use and apply this kind of knowledge (according to Mikelskis-Seifert, 2002). Revising their conceptual framework demands their ability in reflecting on the nature of scientific knowledge. However, recent research has demonstrated students' lack of meta-conceptual awareness (Vosniadou, 1994; Vosniadou & Ioannides, 1998). Explicit teaching approaches focusing on discussing about models and their nature can increase students' meta-conceptual awareness (Mikelskis-Seifert, 2002).

In sum, empirical research studies have focused on explicit teaching approaches to improve students' understanding of models (Gobert et al., 2011; Mikelskis-Seifert, 2002) and representations (Jaber, 2009; Jaber & BouJaoude, 2012) in order to support learning science. While the triplet relationship of representations has considerable importance (Chandrasegaran, Treagust, & Mocerino, 2007; Chandrasegaran et al., 2008, 2009; Davidowitz & Chittleborough, 2009; Johnstone, 1982, 1993; Tan et al., 2009), only a few researchers have addressed the impact of knowing explicitly about the relationship on learning chemistry (Jaber & BouJaoude, 2012). Therefore, the purpose of this study was to investigate the influence of an explicit instruction about macroscopic, submicroscopic and formal representations on students' understanding of electrochemistry. As instructional help a meta-conceptual training and additional prompts were developed and evaluated. The meta-conceptual training aims to develop a greater awareness of the triplet relationship of representations including their modelled nature. A learning environment dealing with electrochemical hands-on activities provides the opportunity for students to apply their required knowledge about representations. According to diSessa (2002a), prompts were used within this learning environment to stimulate students' communication about representations. Thus, it was investigated in a way that the meta-conceptual training and the meta-conceptual training in combination with the prompts have an influence on learning electrochemistry. The intervention is embedded in a pre-, post- and follow-up-test in order to identify a relationship between the knowledge about scientific representations and models and the development of conceptual knowledge of electrochemistry. In order to detect the influence two experimental groups are needed to identify the effect of the instruction and the instruction combined with prompts compared to the control group. Furthermore, a video study was integrated focusing on students' communication about representations. One hundred-eleven 10^{th}-grade students from three secondary schools within Lower Saxony, Germany, were recruited. Students were aged 15 to 17. The research project took place after regular school lessons but inside of the school building. Pre-test data were used to balance the treatment groups.

Based on recent research, it is assumed that students achieve a better conceptual understanding of electrochemistry if they know about the nature of scientific representations and models. The result of students' development in conceptual knowledge shows a significant difference between the treatment groups. However, this difference is only significant for recalling chemical knowledge and only between the control and second experimental group. Consequently, the assumption about a better conceptual understanding can be partially confirmed. The significant difference between the control and the second experimental group indicates the positive impact of prompts on students' ability to recall chemical knowledge. The video analysis illustrates that using prompts stimulates the communication regarding their procedural knowledge about different representations. Moreover, the findings are in line with previous research underlining that students communicate their knowledge rarely at a meta-level. In 17 situations, students of the experimental groups talk about meta-representational knowledge. There is no situation identified where students communicate their meta-modelling knowledge. The video data merely reflects the significant difference in recalling chemical knowledge between the treatment groups. There is a tendency of the second experimental group showing more conceptual related statements compared to the other groups, but this difference is non-significant. Nevertheless, comparing students' conceptual statements referring to their representational domain indicates a significant difference in expressing knowledge at the submicroscopic domain between the control and the second experimental group during the second session of interactive boxes. This is an important finding related to students' difficulty of separating the representation domains (Johnstone, 1982). This result supports the effectiveness of the meta-conceptual training in combination with the prompts. The lab journal analysis confirms this finding. Only students from the experimental groups visualized the chemical processes including submicroscopic entities. Research in the field has demonstrated the importance of students' ability to visualize their conceptions (Ainsworth, 2006; Ainsworth et al., 2011). Moreover, students from the second experimental group gave significantly more explanatory statements on the formal representation domain.

Related to the presented results, it becomes obvious that the meta-conceptual training in combination with the prompts has a positive effect on students' ability to recall chemical knowledge. This finding supports the first considerable implication of this study saying that knowledge of representations should be constantly stimulated within the learning process. Vosniadou and Ioannides (1998) underline that "to help students their meta-conceptual awareness, it is necessary to create learning environments that make it possible for students to express their representations" (p. 1224). According to this citation, the meta-conceptual training and the hands-on activities failed to satisfy an environment where students express their representations. Moreover, knowing about the different representations and its modelled nature in combination with the prompts has a positive influence on precisely communicating conceptual knowledge. The video analysis provides the second implication that students need to be constantly reminded about the representation domains in order to integrate them in their conceptual knowledge.

This study supports the importance of the triplet relationship of chemical knowledge representations despite the general limitation of this study. In conclusion, school science lessons should explicitly focus on the interplay between macroscopic, submicroscopic and formal representations. Moreover, reflecting the representation domains requires practice and explicit instructions. This research project emphasise the importance of knowing about representations. However, students still have difficulties in separating and transferring the representations as the video and lab journal analysis demonstrates. Hence, further research would have to focus on explicit instructions which help students to separate and transfer between the different representations. Furthermore, this study was embedded in the context of electrochemistry. Further research would have to focus on other chemical content.

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A. Small Group Material

I. Material in Interactive Boxes

i. Session 1

Aufgabenkarte

Wenn man einen Zinknagel länger in eine Kupfersulfat-Lösung taucht, stellt man etwas Interessantes fest.

Erklärt dieses Phänomen mithilfe eures Vorwissens und den Info-Karten!

Info-Karte

In einer Metallsalz-Lösung (z.B. Kupfersulfat-Lösung) liegen positiv geladene Metall-Ionen (z.B. Kupfer-Kationen) und negativ geladene Ionen (z.B. Sulfat-Anionen) gelöst vor. In der Lösung sind alle Ionen hydratisiert, d.h. sie sind von Wassermolekülen umgeben. Eine Metallsalz-Lösung ist elektrisch neutral, da sich positive und negative Ladungsträger ausgleichen.

Info-Karte

Feinverteile, hauchdünne Metallschichten wirken häufig schwarz. Erst ab einer bestimmten Schichtdicke erlangen sie ihr metallisches Aussehen.

Info-Karte

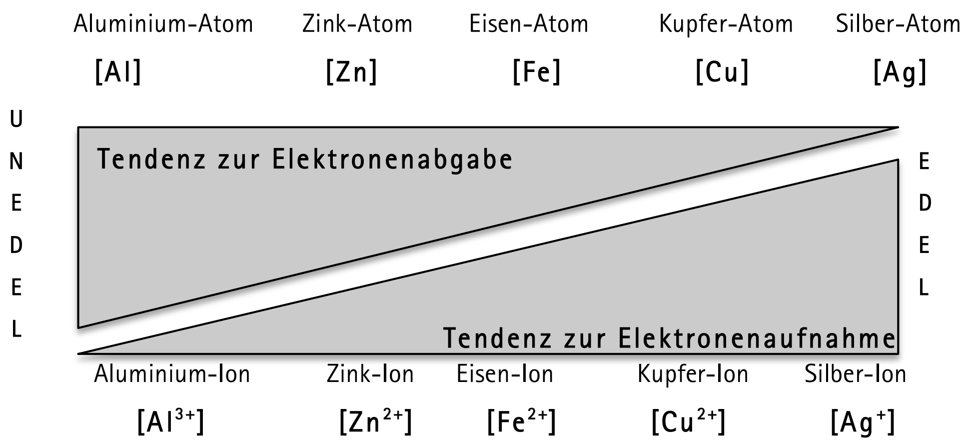
Redoxreaktionen sind chemische Reaktionen, bei denen Elektronen des einen Reaktionspartners auf den anderen Reaktionspartner übertragen werden. Reduktion und Oxidation laufen **immer gleichzeitig** ab.

	Oxidation	Reduktion	
Elektronen-abgabe	Wenn ein Metall-Atom (M1) Elektronen abgibt, so findet eine **Oxidation** statt: $M1\ (s) \rightarrow M1^{x+}\ (aq) + x\ e^-$	Wenn ein Metall-Ion ($M2^{x+}$) Elektronen aufnimmt, so findet eine **Reduktion** statt: $M2^{x+}\ (aq) + x\ e^- \rightarrow M2\ (s)$	Elektronen-aufnahme

Die gesamte Reaktionsgleichung der Redoxreaktion lautet:

$$M1\ (s) + M2^{x+}\ (aq) \rightarrow M1^{x+}\ (aq) + M2\ (s)$$

Info-Karte



Atome unedler Metalle (z.B. Aluminium-Atome) geben leicht Elektronen ab und bilden Metall-Ionen (z.B. Aluminium-Ionen).

Metall-Ionen edler Metalle (z.B. Silber-Ionen) nehmen leicht Elektronen auf und bilden Atome (z.B. Silber-Atome).

Ergebniskarte


Zink ist ein unedleres Metall als Kupfer. Die Tendenz der Zink-Atome zur Elektronenabgabe ist groß. Die Zink-Atome werden oxidiert. Es entstehen Zink-Kationen, welche in Lösung gehen.
Im Gegenzug ist die Tendenz der Kupfer-Ionen zur Elektronenaufnahme groß. Die Kupfer-Ionen werden reduziert. Es entstehen Kupfer-Atome. Daher ist eine kupferfarbene Schicht am Zinknagel zu beobachten.
Die Reaktion läuft spontan und freiwillig ab.
Es handelt sich um eine Redoxreaktion, eine Elektronenübertragungsreaktion. Oxidation (Elektronenabgabe) und Reduktion (Elektronenaufnahme) laufen jedoch immer gleichzeitig ab.

Die Oxidation lautet:	Die Reduktion lautet:
Elektronen-abgabe: $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2\ e^-$	$Cu^{2+}\ (aq) + 2\ e^- \rightarrow Cu\ (s)$:Elektronen-aufnahme

Die gesamte Reaktionsgleichung der Redoxreaktion lautet:

Oxidation: Elektronenabgabe

$$Zn\ (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$$

Reduktion: Elektronenaufnahme

Fazit:
Bei dem Versuch „Zinknagel in Kupfersulfat-Lösung" werden Elektronen übertragen. Um einen solchen Elektronenfluss jedoch messen zu können, darf die Elektronenübertragung nicht direkt an der Oberfläche des in Lösung gehenden Metalls stattfinden, d.h. die Metalle dürfen nicht direkt miteinander in Kontakt gebracht werden. Es muss also ein Versuchsaufbau gefunden werden, bei dem Oxidation und Reduktion räumlich voneinander getrennt werden.

ii. Session 2

Aufgabenkarte

In der letzten Box habt ihr gelernt, dass Redoxreaktionen spontan ablaufen können. Solche Reaktionen kann man nutzen, um chemische Energie in elektrische Energie umzuwandeln. Hierzu dürfen die Metalle nicht direkt miteinander in Kontakt gebracht werden, sondern Oxidation und Reduktion müssen räumlich voneinander getrennt ablaufen.

Führt mithilfe der Materialien in der Box ein Experiment durch, mit dem ihr zeigen könnt, dass elektrische Energie frei wird.

Erklärt dieses Phänomen mithilfe eures Vorwissens und den Info-Karten!

Info-Karte

Elektrische Energie ist nicht direkt messbar. Sie steht aber in direktem Zusammenhang mit der elektrischen Spannung.

Wenn man in einem Aufbau eine Spannung misst, ist dies also ein Nachweis für elektrische Energie.

Info-Karte

Die Messung einer elektrischen Spannung erfolgt immer zwischen zwei Punkten, beispielsweise zwischen zwei Elektroden. Um eine Spannung messen zu können, müssen Ladungsträger unterschiedlich verteilt sein. Das heißt, dass eine Elektrode stärker negativ geladen sein muss als die andere. Der Ausgleich dieser Ladungsdifferenz macht eine Spannungsmessung möglich.

Info-Karte

Redoxreaktionen sind chemische Reaktionen, bei denen Elektronen des einen Reaktionspartners auf den anderen Reaktionspartner übertragen werden. Reduktion und Oxidation laufen **immer gleichzeitig** ab.

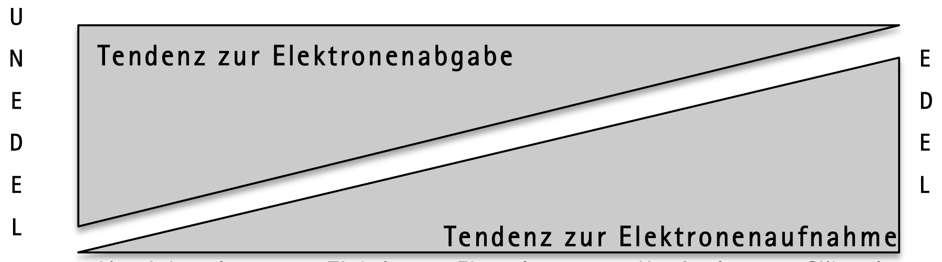
	Oxidation	Reduktion	
Elektronen-abgabe	Wenn ein Metall-Atom (M1) Elektronen abgibt, so findet eine **Oxidation** statt:	Wenn ein Metall-Ion ($M2^{x+}$) Elektronen aufnimmt, so findet eine **Reduktion** statt:	Elektronen-aufnahme
	M1 (s) → $M1^{x+}$ (aq) + x e^-	$M2^{x+}$ (aq) + x e^- → M2 (s)	

Die gesamte Reaktionsgleichung der Redoxreaktion lautet:

M1 (s) + $M2^{x+}$ (aq) → $M1^{x+}$ (aq) + M2 (s)

Info-Karte

Aluminium-Atom [Al] | Zink-Atom [Zn] | Eisen-Atom [Fe] | Kupfer-Atom [Cu] | Silber-Atom [Ag]



Aluminium-Ion [Al^{3+}] | Zink-Ion [Zn^{2+}] | Eisen-Ion [Fe^{2+}] | Kupfer-Ion [Cu^{2+}] | Silber-Ion [Ag^{+}]

Atome unedler Metalle (z.B. Aluminium-Atome) geben leicht Elektronen ab und bilden Metall-Ionen (z.B. Aluminium-Ionen).

Metall-Ionen edler Metalle (z.B. Silber-Ionen) nehmen leicht Elektronen auf und bilden Atome (z.B. Silber-Atome).

Info-Karte

Gibt man ein Metall in seine entsprechende Metallsalz-Lösung (z.B.: ein Zinkblech in eine Zinksulfat-Lösung), können sich auf der Teilchenebene unter Abgabe von Elektronen (negativen Ladungsträgern) eine bestimmte Anzahl an Metall-Atomen aus dem Metallgitter lösen, welche dann als Metall-Kationen in Lösung vorliegen. Die Elektronen bleiben im Metallgitter zurück. Dadurch lädt sich das Metall negativ auf, so dass die positiv geladenen Metall-Kationen in der Lösung wieder an das Metall herangezogen werden.

Diese Metall-Kationen können nun erneut Elektronen aufnehmen und werden zum Metall-Atom. Wenn ein Metall-Kation wieder zum Metall-Atom wird, löst sich dafür ein anderes aus dem Metall, sodass sich immer gleich viele positiv geladene Metall-Kationen in der Lösung befinden. Es findet also immer ein Ausgleich statt. Dieser ständige Ausgleich nennt sich **chemisches Gleichgewicht**. Es wird durch die Konzentration der Lösung beeinflusst.

Ergebniskarte

Zink ist ein unedleres Metall als Kupfer. Daher ist die Tendenz der Zink-Atome zur Elektronenabgabe groß. Die Zink-Atome werden zu Zink-Kationen oxidiert und gehen in Lösung. Die Elektronen bleiben im Metallgitter zurück. Es entsteht ein Elektronenüberschuss.
Kupfer ist ein edleres Metall als Zink. Daher ist die Tendenz der Kupfer-Ionen zur Elektronenaufnahme groß. Die Kupfer-Ionen aus der Kupfersulfat-lösung werden zu Kupfer-Atomen reduziert. Die notwendigen Elektronen werden aus dem Metallgitter entzogen. Es entsteht ein Elektronenmangel im Metallgitter.
Durch die Unterschiede in der Elektronendichte an den beiden Metallblechen ist eine Spannung messbar. Dabei stellt das Kupferblech den Pluspol und das Zinkblech den Minuspol dar. U=1,1V
Elektronen fließen vom Punkt hoher Elektronendichte (Minuspol) zum Punkt niedriger Elektronendichte (Pluspol).

Die Oxidation findet am Zinkblech statt (Minuspol):		Die Reduktion findet am Kupferblech statt (Pluspol):	
Elektronen-abgabe	$Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2\ e^-$	$Cu^{2+}\ (aq) + 2\ e^- \rightarrow Cu\ (s)$	Elektronen-aufnahme

Die gesamte Reaktionsgleichung der Redoxreaktion lautet:

Oxidation: Elektronenabgabe

$$Zn\ (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$$

Reduktion: Elektronenaufnahme

Fazit:
In einem galvanischen Element wird chemische Energie in elektrische Energie umgewandelt. Ein galvanisches Element mit einer Kupfer- und einer Zinkhalbzelle nennt man Daniell-Element.

iii. Session 3

Aufgabenkarte

In der letzten Box habt ihr gelernt, wie man mithilfe zwei verschiedener Metalle eine Spannung erzeugen kann. In der vorliegenden Box habt ihr jedoch nur zwei Bleche eines Metalls. Entwickelt einen Aufbau, der es trotzdem möglich macht, eine Spannung zu messen. Beobachtet genau!

Erklärt dieses Phänomen mithilfe eures Vorwissens und den Info-Karten!

Info-Karte

Die Messung einer elektrischen Spannung erfolgt immer zwischen zwei Punkten, beispielsweise zwischen zwei Elektroden. Um eine Spannung messen zu können, müssen Ladungsträger unterschiedlich verteilt sein. Das heißt, dass eine Elektrode stärker negativ geladen sein muss als die andere. Der Ausgleich dieser Ladungsdifferenz macht eine Spannungsmessung möglich.

Info-Karte

Unter **Stoffmengenkonzentration [c]** versteht man, welche Stoffmenge [n] eines Stoffes in einem Liter einer Flüssigkeit (z.B. Wasser) gelöst ist. Je größer die Stoffmengenkonzentration ist, desto mehr Teilchen eines Stoffes sind also in der Lösung enthalten.

$$c = \frac{n}{V} = \left[\frac{mol}{L}\right]$$

Info-Karte

Gibt man ein Metall in seine entsprechende Metallsalz-Lösung (z.B.: ein Zinkblech in eine Zinksulfat-Lösung), können sich auf der Teilchenebene unter Abgabe von Elektronen (negativen Ladungsträgern) eine bestimmte Anzahl an Metall-Atomen aus dem Metallgitter lösen, welche dann als Metall-Kationen in Lösung vorliegen. Die Elektronen bleiben im Metallgitter zurück. Dadurch lädt sich das Metall negativ auf, so dass die positiv geladenen Metall-Kationen in der Lösung wieder an das Metall herangezogen werden.

Diese Metall-Kationen können nun erneut Elektronen aufnehmen und werden zum Metall-Atom. Wenn ein Metall-Kation wieder zum Metall-Atom wird, löst sich dafür ein anderes aus dem Metall, sodass sich immer gleich viele positiv geladene Metall-Kationen in der Lösung befinden. Es findet also immer ein Ausgleich statt. Dieser ständige Ausgleich nennt sich **chemisches Gleichgewicht**. Es wird durch die Konzentration der Lösung beeinflusst.

Info-Karte

Wenn die Konzentration der Lösung erhöht wird, dann nehmen vermehrt Metall-Kationen Elektronen auf und scheiden sich als Metall-Atome am Metallgitter ab.

Wenn die Konzentration der Lösung erniedrigt wird, dann lösen sich vermehrt Metall-Atome aus dem Metallgitter und liegen als Metall-Kationen in Lösung vor.

II. Lab Journal

Dein Code:

Laborjournal

Allgemeine Hinweise

In einem Laborjournal hast du ausreichend Platz, um ein Experiment zu protokollieren. Zusätzlich kannst du aber auch Ideen, Gedanken oder Kommentare aufschreiben. Ziel des Laborjournals ist es, dass du auch zu einem späteren Zeitpunkt das Experiment nachvollziehen kannst. Daher ist es wichtig, dass du möglichst genau deine Aussagen formulierst.

Nummer der Box: ________ Thema der Box:____________________________________

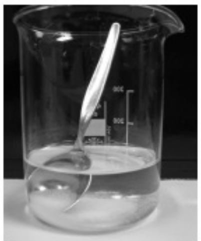
B. Intervention Measure

I. Meta-conceptual Training

1

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Versuch: Lösen von Kochsalz in Wasser



Was kannst du beobachten?

2

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Versuch: Lösen von Kochsalz in Wasser

Aufgabe 1: Trage deine Beobachtungen links in die Tabelle ein.

Dein Code:____________

Beobachtungen	Deutungen

Aufgabe 2: Deute deine Beobachtungen! Trage deine Deutungen rechts in die Tabelle ein.

3

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

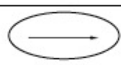
Wir unterscheiden zwischen

Erfahrungswelt	Modellwelt
	
Die Erfahrungswelt enthält Phänomene, die entweder direkt mit unseren Sinnen oder indirekt über Hilfsmittel, wie z.B. Messgeräte, erfahrbar sind. So können Stoffeigenschaften, wie Farbe oder Geruch, eines Stoffes direkt wahrgenommen werden; Masse, Temperatur oder Spannung hingegen müssen gemessen werden.	Die Modellwelt fängt da an, wo unsere Sinneswahrnehmungen an die Grenze gelangen, weil Ursachen und Erklärungen von einem Phänomen in einem zu kleinen oder zu großen Bereich gesucht werden müssten. Daher werden Interpretationen in Form von Modellvorstellungen benötigt. Solche Modellvorstellungen im kleinen Bereich sind Hilfsmittel für einen Chemiker, um Informationen über die Realität zu erhalten, welche nicht direkt beobachtbar oder messbar sind. Modelle sind aber KEIN Abbild der Realität. Im Rahmen von Modellvorstellungen werden **Bezüge** zwischen Erfahrungs- und Modellwelt **hergestellt**, die meist zu einem bestimmten Zweck **vereinfacht** werden und daher nur **ausgewählte** Informationen beinhalten. Sie dienen zum Erklären und zum Verstehen von Sachverhalten. In der Chemie spielen vor allem Modelle kleinster Teilchen eine große Rolle. Ebenso beschreiben Chemiker mithilfe von Formeln oder Reaktionsgleichungen chemische Zusammenhänge. Daher unterteilen wir im Folgenden die Modellwelt in die **Atomare Ebene** und die **Formale Ebene**.

4

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Überblick der verschiedenen Ebenen

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
Die erfahrbare Ebene enthält alle Phänomene, die für uns erfahrbar/ messbar sind: • Farbe • Geruch • Form • Temperatur • Volumen • Masse • Spannung • ...	Die atomare Ebene beschreibt die Vorstellung von der Existenz kleinster Teilchen und deren Anordnung: • Moleküle • Atome • Ionen • Elektronen • Ionengitter • ...	Die formale Ebene enthält abstrakte Darstellungen wie: • Elementsymbole • Reaktionsgleichungen • Mathematische Gleichungen • Summenformeln • ...
		

5

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Versuch: Lösen von Kochsalz

Dein Code:______________

In der Chemie können wir also zwischen Erfahrungs- und Modellwelt unterscheiden. Nun habt ihr noch ein Mal die Gelegenheit, den Versuch „Lösen von Kochsalz" mithilfe der drei Ebenen auszuwerten. Verwendet hierfür eure Tabelle von Seite 3.

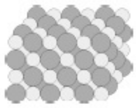
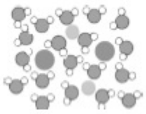
Aufgabe: Ordnet alle Aussagen aus der alten Tabelle in die drei Ebenen der neuen Tabelle ein.

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
		

6

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Eine mögliche Auswertung des Versuchs

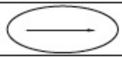
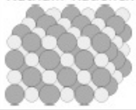
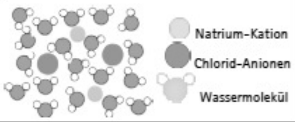
Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
		
• Kochsalz ist ein weißer Feststoff. • Kochsalz besteht aus vielen kleinen Kristallen. • Das Kochsalz löst sich im destillierten Wasser. • Es entsteht eine klare Lösung. Kochsalz ist nicht mehr sichtbar. • Das Gewicht der Lösung ist gleich dem Gewicht von Wasser und Salz zusammen.	• Natrium-Kationen und Chlorid-Anionen sind fest in einem Gitter angeordnet.  Natrium-Kation Chlorid-Anionen • Natrium-Kationen und Chlorid-Anionen lösen sich aus dem Ionengitter. • Im Wasser bildet sich eine Hydrathülle um die gelösten Ionen. Je nach Ladung der Ionen sind die Wassermoleküle unterschiedlich ausgerichtet.  Natrium-Kation Chlorid-Anionen Wassermolekül	$NaCl_{(s)} + H_2O_{(l)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(l)}$ $m(NaCl_{(aq)}) = m(NaCl_{(s)}) + m(H_2O_{(l)})$

Aufgabe: Kreise mit gleicher Farbe auf den drei Ebenen die Aussagen ein, die einen direkten Bezug zueinander haben.

7

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Welche Aussagen auf den drei Ebenen haben einen direkten Bezug zueinander?

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
		
• Kochsalz ist ein weißer Feststoff. • Kochsalz besteht aus vielen kleinen Kristallen.	• Natriumchlorid ist eine Ionenverbindung. Natrium-Kationen und Chlorid-Anionen sind fest in einem Gitter angeordnet. 	$NaCl_{(s)} + H_2O_{(l)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(l)}$ $m(NaCl_{(aq)}) = m(NaCl_{(s)}) + m(H_2O_{(l)})$
• Das Kochsalz löst sich im destillierten Wasser.	• Natrium-Kationen und Chlorid-Anionen lösen sich aus dem Ionengitter.	
• Es entsteht eine klare Lösung. Kochsalz ist nicht mehr sichtbar.	• Wassermoleküle bilden eine Hydrathülle um Natrium-Kationen und Chlorid-Anionen. Je nach Ladung der Ionen sind die Wassermoleküle unterschiedlich ausgerichtet. 	
• Das Gewicht der Lösung ist gleich dem Gewicht von Wasser und Salz zusammen.		

8

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

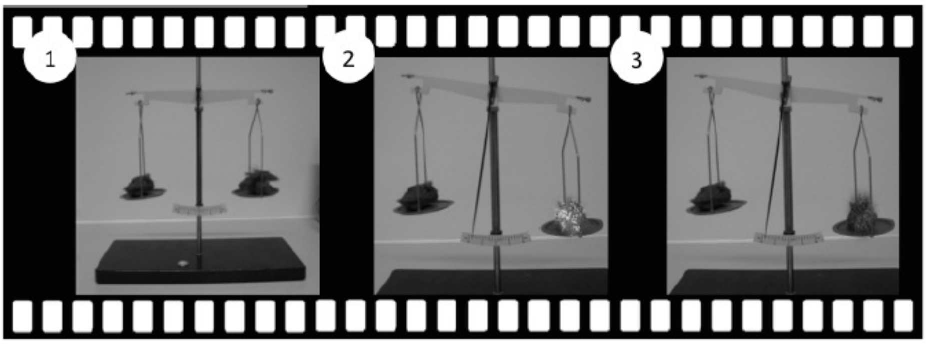
Ein Beispiel zum Üben

9

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Beispiel: Verbrennen von Eisenwolle

Die folgende Bildreihe zeigt dir die Verbrennung von Eisenwolle an der Luft vor, während und nach der Reaktion.

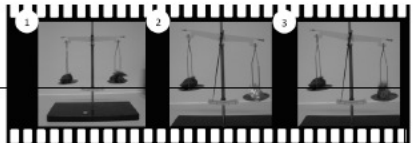


(1) Vor der Reaktion (2) Reaktion (3) Nach der Reaktion

Aufgabe: Was kannst du beobachten?

10

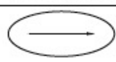
STOP Erst umblättern, wenn ich das Zeichen dafür gebe!



Beispiel: Verbrennen von Eisenwolle

Dein Code:______________

Aufgabe 1: Trage deine Beobachtungen und deine Deutungen in die folgende Tabelle ein.

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
		

Aufgabe 2: Kreise mit gleicher Farbe auf den drei Ebenen die Aussagen ein, die einen direkten Bezug zueinander haben.

11

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Eine mögliche Auswertung des Beispiels

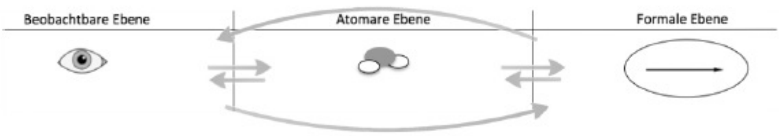
Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
• Die Eisenwolle ist fest. • Die Eisenwolle ist dunkelgrau. • Vor der Reaktion ist die Waage im Gleichgewicht. • Die Eisenwolle verbrennt orangeglühend. • Das Produkt ist fest. • Das Produkt ist schwarz. • Nach der Reaktion ist die Seite mit der verbrannten Eisenwollen tiefer.	• Die Eisen-Atome liegen fest angeordnet im Metallgitter. (Eisen-Atom) • Die Eisen-Atome reagieren mit den Sauerstoff-Molekülen der Luft. (Sauerstoff-Atom) • Es entsteht eine Eisenoxid-Verbindung. Eisen-Kationen und Oxid-Anionen liegen fest angeordnet in einem Ionengitter. (Eisen-Ion, Oxid-Ion)	Die Reaktionsgleichung lautet: $2\,Fe(s) + O_2(g) \rightarrow 2\,FeO(s)$ $m(Fe) < m(FeO)$

12

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
Was kannst du direkt oder indirekt durch Messgeräte beobachten? • Farbe • Geruch • Form • Temperatur • Volumen • Masse • Spannung ...	Wie kannst du deine Beobachtungen auf atomarer Ebene erklären? Welche Modellvorstellungen helfen dir dabei? • Moleküle • Atome • Ionen • Elektronen • Ionengitter ...	Wie lassen sich deine Beobachtungen und/ oder deine Erklärungen der atomaren Ebene auf formaler Ebene darstellen? • Elementsymbole • Reaktionsgleichungen • Mathematische Gleichungen • Summenformeln ...

Welche Aussagen auf den drei Ebenen haben einen direkten Bezug zueinander?

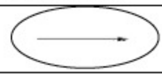


13

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Zusammenfassung

In der Chemie können wir zwischen Erfahrungs- und Modellwelt unterscheiden. Zur Erfahrungswelt gehören alle Phänomene, die entweder direkt mit unseren Sinnen oder indirekt über Hilfsmittel, wie z.B. Messgeräte, erfahrbar sind. Um diese Phänomene jedoch deuten zu können, benötigen wir geeignete Modellvorstellungen, wie zum Beispiel die Vorstellung der Existenz kleinster Teilchen. Ebenso dienen formale Darstellungen, wie Reaktionsgleichungen, zum Ausdruck von chemischen Zusammenhängen. Die folgende Tabelle soll dir in Zukunft helfen, Phänomene auf allen drei Ebenen zu betrachten.

Erfahrungswelt	Modellwelt	
Erfahrbare Ebene	Atomare Ebene	Formale Ebene
		

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

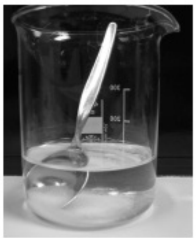
II. Training (Control Group)

Institut für Didaktik der Naturwissenschaften

Leibniz Universität Hannover

Dein Code:____________

Fachwissen trainieren



Versuch: Lösen von Kochsalz in Wasser

Was kannst Du beobachten?

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Versuch: Lösen von Kochsalz in Wasser

Aufgabe:

Schreibe deine Beobachtungen und deine Deutungen auf.

STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

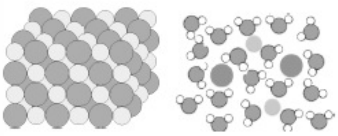
Eine mögliche Auswertung des Versuchs

Beobachtungen:

Kochsalz ist ein weißer Feststoff. Er besteht aus vielen kleinen Kristallen. Kochsalz löst sich im destillierten Wasser. Es entsteht eine klare Lösung. Das Kochsalz ist nicht mehr sichtbar. Das Gewicht der Lösung ist gleich dem Gewicht von Wasser und Salz zusammen.

Deutungen:

Kochsalz ist eine Ionenverbindung. Sie besteht aus Natrium-Kationen und Chlorid-Anionen, welche fest in einem Gitter angeordnet sind. Durch die Zugabe des Wassers löst sich das Gitter. Im Wasser liegen die Natrium-Kationen und die Chlorid-Anionen nun einzeln vor. Sie sind umgeben von Wassermolekülen, welche je nach Ladung der Ionen unterschiedlich ausgerichtet sind.



Die Reaktionsgleichung lautet:

$NaCl_{(s)} + H_2O_{(l)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(l)}$

$m(NaCL_{(aq)}) = m(NaCl_{(s)}) + m(H_2O_{(l)})$

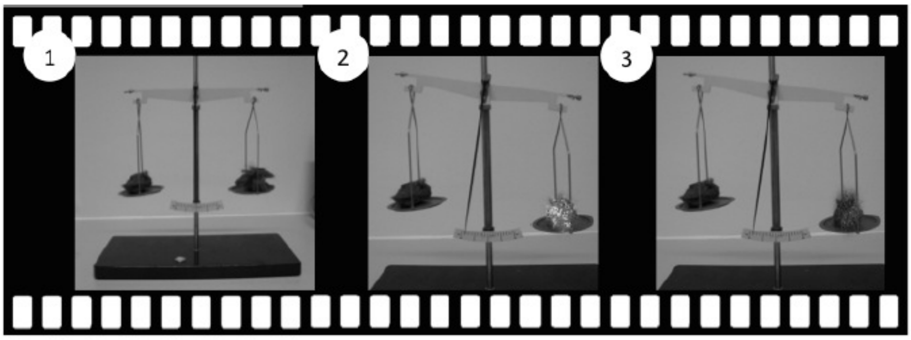
STOP Erst umblättern, wenn ich das Zeichen dafür gebe!

Verbrennen von Eisenwolle

Erst umblättern, wenn ich das Zeichen dafür gebe!

Beispiel: Verbrennen von Eisenwolle

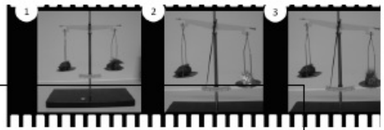
Die folgende Bildreihe zeigt dir die Verbrennung von Eisenwolle an der Luft vor, während und nach der Reaktion.



(1) Vor der Reaktion (2) Reaktion (3) Nach der Reaktion

Was kannst du beobachten?

Erst umblättern, wenn ich das Zeichen dafür gebe!



Beispiel: Verbrennen von Eisenwolle

Schreibe deine Beobachtungen und deine Deutungen auf.

Erst umblättern, wenn ich das Zeichen dafür gebe!

Eine mögliche Auswertung des Versuchs

Beobachtungen:

Die feste Eisenwolle ist vor der Reaktion dunkelgrau. Vor der Reaktion ist die Waage im Gleichgewicht. Die Eisenwolle verbrennt orangeglühend. Das Produkt ist fest und schwarz. Nach der Reaktion ist die Seite mit der verbrannten Eisenwolle tiefer.

Deutungen:

Die Eisen-Atome liegen fest angeordnet im Metallgitter. Eisenatome reagieren mit den Sauerstoffmolekülen der Luft. Es entsteht Eisenoxid. In der Eisenoxid-Verbindung sind Eisen-Kationen und Oxid-Anionen fest angeordnet in einem Ionengitter.

Die Reaktionsgleichung lautet:

$2\,Fe\,(s) + O_2\,(g) \rightarrow 2\,FeO\,(s)$

$m(Fe) < m(FeO)$

Erst umblättern, wenn ich das Zeichen dafür gebe!

C. Test Instruments

I. Control Measures

Liebe Schülerinnen und Schüler,

mit den folgenden Fragebögen wollen wir etwas über deine allgemeinen Fähigkeiten (Teil I), dein Interesse im Fach Chemie (Teil II), dein Fachwissen (Teil IIIa+IIIb) und deine Vorstellungen über Modelle (Teil IV) erfahren. Deine Antworten werden selbstverständlich anonym behandelt. Deine Lehrerin oder dein Lehrer sowie deine Eltern werden keine Einsicht in deine Antworten erhalten. Für unser Forschungsprojekt ist es aber sehr wichtig, dass du die Aufgaben **alleine, gewissenhaft und so gut du es kannst beantwortest.**

Jeder Teil muss in einer bestimmten Zeit bearbeitet werden. Es gibt jeweils eine kurze Einführung und wir fangen jeweils gemeinsam wieder an, wenn das Zeichen hierfür gegeben wird.

Bevor es losgeht, möchten wir noch ein paar wichtige Hintergrundinformationen von dir erfragen und dir einige Hinweise geben.

Geschlecht	☐ weiblich	☐ männlich	Alter:_________
Jahrgang	☐ 10	☐ 11	
Schulform	☐ Gesamtschule	☐ Gymnasium	
Bundesland	☐ Niedersachsen	☐ Nordrhein-Westfalen	

Möchtest du folgende Fächer auf grundlegendem oder erhöhtem Anforderungsniveau wählen?

Chemie:	☐ Grundlegendes Niveau	☐ Erhöhtes Niveau	☐Abwahl	Zeugnisnote: ______
Physik:	☐ Grundlegendes Niveau	☐ Erhöhtes Niveau	☐Abwahl	Zeugnisnote: ______

Damit wir nachher den Fragebogen nicht mehr deiner Person zuordnen können, geben wir dir einen Code, der uns hilft, die Fragebögen der gleichen Person zuzuordnen. Du musst ihn auf jedem der folgenden Fragebögen eintragen und dir daher merken. Hebe deinen ausgeteilten Code gut auf. Er ist für die nächsten Stunden deine persönliche ID.

Zum Schluss noch ein wichtiger Hinweis:
Falls du bei den Multiple-Choice-Aufgaben versehentlich ein falsches Kästchen markierst, dann male es bitte vollständig aus und kreuze das richtige Kästchen an!

■ Antwort 1

☒ Antwort 2

Viel Erfolg!

i. Interest, Motivation and Attitudes

Dein Code: ____________

Allgemeine Hinweise

Mit diesem Fragebogen möchten wir etwas über eure Interessen im Fach Chemie erfahren. Es geht um eure persönliche Meinung. Es handelt sich dabei nicht um eine Leistungsüberprüfung.
Bei den folgenden Aussagen sollt ihr von den verschiedenen Antwortmöglichkeiten immer die ankreuzen, die am ehesten eure Meinung wiedergibt. Bitte versucht, euch dabei immer möglichst spontan zu entscheiden.
Hier ist erst einmal eine Beispielfrage, damit ihr ganz genau wisst, wie das geht.

	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
Ich gehe gerne zur Schule.	☐	☐	☐	☐

Lies dir zuerst die Aussage und die vier Antwortmöglichkeiten durch.
Je nachdem, ob du gerne zur Schule gehst oder nicht, kreuzt du **ein** Kästchen an.

- Wenn du gar nicht gerne zur Schule gehst, dann kreuzt du in der ersten Spalte das Kästchen bei *'stimmt gar nicht'* an.
- Wenn du nur selten gerne zur Schule gehst, dann kreuzt du in der zweiten Spalte das Kästchen bei *'stimmt wenig'* an.
- Wenn du öfter gerne zur Schule gehst und nur manchmal nicht so gerne, dann kreuzt du in der dritten Spalte das Kästchen bei *'stimmt ziemlich'* an.
- Wenn du immer gerne zur Schule gehst, dann kreuzt du in der vierten Spalte das Kästchen bei *'stimmt völlig'* an.

Wichtig ist, dass du immer nur ein Kästchen ankreuzt.
Wenn du nicht genau weißt, welches Kästchen du ankreuzen sollst, dann entscheide dich für das Kästchen, das deiner Meinung am nächsten kommt.
Denke daran: **Es gibt keine richtigen oder falschen Antworten.**
Viel Spaß!

	Gib hier bitte an, in wieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
TOSRA_ES_2	1. Chemieunterricht langweilt mich.	☐	☐	☐	☐
TOSRA_SI_62	2. Ich bekomme lieber wissenschaftliche Ergebnisse erzählt als selber welche durch chemische Experimente zu erhalten.	☐	☐	☐	☐
PMI_SAI_42	3. Wenn ich Chemie abwählen könnte, so würde ich dies sofort tun.	☐	☐	☐	☐
TOSRA_ES_68	4. Ich würde Schule ohne Chemieunterricht besser finden.	☐	☐	☐	☐
PMI FGN_39	5. Im Chemieunterricht viel zu können und gut zu sein ist für mich wichtig, weil ich einen guten Durchschnitt in Chemie haben möchte.	☐	☐	☐	☐
PMI SAI_18	6. In meiner Freizeit beschäftige ich mich auch unabhängig vom Unterricht mit Dingen, die mit Chemie zutun haben.	☐	☐	☐	☐
TOSRA_SI_59	7. Ich führe lieber chemische Experimente zu einem Thema durch als darüber in einem Chemiebuch zu lesen.	☐	☐	☐	☐
TOSRA_ES 05	8. Chemieunterricht macht mir Spaß.	☐	☐	☐	☐
PMI FGN_91	9. In Chemie viel zu können und gut zu sein ist für mich wichtig, weil ich gute Noten bekommen möchte.	☐	☐	☐	☐
TOSRA_SI_24	10. Ich schließe mich lieber anderen an als selber etwas durch ein chemisches Experiment herauszufinden.	☐	☐	☐	☐
PMI_GTA_41	11. Ich wünschte mir, dass ich mich nicht mit Chemie beschäftigen müsste.	☐	☐	☐	☐
TOSRA SI_38	12. Ich frage lieber einen Experten, um etwas herauszufinden, als selber ein chemisches Experiment durchzuführen.	☐	☐	☐	☐

	Gib hier bitte an, in wieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
TOSRA_ ES_33	13. Chemie ist eines der interessantesten Schulfächer.	☐	☐	☐	☐
TOSRA_ SI_52	14. Ich frage lieber den Lehrer, um etwas herauszufinden, als selber ein chemisches Experiment durchzuführen	☐	☐	☐	☐
PMI_SA I_26	15. Ich mache für Chemie mehr als ich für die Schule brauchen würde.	☐	☐	☐	☐
TOSRA_ ES_61	16. Ich freue mich auf den Chemieunterricht.	☐	☐	☐	☐
PMI_SA I_26	17. Chemische Themen interessieren mich nicht.	☐	☐	☐	☐
PMI_FB F_86	18. Im Chemieunterricht viel zu können und gut zu sein ist für mich wichtig, damit meine Chemielehrerin/mein Chemielehrer mit mir zufrieden ist.	☐	☐	☐	☐
TOSRA_ ES_12	19. Ich mag keinen Chemieunterricht.	☐	☐	☐	☐
PMI GT A_47	20. Zu Chemie muss ich mich zwingen.	☐	☐	☐	☐
TOSRA ES_19	21. Ich hätte gerne mehr Chemieunterricht in der Woche.	☐	☐	☐	☐
TOSRA SI_45	22. Um ein Problem zu lösen, führe ich lieber selber ein chemisches Experiment durch als einen Experten zu fragen.	☐	☐	☐	☐
PMI FG N_78	23. Im Chemieunterricht viel zu können und gut zu sein ist für mich wichtig, damit ich ein gutes Zeugnis bekomme.	☐	☐	☐	☐
TOSRA_ ES_40	24. Chemieunterricht ist Zeitverschwendung.	☐	☐	☐	☐

Wie siehst du dich selbst im Chemieunterricht?

	Wenn ich mich anstrenge…	Stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
Swe1	1. …kann ich die Fragen des Chemielehrers immer beantworten.	☐	☐	☐	☐
Swe2	2. …komme ich im Chemieunterricht problemlos mit.	☐	☐	☐	☐
Swe3	3. …finde ich für fast alle chemischen Probleme eine Lösung.	☐	☐	☐	☐

Manche Fächer findet man ziemlich schwer und in anderen wiederum kommt man besser zurecht.

Wie geht es dir mit Chemie?

		Stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
Sbk1	1. Ich bin in Chemie gut.	☐	☐	☐	☐
Sbk2	2. Chemie fällt mir leicht.	☐	☐	☐	☐
Sbk3	3. Wenn der Chemielehrer eine Frage stellt, weiß ich meistens die richtige Antwort.	☐	☐	☐	☐
Sbk4	4. In Chemie bin ich gut, auch ohne dass ich dafür lerne.	☐	☐	☐	☐
Sbk5	5. Im Chemie-Unterricht mitzukommen fällt mir leicht.	☐	☐	☐	☐
Sbk6	6. Chemieaufgaben kann ich gut lösen.	☐	☐	☐	☐

In diesem Teil geht es um die Schule. Du kennst das bestimmt auch: Bei manchen Lehrern macht der Unterricht Spaß und man kann alles gut verstehen. Bei anderen Lehrern ist es unheimlich langweilig oder man versteht fast gar nichts.

Wir wollen wissen, wie du deinen Chemieunterricht erlebst.

	Im Chemieunterricht...	Stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
Kos1	1. ...bekomme ich ausreichend Gelegenheit das Gelernte zu üben.	☐	☐	☐	☐
Kos2	2. ...sind die Übungsaufgaben meist so gestellt, dass sie weder zu einfach, noch zu schwer für mich sind.	☐	☐	☐	☐
Kos3	3. ...weiß ich nie so genau, wie mein Lehrer meine Antwort findet.	☐	☐	☐	☐
Kos4	4. ...kann mein Lehrer gut erklären.	☐	☐	☐	☐
Kos5	5. ...erklärt mein Lehrer besonders an schwierigen Stellen ganz langsam und sorgfältig.	☐	☐	☐	☐
Kos5	6. ...geht mir oft alles viel zu schnell.	☐	☐	☐	☐

Ihr arbeitet im Unterricht sicherlich öfter auch mal in Gruppen.

Wie gefällt dir Gruppenarbeit?

		Stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
Koop 1	1. Meine Mitschüler hören mir zu, wenn ich in einer Gruppenarbeit etwas zu sagen habe.	☐	☐	☐	☐
Koop 2	2. Bei einer Gruppenarbeit arbeite ich gut mit meinen Mitschülern zusammen.	☐	☐	☐	☐
Koop 3	3. Wenn jemand in einer Gruppenarbeit nicht mehr mitkommt, helfe ich gern weiter.	☐	☐	☐	☐
Koop 4	4. Ich arbeite gern mit meinen Mitschülern in Gruppen zusammen.	☐	☐	☐	☐

ii. Cognitive Load and Situational Interest

Allgemeine Hinweise

Mit diesem Fragebogen wollen wir erfahren, wie du das Experimentieren mithilfe der Boxen erlebt hast. Es handelt sich hierbei nicht um eine Leistungsüberprüfung. Wir wollen deine persönliche Meinung kennenlernen.

Du darfst nur ein Kästchen ankreuzen!

	sehr gering			mittel			sehr hoch
1. Beim Bearbeiten und Verstehen der Experimentierboxen war meine Denk-Anstrengung...	☐	☐	☐	☐	☐	☐	☐

	sehr leicht			mittel			sehr schwer
2. Wie leicht waren die Aufgaben-stellungen zu verstehen?	☐	☐	☐	☐	☐	☐	☐

	stimmt völlig			teils-teils			stimmt überhaupt nicht	Nicht Beant-wortbar
3. Die Info-Karten habe ich benutzt.	☐	☐	☐	☐	☐	☐	☐	☐
4. Die Info-Karten waren leicht zu verstehen.	☐	☐	☐	☐	☐	☐	☐	☐
5. Die Info-Karten haben zur Lösung der Aufgaben-stellung beigetragen.	☐	☐	☐	☐	☐	☐	☐	☐

Gib hier bitte an, inwieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
1. Beim Experimentieren habe ich mich wohl gefühlt.	☐	☐	☐	☐
2. Ich habe heute gut mit meinem Mitschüler zusammengearbeitet.	☐	☐	☐	☐
3. Nach dem Lesen der Aufgabenkarte fand ich das Thema sehr interessant.	☐	☐	☐	☐
4. Beim Experimentieren habe ich über nichts anderes nachgedacht.	☐	☐	☐	☐
5. Ich war fest entschlossen, mich bei dieser Aufgabe voll anzustrengen.	☐	☐	☐	☐
6. Der Inhalt der Gruppenarbeit war für mich persönlich von Bedeutung.	☐	☐	☐	☐
7. Die Experimente haben mir Spaß gemacht.	☐	☐	☐	☐
8. Ich würde gerne noch mehr Experimente zu dem Thema durchführen.	☐	☐	☐	☐
9. Ich freue mich auf die nächste Gruppenarbeit mit meinem Partner.	☐	☐	☐	☐
10. Die Gruppenarbeit war langweilig.	☐	☐	☐	☐
11. Das Thema heute scheint mir persönlich wichtig.	☐	☐	☐	☐
12. Mein Mitschüler hat mir zugehört, wenn ich eine Idee zu unserer Aufgabenstellung hatte.	☐	☐	☐	☐

Gib hier bitte an, inwieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
13. Ich finde es wichtig, solche Themen wie heute kennen zu lernen.	☐	☐	☐	☐
14. Ich war stolz, wenn wir einen Teil der Aufgabenstellung lösen konnten.	☐	☐	☐	☐
15. Mein Partner und ich haben heute gut über das Thema diskutiert.	☐	☐	☐	☐
16. Beim Experimentieren ist die Zeit sehr schnell vergangen.	☐	☐	☐	☐
17. Was ich über das Thema erfahren habe, bringt mir was.	☐	☐	☐	☐
18. Ich werde meinen Eltern und Freunden von dem Thema erzählen, zu dem wir heute Experimente gemacht haben.	☐	☐	☐	☐
19. Ich und mein Partner haben uns heute gut geholfen.	☐	☐	☐	☐
20. Ich würde sehr gerne erfahren, ob wir die Aufgabe richtig gelöst haben.	☐	☐	☐	☐

II. Independent Variable

i. Understanding of Scientific Representations

Allgemeine Hinweise

Im ersten Teil des Fragebogens wollen wir erfahren, was du dir unter bestimmten Begriffen vorstellst. Im zweiten Teil wollen wir dann herausfinden, wie du diese Begriffe mit bestimmten Beschreibungen chemischer Sachverhalte verbindest. Es handelt sich hierbei nicht um eine Leistungsüberprüfung. Wir wollen deine persönliche Meinung kennenlernen.

Teil I

Was verstehst du unter den folgenden Begriffen? Schreibe eine kurze Definition in das hierfür vorgesehene Feld.

1	2	3	4	5	6
Beobachtung	Deutung	Modellwelt	Erfahrungs-welt	Atomare Ebene	Formale Ebene

(1) Beobachtung

(2) Deutung

(3) Modellwelt

(4) Erfahrungswelt

(5) Atomare Ebene

(6) Formale Ebene

Allgemeine Hinweise

Teil II

Mit diesem Teil des Fragebogens wollen wir erfahren, welche der Begriffe du mit bestimmten Beschreibungen chemischer Sachverhalte verbindest.

Hier erst einmal eine Beispielaufgabe, damit du ganz genau weißt, wie das geht.

Die folgenden Begriffe (1)-(4) sollst du den Sätzen in der Tabelle zuordnen. Du darfst **ein bis drei Begriffe** auswählen und die entsprechenden Zahlen in die jeweilige Zeile schreiben.

Bitte **kreise** zusätzlich die Zahl des deiner Meinung nach wichtigsten Begriffes ein und unterstreiche die Zahl des Begriffes, bei welchem du am unsichersten bist.

1	2	3	4
Frage	Aussage	Entscheidung	Ausruf

„.Hast du ein cooles Handy."	

Wenn du glaubst, dass dieser Satz eine Aussage ist, dann schreibe in die erste Zeile eine 2. Kreise die Zahl des deiner Meinung nach wichtigsten Begriffes ein und unterstreiche die Zahl des Begriffes, bei welchem du am unsichersten bist.

Die folgenden Begriffe sollst du den Aussagen über chemische Inhalte in der Tabelle unten zuordnen.

1	2	3	4	5	6
Beobachtung	**Deutung**	**Modell-welt**	**Erfahrungs-welt**	**Atomare Ebene**	**Formale Ebene**

Du darfst **ein bis drei Begriffe** auswählen und die entsprechende Zahl in die jeweilige Zeile schreiben.
Bitte **kreise** zusätzlich die Zahl des deiner Meinung nach wichtigsten Begriffes ein und unterstreiche die Zahl des Begriffes, bei welchem du am unsichersten bist.

1. In einem Becherglas befinden sich zwei Spatel Kochsalz.	
2. Wenn ich einen glühenden Glimmspan in ein Gefäß mit Gas halte und er aufglüht, kann ich darauf schließen, dass Sauerstoff vorhanden ist.	
3. Natrium-Ionen sind positiv geladene Metall-Ionen.	
4. Die Summenformel von Natriumchlorid lautet NaCl.	
5. Destilliertes Wasser ist farblos.	
6. Metallbleche können als Elektroden benutzt werden.	
7. Chlorid-Ionen sind negativ geladene Nichtmetall-Ionen.	
8. Natriumchlorid ist eine chemische Verbindung, die aus Natrium- und Chlorid-Ionen zusammengesetzt ist.	
9. Wassermoleküle sind gewinkelt.	
10. Ionenverbindungen bestehen aus Kationen und Anionen.	
11. Die Summenformel für Wasser lautet H_2O.	
12. Sauerstoffmoleküle sind linear.	

ii. Understanding of Scientific Models

Allgemeine Hinweise

Mit diesem Fragebogen möchten wir etwas über deine Vorstellungen von Modellen erfahren. Wir wollen deine persönliche Meinung kennenlernen. Es handelt sich dabei nicht um eine Leistungsüberprüfung.

Bei den folgenden Aussagen sollst du von den verschiedenen Antwortmöglichkeiten immer die ankreuzen, die am ehesten deine Meinung wiedergibt. Bitte versuche, dich dabei immer möglichst spontan zu entscheiden.

Wichtig ist, dass du immer nur ein Kästchen ankreuzt.

Wenn du nicht genau weißt, welches Kästchen du ankreuzen sollst, dann entscheide dich für das Kästchen, das deiner Meinung am nächsten kommt.

Denke daran: **Es gibt keine richtigen oder falschen Antworten.**

Viel Spaß!

Gib hier bitte an, inwieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
1. Ein Modell soll eine genaue Abbildung des Originals sein.	☐	☐	☐	☐
2. Modelle werden benutzt, um etwas bildlich oder materiell darzustellen.	☐	☐	☐	☐
3. Modelle helfen, in unserem Kopf ein Bild von naturwissenschaftlichen Vorgängen zu bekommen.	☐	☐	☐	☐
4. Ein Modell muss nahe an der Realität sein.	☐	☐	☐	☐
5. Modelle werden benutzt, um Vorhersagen über einen naturwissenschaftlichen Vorgang zu machen und zu testen.	☐	☐	☐	☐
6. Modelle werden benutzt, um naturwissenschaftliche Phänomene zu erklären.	☐	☐	☐	☐
7. Modelle helfen, Ideen und Theorien über naturwissenschaftliche Phänomene zu machen.	☐	☐	☐	☐
8. Ein Modell muss nahe an der Realität und sehr exakt sein, damit es keiner widerlegen kann.	☐	☐	☐	☐
9. Ein Modell bildet immer etwas in einem kleineren Maßstab ab.	☐	☐	☐	☐

Nun wollen wir speziell etwas über deine Vorstellungen von Teilchen auf der atomaren Ebene erfahren.

Gib hier bitte an, inwieweit folgende Aussagen auf dich zutreffen.	stimmt **gar nicht**	stimmt **wenig**	stimmt **ziemlich**	stimmt **völlig**
1. Die Modellvorstellung „Teilchen auf der atomaren Ebene" ist ein Abbild der Realität.	☐	☐	☐	☐
2. Teilchen auf der atomaren Ebene gehören zur Realität.	☐	☐	☐	☐
3. Da es Teilchen auf der atomaren Ebene gibt, lässt sich ihr Aussehen früher oder später noch genau erforschen.	☐	☐	☐	☐
4. Teilchen auf der atomaren Ebene sind eine Modellvorstellung.	☐	☐	☐	☐
5. Die Vorstellung, die wir uns von den Teilchen auf der atomaren Ebene machen, ist eine menschliche Erfindung, die gezielt nur zur Deutung bestimmter Phänomene dienen soll.	☐	☐	☐	☐

III. Dependant Variable

Mit diesem Fragebogen wollen wir erfahren, welches Hintergrundwissen du im Fach Chemie hast. Hierbei handelt es sich **NICHT** um eine Leistungsüberprüfung. Wir bitten dich trotzdem die Aufgaben so gut es geht zu lösen. Wenn du die Antwort gar nicht weißt, musst du nicht antworten und solltest nicht raten. Bevor es los geht, möchten wir dir noch einige Informationen geben.

Es gibt zwei verschiedene Arten von Aufgaben:

1. Die Aufgaben im ersten Teil fragen nach deinem Wissen über Begriffe und Themen aus der Chemie. Kreuze jeweils diejenige Antwort an, von der du überzeugt bist, dass sie

   Beispiel

   Die Erde ist...

   ☐ ein Kontinent.

   ☐ eine Sonne.

   ☐ ein Planet.

   ☐ ein Stern.

   richtig ist.

   Du darfst nur ein Kreuz setzen!

2. Die Aufgaben im zweiten Teil bestehen aus zwei Schritten. Im ersten Schritt kreuzt du diejenige Beobachtung an, von der du sicher bist, dass du sie bei dem entsprechenden Experiment sehen würdest. Danach hast du Platz, deine Antwort schriftlich sowie auch anschaulich zu begründen.

Beispiel

Du wirfst einen aufgeblasenen Wasserball in ein mit Wasser gefülltes Schwimmbecken.

Was beobachtest du?

- ☐ Der Ball geht unter.
- ☐ Der Ball schwimmt zunächst auf der Wasseroberfläche und geht dann unter.
- ☐ Der Ball schwimmt auf der Wasseroberfläche.
- ☐ Der Ball geht zunächst unter und schwimmt dann auf der Wasseroberfläche.

Erkläre deine Beobachtung...

a) ...schriftlich!

Hier hast du Platz, um in Worten deine Beobachtungen zu erklären.

b) ...anschaulich!

Hier hast du Platz, um mithilfe von Bildern, Diagrammen, Formeln, etc. deine Beobachtungen zu erklären.

1 **Welche Aussage beschreibt den Ablauf einer Redoxreaktion?**
Bei Redoxreaktionen...
- ☐ werden die Reaktionspartner zunächst oxidiert und danach reduziert.
- ☐ laufen Oxidation und Reduktion gleichzeitig ab.
- ☐ werden die Reaktionspartner zunächst reduziert und danach oxidiert.
- ☐ laufen Oxidation und Reduktion unabhängig voneinander ab.

FTC_1

2 **Wie ist die Oxidation definiert**

- ☐ als Aufnahme von Elektronen
- ☐ als Aufnahme von Elektronenpaaren
- ☐ als Abgabe von Sauerstoffatomen
- ☐ als Abgabe von Elektronen

FTC_2

3 **Redoxreaktionen sind...**

- ☐ Neutralisationsreaktionen
- ☐ Elektronenübertragungsreaktionen
- ☐ Protonenübertragungsreaktionen.
- ☐ Elektronenpaarübertragungsreaktionen.

FTC_3

4 **Welcher Stoff wird bei der Reaktion von Kupferoxid und Kohlenstoff zu Kupfer und Kohlenstoffdioxid reduziert?**

- ☐ Kohlenstoff
- ☐ Kupfer
- ☐ Kupferoxid
- ☐ Kohlenstoffdioxid

FTC_4

5 **Salze bestehen aus...**

- ☐ Ionen
- ☐ Atomen
- ☐ Molekülen
- ☐ Elementen

FTC_5

6 **Durch welche Art von Bindung werden Salze zusammen gehalten?**

- ☐ Kovalente Bindung
- ☐ Wasserstoffbrücken
- ☐ Ionenbindung
- ☐ Metallische Bindung

FTC_6

7 Welcher der folgenden Stoffe entsteht bei der Reaktion von Eisenoxid mit Aluminium?

- ☐ Eisen-Aluminium-Legierung
- ☐ Eisendioxid
- ☐ Sauerstoff
- ☐ Aluminiumoxid

FTC_7

8 Welche Teilchen sind in einer Kupfersulfatlösung gelöst vorhanden?

- ☐ Oxid-Ionen
- ☐ Sauerstoff-Atome
- ☐ Sulfat-Atome
- ☐ Kupfer-Ionen

FTC_8

9 Welches der folgenden Metall-Atome wird am leichtesten oxidiert?

- ☐ Eisen-Atom
- ☐ Silber-Atom
- ☐ Zink-Atom
- ☐ Kupfer-Atom

FTC_9

10 Wenn man einen Zinknagel in eine Kupfersulfatlösung gibt, ...

- ☐ werden Zink-Atome oxidiert und Kupfer-Ionen reduziert.
- ☐ bleiben Zink-Atome unverändert und Kupfer-Ionen werden reduziert.
- ☐ passiert gar nichts.
- ☐ werden Zink-Atome oxidiert und Kupfer-Ionen bleiben unverändert.

FTC_10

11 Wie ist die Reduktion definiert?

- ☐ als Aufnahme von Sauerstoff
- ☐ als Abgabe von Elektronen
- ☐ als Aufnahme von Elektronen
- ☐ als Abgabe von Elektronenpaaren

FTC_11

12 Welche Aussage trifft zu?

- ☐ Metall-Ionen unedler Metalle nehmen leicht Elektronen auf.
- ☐ Atome edler Metalle nehmen leicht Elektronen auf.
- ☐ Metall-Ionen edler Metalle geben leicht Elektronen ab.
- ☐ Atome unedler Metalle geben leicht Elektronen ab.

FTC_12

13 Welches der folgenden Metall-Ionen wird am leichtesten reduziert?

- ☐ Silber-Ion
- ☐ Aluminium-Ion
- ☐ Zink-Ion
- ☐ Kupfer-Ion

FTC_13

14 Was ist das zugrunde liegende Reaktionsprinzip eines Daniell-Elements?

- ☐ Die Elektronenübertragung von der Kupferelektrode auf die Zinkelektrode.
- ☐ Die Reaktion zwischen Zink-Ionen und Kupfer-Ionen.
- ☐ Die Elektronenübertragung von der Zinkelektrode auf die Kupferelektrode.
- ☐ Die Elektronenübertragung durch Oxidation der Kupfer-Atome und Reduktion der Zink-Ionen.

FTC_14

15 Wie lautet das Reaktionsschema für die ablaufenden Reaktionen im Daniell-Element?

- ☐ Cu^{2+} (aq) + 2e$^-$ → Cu (s)
  Zn^{2+} (aq) + 2e$^-$ → Zn (s)
- ☐ Cu^{2+} (aq) + 2e$^-$ → Cu (s)
  Zn (s) → Zn^{2+} (aq) + 2e$^-$
- ☐ Cu (s) → Cu^{2+} (aq) + 2e$^-$
  Zn^{2+} (aq) + 2e$^-$ → Zn (s)
- ☐ Cu (s) → Cu^{2+} (aq) + 2e$^-$
  Zn (s) → Zn^{2+} (aq) + 2e$^-$

FTC_15

1 **Du hältst ein Eisenblech in eine Kupfersulfatlösung.**

Was beobachtest du?

- ☐ Das Eisenblech löst sich auf.
- ☐ Das Eisenblech verändert sich nicht.
- ☐ Das Eisenblech überzieht sich mit einer bläulichen Schicht.
- ☐ Das Eisenblech überzieht sich mit einer kupferfarbenen Schicht.

Erkläre deine Beobachtung...

a) ...schriftlich!

b) ...anschaulich!

FTC_tt2

2 **Ein Magnesiumband wird über dem Brenner zur Reaktion gebracht.**

Was beobachtest du?

- ☐ Es entsteht ein weißer Feststoff, welcher mehr wiegt als das Magnesiumband.
- ☐ Das Magnesiumband schmilzt.
- ☐ Es entsteht ein weißer Feststoff, welcher weniger wiegt als das Magnesiumband.
- ☐ Das Magnesiumband glüht auf und verschwindet.

Erkläre deine Beobachtung...

a) ...schriftlich!

____

____

____

____

b) ...anschaulich!

FTC_tt3

3 In ein Gefäß mit zwei Kammern stellst du auf eine Seite ein Silberblech in eine 0,01 molare Silbernitratllösung und auf die andere Seite ein Silberblech in eine 1 molare Silbernitratlösung. Die Kammern sind so miteinander verbunden, dass ein Ionenaustausch möglich ist. Du verbindest die Silberbleche elektrisch leitend über einen Verbraucher (z.B. ein LED-Lämpchen) (Abbildung 1).

Du wiegst die Silberbleche vor und nach dem Versuch.

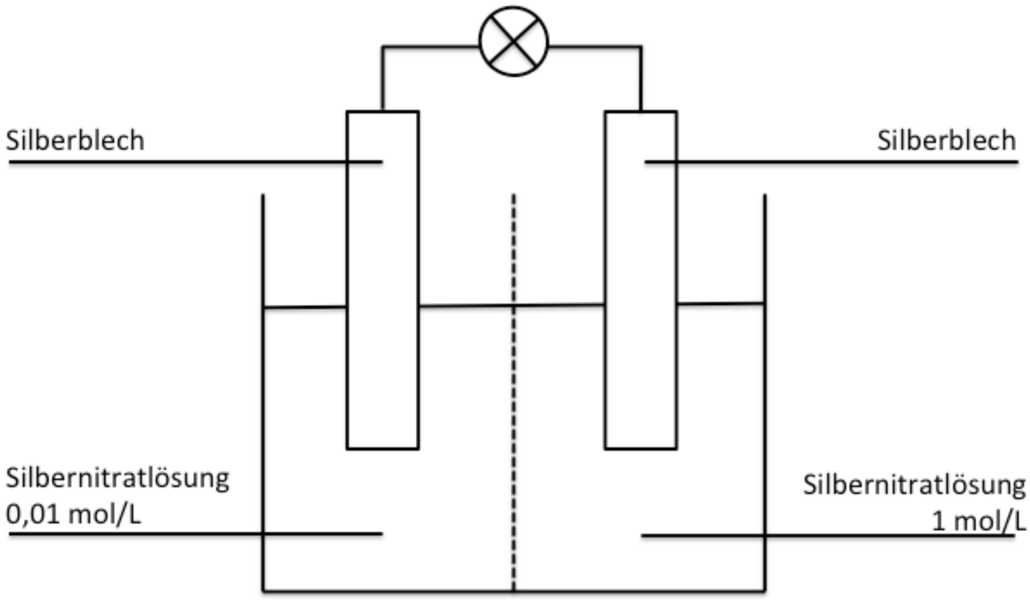


Abbildung 1

Was beobachtest du?

- ☐ Das LED-Lämpchen leuchtet nicht und beide Silberbleche bleiben unverändert.
- ☐ Das LED-Lämpchen leuchtet und beide Silberbleche bleiben unverändert.
- ☐ Das LED-Lämpchen leuchtet und das Silberblech in der 1 molaren Lösung wiegt mehr als vor dem Versuch.
- ☐ Das LED-Lämpchen leuchtet und das Silberblech in der 0,01 molaren Lösung wiegt mehr als vor dem Versuch.

Erkläre deine Beobachtung...

a) ...schriftlich!

b) ...anschaulich!

FTC_tt4

4 Im Abzug wird elementares Natrium geschmolzen und giftiges Chlorgas drüber geleitet.
Was beobachtest du nach der Reaktion?

- ☐ Chlor und Natrium haben miteinander reagiert und es ist ein weißer Feststoff mit einer größeren Masse als das Natrium entstanden.
- ☐ Es ist nichts passiert.
- ☐ Chlor und Natrium haben miteinander reagiert und es ist ein weißer Feststoff mit der gleichen Masse wie das Natrium entstanden.
- ☐ Chlor und Natrium haben miteinander reagiert und es ist ein metallisch glänzender Stoff entstanden.

Erkläre deine Beobachtung…

a) …schriftlich!

____

____

____

____

b) …anschaulich!

FTC_tt5

5 **Du hältst ein Silberblech und ein Nickelblech jeweils in eine Kupfersulfatlösung.**

Was beobachtest du?

- ☐ Es verändert sich nichts.
- ☐ Das Silberblech wird kupferfarben, das Nickelblech bleibt unverändert.
- ☐ Beide Bleche werden kupferfarben.
- ☐ Das Nickelblech wird kupferfarben, das Silberblech bleibt unverändert.

Erkläre deine Beobachtung...

a) ...schriftlich!

b) ...anschaulich!

FTC_tt6

6 In ein Gefäß mit zwei Kammern stellst du auf eine Seite ein Kupferblech in eine Kupfersulfatlösung und auf die andere Seite ein Eisenblech in eine Eisensulfatlösung (Abbildung 2).
In ein zweites Gefäß stellst du auf eine Seite ein Zinkblech in eine Zinksulfatlösung und auf die andere Seite wieder ein Eisenblech in eine Eisensulfatlösung (Abbildung 3).
Die beiden Gefäße lassen durch die Kammern einen Ionenaustausch zu. Du verbindest jeweils die zwei Metalle elektrisch leitend über einen Verbraucher (z.B. ein LED-Lämpchen). Du wiegst die Metallbleche vor und nach dem Versuch.

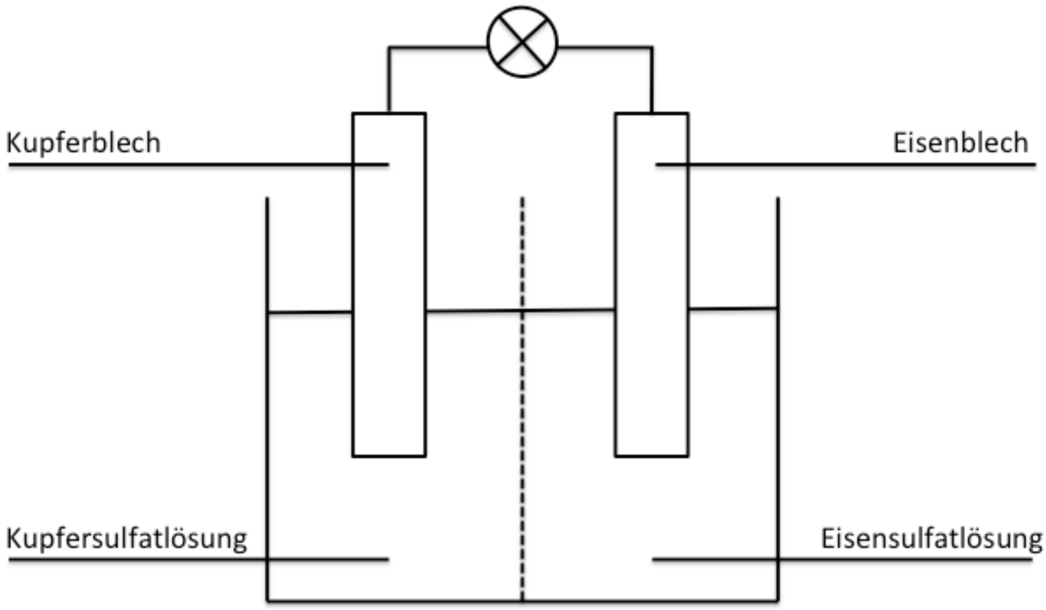


Abbildung 2

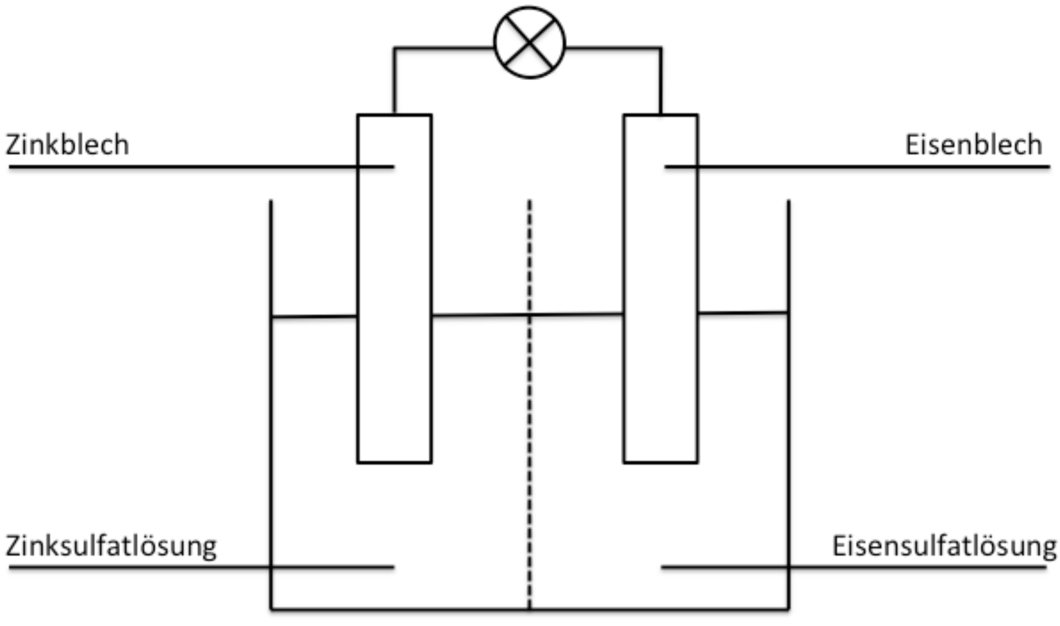


Abbildung 3

Was beobachtest du?

- ☐ Das LED-Lämpchen leuchtet bei beiden Gefäßen. In dem Gefäß mit dem Zink- und dem Eisenblech wiegt das Zinkblech mehr als vor dem Versuch. In dem Gefäß mit dem Kupfer- und dem Eisenblech wiegt das Eisenblech mehr als vor dem Versuch.
- ☐ Das LED-Lämpchen leuchtet nur in dem Gefäß mit Kupfer und Eisen. Das Kupferblech wiegt mehr als vor dem Versuch.
- ☐ Das LED-Lämpchen leuchtet bei beiden Gefäßen. In dem Gefäß mit dem Zink- und dem Eisenblech wiegt das Eisenblech mehr als vor dem Versuch. In dem Gefäß mit dem Kupfer- und dem Eisenblech wiegt das Kupferblech mehr als vor dem Versuch.
- ☐ Bei beiden Gefäßen leuchtet das LED-Lämpchen nicht und das Gewicht der Bleche bleibt unverändert.

Erkläre deine Beobachtung...

a) ...schriftlich!

____

____

____

____

b) ...anschaulich!

FTC_tt7

7 In ein Gefäß mit zwei Kammern stellst du auf eine Seite ein Kupferblech in destilliertes Wasser und auf die andere Seite ein Zinkblech in destilliertes Wasser (siehe Abbildung 4).
Die Kammern sind so miteinander verbunden, dass ein Ionenaustausch möglich ist. Du verbindest die Bleche elektrisch leitend über einen Verbraucher (z.B. ein LED-Lämpchen). Du wiegst die Metallbleche vor und nach dem Versuch.

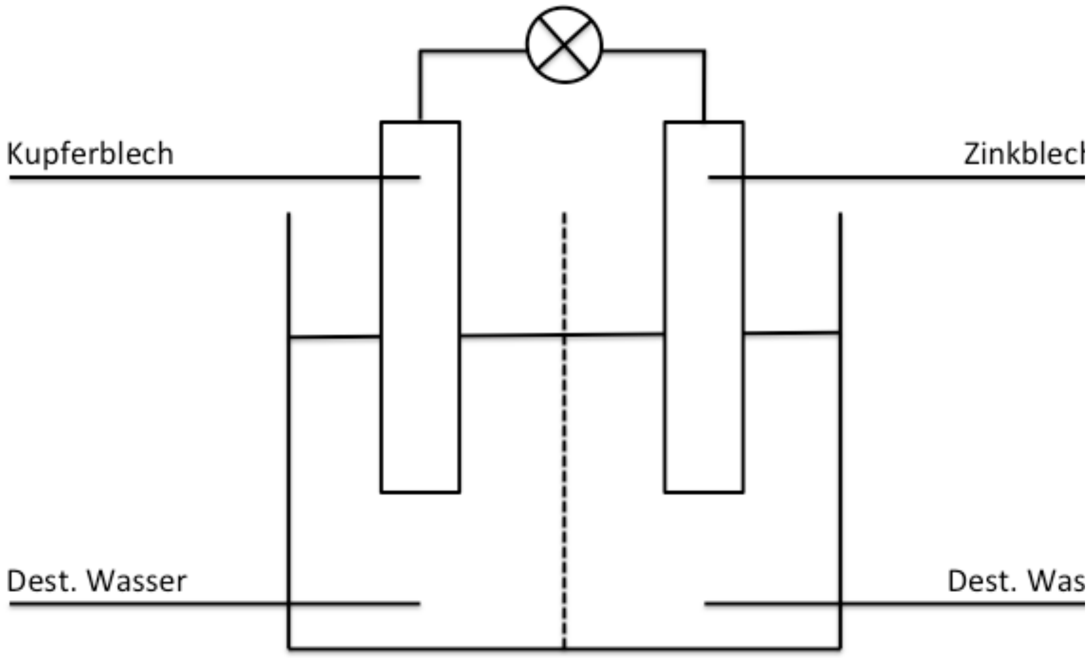


Abbildung 4

Was beobachtest du?

- ☐ Das LED-Lämpchen leuchtet nicht. Das Gewicht des Zinkblechs bleibt unverändert.
- ☐ Das LED-Lämpchen leuchtet. Das Zinkblech wiegt weniger als vor dem Versuch.
- ☐ Das LED-Lämpchen leuchtet. Das Zinkblech wiegt mehr als vor dem Versuch.
- ☐ Das LED-Lämpchen leuchtet. Das Zinkblech bleibt unverändert.

Erkläre deine Beobachtung...

a) ...schriftlich!

b) ...anschaulich!

FTC_tt8

D. Coding Schemes

I. Knowledge about representations

In order to answer the research question: What do students know about representations and about the specific terms related to representation domain?

According to Grosslight and colleagues (1991) three different levels of understanding of representations are defined. Therefore, with the help of this coding scheme students' answer are analysed in order to investigate which level of understanding they have.

General Considerations:

- The statistic software SPSS ® is used.
- Non-classifiable answers are coded as *888*.
- No answer is coded as *999*.
- Level 0 is coded as 0.
- Level 1 is coded as 1.
- Level 2 is coded as 2.

Observation

Level 0	Is defined as students describe an observation as something, which is **directly accessible to the senses** or which is **directly measurable**.

Level 1	Is defined as students describe an observation as something, which is directly accessible to the senses or which is directly measurable. Furthermore, students define an observation **as a tool to describe/ identify changes** during a hands-on activity.

Level 2	Is defined as students describe an observation as something, which is directly accessible to the senses or which is directly measurable. Furthermore, students define an observation as a tool to describe/ identify/ control changes during a hands-on activity. Moreover, an observation **depends on the observer** and is **theory-laden.**

Inference

Level 0	Is defined as students describe an explanation as an **inference from the observation.**

Level 1	Is defined as students describe an explanation as an inference from the observation. Furthermore, students define an explanation as an inference from the observations related to existing **knowledge** in order to interpret experimental data. **Chemical equations** are used.

Level 3	Is defined as students describe an explanation as an inference from the observation. Furthermore, students define an explanation as an inference from the observations related to existing knowledge in order to interpret experimental data. Chemical equations are used. Moreover, **scientific models** are needed in order to analyse the phenomenon.

Modelled World

Level 0	Is defined as students describe the modelled world as **visualization** with the help of models in order to **simplify** something. **OR:** The modelled world consists of the formal and submicroscopic domain.

Level 1	Is defined as students describe the modelled world as visualization with the help of models in order to simplify something. **OR:** The modelled world consists of the formal and submicroscopic domain. Furthermore, scientific models are used **to explain and to understand phenomena**. Atoms/ Ions/ Molecules are **visualized.** Scientific models are used to **represent** something, which is **too big** or **too small.**

Level 2	Is defined as students describe the modelled world as visualization with the help of models in order to simplify something. **OR:** The modelled world consists of the formal and submicroscopic domain. Furthermore, scientific models are used to explain and to understand phenomena. Atoms/ Ions/ Molecules are visualized. Scientific models are used to represent something, which is too big or too small**.** Moreover**,** scientific models are **simplified for a specific purpose** and they **do not directly represent the reality**. They are used to **visualize a conception**.

Experienced World

Level 0	Is defined as students describe the experienced world as something based on experiences.

Level 1	Is defined as students describe an observation as something, which is **directly accessible to the senses** like colour, smell, shape, or which is **directly measurable** like voltage, volume, mass or temperature.

Level 2	Is defined as students describe an observation as something, which is directly accessible to the senses like colour, smell, shape, or which is directly measurable like voltage, volume, mass or temperature. Furthermore, the **experienced world is limited** because our sensory system is limited.

Submicroscopic Domain

Level 0	Is defined as students describe the submicroscopic domain as **representations** of atoms/ particles and their behaviour.

Level 1	Is defined as students describe the submicroscopic domain as representations of atoms/ particles and their behaviour. Furthermore, students describe the **existence** of atoms/ ions/ molecules/ particles and define the representations of them as **modelled nature**.

Level 2	Is defined as students describe the submicroscopic domain as representations of atoms/ particles and their behaviour. Furthermore, students describe the existence of atoms/ ions/ molecules/ particles and define the representations of them as modelled nature. Moreover, students describe the submicroscopic domain as a concrete visualization of the **mental model**.

Formal Domain

Level 0	Is defined as students describe the formal domain as the use of **formulae** or **mathematics**. **OR:** The formal domain is a part of the **modelled world.**

Level 1	Is defined as students describe the formal domain as the use of formulae or mathematics. **OR:** The formal domain is a part of the modelled world. Furthermore, students describe the formal domain as **abstract representations** like element symbols, chemical or mathematical equations.

Level 2	Is defined as students describe the formal domain as the use of formulae or mathematics. **OR:** The formal domain is a part of the modelled world. Furthermore, students describe the formal domain as abstract representations like element symbols, chemical or mathematical equations. Moreover, students describe the formal domain as an abstract visualization of the **mental model**.

II. Explaining Chemical Phenomena (Conceptual Knowledge Part II)

General Considerations:

- The statistic software SPSS ® is used.
- 1 is coded for each code when the student wrote a similar description.
- 0 is coded for each code when the students did not write a similar description.

Codes	Description
T1a_EWe2_tt2_01	Eisen ist unedler als Kupfer/ Kupfer ist edler als Eisen.
T1a_SLe2_tt2_01a	Die Tendenz der Eisen-Atome zur Elektronenabgabe ist groß.
T1a_Me3_tt2_01b	Eisen gibt gerne Elektronen ab.
T1a_SLe2_tt2_02a	Die Tendenz der Kupfer-Kationen zur Elektronenaufnahme ist groß.
T1a_Me3_tt2_02b	Kupfer nimmt gerne Elektronen auf.
T1a_SLe2_tt2_03a	Eisen-Atome geben (zwei) Elektronen ab.
T1a_Me3_tt2_03b	Eisen gibt Elektronen ab.
T1a_SLe2_tt2_04a	Kupfer-Ionen nehmen (zwei) Elektronen auf.
T1a_Me3_tt2_04b	Kupfer nimmt (zwei) Elektronen auf.
T1a_SLe2_tt2_05a	Eisen-Atome werden oxidiert.
T1a_SLe2_tt2_05b	Es findet eine Oxidation statt.
T1a_Me3_tt2_05c	Eisen wird oxidiert.
T1a_SLe2_tt2_06a	Es entstehen Eisen-Ionen.
T1a_SLe2_tt2_06b	Eisen-Ionen liegen hydratisiert in der Lösung vor.
T1a_Me3_tt2_06c	Eisen geht in Lösung.
T1a_EWe2_tt2_06d	Eisensulfat(-lösung) entsteht.
T1a_Me3_tt2_06e	Eisen-Ionen gehen in Lösung.
T1a_SLe2_tt2_07a	Kupfer-Ionen werden reduziert.
T1a_SLe2_tt2_07b	Es findet eine Reduktion statt.
T1a_Me3_tt2_07c	Kupfer wird reduziert.

T1a_Me3_tt2_07d	Kupfersulfat(-lösung) wird reduziert.
T1a_SLe2_tt2_08a	Es entstehen Kupfer-Atome.
T1a_EWe2_tt2_08b	(Elementares) Kupfer entsteht (am Eisenblech).
T1a_SLe_tt2_09	Es findet eine Redoxreaktion statt.
T1a_FLe2_tt2_10	Fe (s) → Fe2+ (aq) + 2e-
T1a_FLe2_tt2_11	Cu2+ (aq) + 2e- → Cu (s)
T1a_FLe2_tt2_12	Fe (s) + Cu2+ (aq) → Fe2+ (aq) + Cu (s)
T1a_EWe3_tt2_13	Das Phänomen wird dargestellt.
T1a_EWe3_tt2_14	Der Versuchsaufbau wird dargestellt.
T1a_SLe3_tt2_15a	Reaktion wird atomar dargestellt.
T1a_FLe3_tt2_15b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung)
T1a_Me2_tt2_16	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt2_17	Reaktion wird auf Erfahrungswelt und formaler Ebene zugleich dargestellt.
T1a_Me4_tt2_18	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.

Code	Description
T1a_EWe2_tt3_01a	Magnesium reagiert mit dem Sauerstoff der Luft.
T1a_EWe2_tt3_01b	Magnesium reagiert mit hellem Licht.
T1a_EWe2_tt3_01c	Magnesium reagiert mit der Luft.
T1a_SLe2_tt3_02	Magnesium-Atome geben (zwei) Elektronen ab.
T1a_Me3_tt3_02	Magnesium gibt Elektronen ab.
T1a_SLe2_tt3_02a	Magnesium-Atome werden oxidiert.
T1a_SLe2_tt3_02b	Es findet eine Oxidation statt.
T1a_Me3_tt3_02c	Magnesium wird oxidiert.
T1a_Me3_tt3_02d	Magnesium wird mit der Luft oxidiert.
T1a_SLe2_tt3_03	Sauerstoff-Moleküle geben (vier) Elektronen ab.
T1a_Me3_tt3_03	Sauerstoff gibt Elektronen ab.
T1a_SLe2_tt3_03a	Sauerstoff-Moleküle werden reduziert.
T1a_SLe2_tt3_03b	Es findet eine Reduktion statt.
T1a_Me3_tt3_03c	Sauerstoff wird reduziert.
T1a_SLe2_tt3_04	Es findet eine Redoxreaktion statt.
T1a_EWe2_tt3_05a	Magnesiumoxid entsteht.
T1a_EWe2_tt3_05b	Der weiße Feststoff ist Magnesiumoxid.
T1a_EWe2_tt3_06a	Das entstandene Magnesiumoxid ist schwerer als (elementares) Magnesium.
T1a_EWe2_tt3_06b	Massenerhaltung/ Summe aus Edukten.
T1a_EWe2_tt3_06c	Magnesium verbindet sich mit dem Sauerstoff. Deswegen ist der Stoff schwerer.
T1a_FLe2_tt3_07	Mg (s) → Mg2+ (s) + 2e- (*2)
T1a_FLe2_tt3_08	O2 (g) + 4e- → 2O2- (s)
T1a_FLe2_tt3_09	2Mg (s) + O2 (g) → 2MgO (s)
T1a_FLe2_tt3_10a	m(Mg)<m(MgO)
T1a_FLe2_tt3_10b	m(Mg)+m(O2)
T1a_EWe3_tt3_11	Das Phänomen wird dargestellt.

T1a_EWe3_tt3_12	Der Versuchsaufbau wird dargestellt.
T1a_SLe3_tt3_13a	Reaktion wird atomar dargestellt.
T1a_FLe3_tt3_13b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung)
T1a_Me2_tt3_14	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt3_15	Reaktion wird auf Erfahrungswelt und formaler Ebene zugleich dargestellt.
T1a_Me4_tt3_16	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.
T1a_FLe2_tt3_17	Magnesiumoxid wird formal als MgO dargestellt.

Code	Description
T1a_EWe2_tt4_01	Die Lösungen haben unterschiedliche Konzentrationen.
T1a_SLe2_tt4_01a	Auf der Seite der höheren Konzentartio, mehr Silber-Ionen
T1a_SLe2_tt4_01b	Auf der Seite der niedrigeren Konzentration, weniger Silber-Ionen.
T1a_EWe2_tt4_02	Es handelt sich um ein galvanisches Element/ Konzentrationszelle.
T1a_EWe2_tt4_03	Es ist ein Strom messbar.
T1a_SLe2_tt4_04a	Auf der Seite mit der höheren Konzentration, nehmen Silber-Ionen zwei Elektronen auf.
T1a_Me3_tt4_04c	Auf der Seite mit der höheren Konzentration, nimmt Silber Elektronen auf.
T1a_SLe2_tt4_05a	Auf der Seite mit der höheren Konzentration, werden Silber-Ionen reduziert.
T1a_SLe2_tt4_05b	Auf der Seite mit der höheren Konzentration findet die Reduktion statt.
T1a_Me3_tt4_05c	Auf der Seite mit der höheren Konzentration, wird Silber reduziert.
T1a_SLe2_tt4_06a	Auf der Seite mit der höheren Konzentration entstehen Silber-Atome.
T1a_EWe2_tt4_06b	Auf der Seite mit der höheren Konzentration entsteht Silber.
T1a_SLe2_tt4_07	Auf der Seite mit der höheren Konzentration wird die Elektronendichte niedriger.
T1a_SLe2_tt4_08a	Auf der Seite mit der niedrigeren Konzentration, lösen sich Silber-Atome unter Abgabe von (zwei) Elektronen aus dem Metallgitter.
T1a_Me3_tt4_08c	Auf der Seite mit der niedrigeren Konzentration, gibt Silber Elektronen ab.
T1a_SLe2_tt4_09a	Auf der Seite mit der niedrigeren Konzentration werden

	Silber-Atome oxidiert.
T1a_SLe2_tt4_09b	Auf der Seite mit der niedrigeren Konzentration findet die Oxidation statt.
T1a_Me3_tt4_09c	Auf der Seite mit der niedrigeren Konzentration wird Silber oxidiert.
T1a_SLe2_tt4_10	Es entstehen Silber-Ionen.
T1a_SLe2_tt4_11	Auf der Seite mit der niedrigeren Konzentration wird die Elektronendichte höher.
T1a_EWe2_tt4_12	Auf der Seite mit der niedrigeren Konzentration wiegt die Silberelektrode weniger.
T1a_SLe2_tt4_13	Es findet eine Redoxreaktion statt.
T1a_SLe2_tt4_14	Die Elektronendichte im Metallgitter ist unterschiedlich.
T1a_SLe2_tt4_15a	Die Elektronen fließen durch den Draht von der Seite der niedrigen Konzentration zur Seite hoher Konzentration.
T1a_SLe2_tt4_15b	Zum Ausgleich der unterschiedlichen Elektronendichten fließen die Elektronen.
T1a_SLe2_tt4_15c	Elektronen fließen.
T1a_SLe2_tt4_16	In der Lösung bewegen sich Nitrat-Ionen von der Seite der höheren Konzentration zur Seite niedrigerer Konzentration.
T1a_FLe2_tt4_17	Ag (s) → Ag+ (aq) + e- (0,01 mol/L)
T1a_FLe2_tt4_18	Ag+ (aq) + e- → Ag (s) (1 mol/L)
T1a_FLe2_tt4_19	Ag (s) + Ag+ (aq) → Ag+ (aq) + Ag (s)
T1a_FLe2_tt4_20	m(Ag(hohe Konzentration)) >m(Ag(niedrige Konzentration))
T1a_EWe3_tt4_21	Das Phänomen wird dargestellt.
T1a_SLe3_tt4_22a	Reaktion wird atomar dargestellt.
T1a_FLe3_tt4_22b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung).
T1a_Me2_tt4_23	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt4_24	Reaktion wird auf Erfahrungswelt und formaler Ebene

	zugleich dargestellt.
T1a_Me4_tt4_25	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.

Code	Description
T1a_SLe2_tt5_02a	Natrium-Atome geben jeweils ein Elektron ab.
T1a_Me3_tt5_02b	Natrium gibt Elektron ab.
T1a_SLe2_tt5_03a	Natrium-Atome werden oxidiert.
T1a_SLe2_tt5_03b	Es findet eine Oxidation statt.
T1a_Me3_tt5_03c	Natrium oxidiert.
T1a_SLe2_tt5_03d	Die Tendenz der Kupfer-Kationen zur Elektronenaufnahme ist groß.
T1a_SLe2_tt5_04a	Chlor-Moleküle nehmen 2 Elektronen auf.
T1a_Me3_tt5_04b	Chlor nimmt Elektronen auf.
T1a_SLe2_tt5_05a	Chlor-Moleküle werden reduziert.
T1a_SLe2_tt5_05b	Es findet eine Reduktion statt.
T1a_Me3_tt5_05c	Chlor wird reduziert.
T1a_SLe2_tt5_05d	Chlorid-Ionen entstehen.
T1a_SLe2_tt5_06	Es findet eine Redoxreaktion statt.
T1a_EWe2_tt5_07a	Natriumchlorid/ Kochsalz entsteht.
T1a_EWe2_tt5_07b	Der weiße Feststoff ist Natirumchlorid
T1a_SLe2_tt5_07c	Ionenbindung
T1a_EWe2_tt5_07d	Metall-Nicht-Metallverbindung.
T1a_EWe2_tt5_08a	Das entstandene Natriumchlorid ist schwerer als elementares Natrium.
T1a_EWe2_tt5_08b	Wegen der Massenerhaltung wiegt das Produkt soviel wie die Summe der Edukte.
T1a_EWe2_tt5_08c	Natrium verbindet sich mit Chlor, deswegen ist der Stoff schwerer.
T1a_FLe2_tt5_09	Na (s) → Na+ (s) + e-
T1a_FLe2_tt5_10	Cl2 (g) + 2e- → 2 Cl- (s)
T1a_FLe2_tt5_11	Na (s) + Cl2 (g) → NaCl (s)
T1a_FLe2_tt5_12a	m(NaCl)>m(Na)

T1a_FLe2_tt5_12b	m(Na)+m(CLl)
T1a_EWe3_tt5_13	Das Phänomen wird dargestellt.
T1a_EWe3_tt5_14	Der Versuchsaufbau wird dargestellt.
T1a_SLe3_tt5_15a	Reaktion wird atomar dargestellt.
T1a_FLe3_tt5_15b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung).
T1a_Me2_tt5_16	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt5_17	Reaktion wird auf Erfahrungswelt und formaler Ebene zugleich dargestellt.
T1a_Me4_tt5_18	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.
T1a_FLe2_tt5_19	Natriumchlorid wird formal als NaCl dargestellt.

Code	Description
T1a_EWe2_tt6_01	Kupfer ist unedler als Silber/ Silber ist edler als Kupfer.
T1a_SLe2_tt6_02a	Die Tendenz der Silber-Atome zur Elektronenabgabe ist klein.
T1a_SLe2_tt6_02b	Silber-Atome geben ungerne Elektronen ab.
T1a_Me3_tt6_02c	Silber gibt ungerne Elektronen ab.
T1a_SLe2_tt6_03a	Die Tendenz der Kupfer-Kationen zur Elektronenaufnahme ist klein.
T1a_SLe2_tt6_03b	Kupfer-Ionen nehmen ungerne Elektronen auf.
T1a_Me3_tt6_03c	Kufper nimmt ungerne Elektronen auf.
T1a_SLe2_tt6_04	Es findet keine Redoxreaktion statt.
T1a_EWe2_tt6_05	Nickel ist unedler als Kupfer/ Kupfer ist edler als Nickel.
T1a_SLe2_tt6_06a	Die Tendenz der Nickel-Atome zur Elektronenabgabe ist groß.
T1a_SLe2_tt6_06b	Nickel-Atome geben gerne Elektronen ab.
T1a_Me3_tt6_06c	Nickel gibt gerne Elektronen ab.
T1a_SLe2_tt6_06d	Nickel-Atome oxideren.
T1a_Me3_tt6_06e	Nickel oxidert.
T1a_EWe2_tt6_06f	Nickelsufat-Lösong entsteht.
T1a_SLe2_tt6_07a	Die Tendenz der Kupfer-Ionen zur Elektronenaufnahme ist groß.
T1a_SLe2_tt6_07b	Kupfer-Ionen nehmen gerne Elektronen auf.
T1a_Me3_tt6_07c	Kupfer nimmt gerne Elektronen auf.
T1a_SLe2_tt6_08a	Kupfer-Ionen nehmen (zwei) Elektronen auf.
T1a_Me3_tt6_08b	Kupfer nimmt Elektronen auf.
T1a_SLe2_tt6_09a	Kupfer-Ionen werden reduziert.
T1a_SLe2_tt6_09b	Es findet eine Reduktion statt.
T1a_Me3_tt6_09c	Kupfer wird reduziert.
T1a_SLe2_tt6_10	Es findet eine Redoxreaktion statt.

T1a_SLe2_tt6_11a	Es entstehen Nickel-Ionen.
T1a_SLe2_tt6_11b	Nickel-Ionen liegen hydratisiert in der Lösung vor.
T1a_EWe2_tt6_11c	Nickel gibt Elektronen ab.
T1a_Me3_tt6_11d	Nickel geht in Lösung.
T1a_SLe2_tt6_12a	Es entstehen Kupfer-Atome.
T1a_EWe2_tt6_12b	Kupfer entsteht am Nickelblech.
T1a_FLe2_tt6_13	Ni (s) → Ni2+ (aq) + 2e-
T1a_FLe2_tt6_14	Cu2+ (aq) + 2e- → Cu (s)
T1a_FLe2_tt6_15	Ni (s) + Cu2+ (aq) → Ni2+ (aq) + Cu (s)
T1a_EWe3_tt6_16	Das Phänomen wird dargestellt.
T1a_EWe3_tt6_17	Der Versuchsaufbau wird dargestellt.
T1a_SLe3_tt6_18a	Reaktion wird atomar dargestellt.
T1a_Fle3_tt6_18b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung).
T1a_Me2_tt6_19	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt6_20	Reaktion wird auf Erfahrungswelt und formaler Ebene zugleich dargestellt.
T1a_Me4_tt6_21	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.

Code	Description
T1a_EWe2_tt7_01	Kupfer ist edler als Eisen/ Eisen ist unedler als Kupfer.
T1a_EWe2_tt7_02	Eisen ist edler als Zink/ Zink ist unedler als Eisen.
T1a_EWe2_tt7_03	Es handelt sich um zwei galvanische Elemente.
T1a_EWe2_tt7_04	In beiden Zellen ist ein Strom messbar.
T1a_SLe2_tt7_05a	Die Tendenz der Eisen-Atome zur Elektronenabgabe ist groß.
T1a_Me3_tt7_05b	Eisen gibt gerne Elektronen ab.
T1a_SLe2_tt7_06a	Die Tendenz der Kupfer-Kationen zur Elektronenaufnahme ist groß.
T1a_Me3_tt7_06b	Kupfer nimmt gerne Elektronen auf.
T1a_SLe2_tt7_07a	Eisen-Atome geben zwei Elektronen ab.
T1a_Me3_tt7_07b	Eisen gibt Elektronen ab.
T1a_SLe2_tt7_08a	Eisen-Atome werden oxidiert.
T1a_SLe2_tt7_08b	Es findet eine Oxidation statt.
T1a_Me3_tt7_08c	Eisen wird oxidiert.
T1a_SLe2_tt7_09a	Es entstehen Eisen-Ionen.
T1a_SLe2_tt7_09b	Eisen-Ionen liegen hydratisiert in der Lösung vor.
T1a_Me3_tt7_09c	Eisen geht in Lösung.
T1a_EWe2_tt7_10	Das Eisenblech wiegt weniger als zuvor, da Eisen in Lösung gegangen ist.
T1a_SLe2_tt7_11a	Kupfer-Ionen nehmen zwei Elektronen auf.
T1a_Me3_tt7_11b	Kupfer nimmt Elektronen auf.
T1a_SLe2_tt7_11c	Kupfer-Ionen werden reduziert.
T1a_Me3_tt7_11d	Kupfer wird reduziert.
T1a_SLe2_tt7_12a	Es entstehen Kupfer-Atome (am Metallgitter).
T1a_EWe2_tt7_12b	Es entsteht (elementares) Kupfer am Kupferblech.
T1a_EWe2_tt7_12c	Das Kupferblech ist schwerer, da Kupfer entstanden ist.
T1a_SLe2_tt7_13	Die Elektronen werden durch den Draht vom Eisenblech

	zum Kupferblech übertragen
T1a_SLe2_tt7_14	In der Lösung fließen Sulfat-Anionen von der Kupfer-Halbzelle zur Eisen-Halbzelle.
T1a_FLe2_tt7_15	Fe (s) → Fe2+ (aq) + 2e-
T1a_FLe2_tt7_16	Cu2+ (aq) + 2e- → Cu (s)
T1a_FLe2_tt7_17	Fe (s) + Cu2+ (aq) → Fe2+ (aq) + Cu (s)
T1a_SLe2_tt7_18a	Die Tendenz der Zink-Atome zur Elektronenabgabe ist groß.
T1a_Me3_tt7_18b	Zink gibt gerne Elektronen ab.
T1a_SLe2_tt7_19a	Die Tendenz der Eisen-Ionen zur Elektronenaufnahme ist groß.
T1a_Me3_tt7_19b	Eisen nimmt gerne Elektronen auf.
T1a_SLe2_tt7_20a	Zink-Atome geben zwei Elektronen ab.
T1a_Me3_tt7_20b	Zink gibt Elektronen ab.
T1a_SLe2_tt7_21a	Zink-Atome werden oxidiert.
T1a_SLe2_tt7_21b	Es findet eine Oxidation statt.
T1a_Me3_tt7_21c	Zink wird oxidiert.
T1a_SLe2_tt7_22a	Es entstehen Zink-Ionen.
T1a_SLe2_tt7_22b	Zink-Ionen liegen hydratisiert in der Lösung vor.
T1a_Me3_tt7_22c	Zink geht in Lösung.
T1a_EWe2_tt7_23	Das Zinkblech wiegt weniger als zuvor, da Zink in Lösung gegangen ist.
T1a_SLe2_tt7_24a	Eisen-Ionen nehmen zwei Elektronen auf.
T1a_Me3_tt7_24b	Eisen nimmt Elektronen auf.
T1a_SLe2_tt7_25a	Es entstehen Eisen-Atome (am Metallgitter).
T1a_EWe2_tt7_25b	Es entsteht (elementares) Eisen am Eisenblech.
T1a_EWe2_tt7_25c	Es entsteht (elementares) Kupfer am Kupferblech.
T1a_SLe2_tt7_26	Die Elektronen werden durch den Draht vom Zinkblech zum Eisenblech übertragen
T1a_SLe2_tt7_27	In der Lösung fließen Sulfat-Ionen von der Eisen-Halbzelle

	zur Zink-Halbzelle.
T1a_FLe2_tt7_28	Zn (s) → Zn2+ (aq) + 2e-
T1a_FLe2_tt7_29	Fe2+ (aq) + 2e- → F (s)
T1a_FLe2_tt7_30	Zn (s) + Fe2+ (aq) → Zn2+ (aq) + Fe (s)
T1a_SLe2_tt7_31	Es findet eine Redoxreaktion statt.
T1a_SLe2_tt7_32	Die Elektronendichte in den Elektroden ist unterschiedlich.
T1a_SLe2_tt7_33	Zum Ausgleich der unterschiedlichen Elektronendichten fließen die Elektronen.
T1a_SLe3_tt7_35a	Reaktion wird atomar dargestellt.
T1a_FLe3_tt7_35b	Reaktion wird formal dargestellt (Keine Reaktionsgleichung)
T1a_Me2_tt7_36	Reaktion wird auf Erfahrungswelt und atomarer Ebene zugleich dargestellt.
T1a_Me3_tt7_37	Reaktion wird auf Erfahrungswelt und formaler Ebene zugleich dargestellt.
T1a_Me4_tt7_38	Reaktion wird auf Erfahrungswelt und atomarer/ formaler Ebene zugleich dargestellt.

Code	Description
T1a_EWe2_tt8_01	Zink ist unedler als Kupfer/ Kupfer ist edler als Zink.
T1a_EWe2_tt8_03	Destilliertes Wasser leitet den Strom nicht.
T1a_EWe2_tt8_04a	Es sind keine Mineralien im destilliertem Wasser vorhanden.
T1a_SLe2_tt8_04b	Es sind keine Ionen gelöst.
T1a_Me3_tt8_04c	Es sind keine Ionen im destillierten Wasser.
T1a_SLe2_tt8_04d	Kein Ionenaustausch möglich.
T1a_SLe2_tt8_05a	Es findet keine Reaktion statt/ Keine Redoxreaktion möglich

III. Video

Coding Scheme Video Analysis

- Open the file memo.mx12
- Every video is integrated two times. The verbal communication of **one** student can be coded per video.
- Select the starting and end point of an activity or a statement in the video.
- Chose a code per drag and drop.
- If you are insure while coding, make a short comment ('memo') on the scene.

Surface Structure of Activity

Preparing

T_Prep	Is defined as students prepare the following hands-on activity

In- and Out-Points

- T_Prep starts when students open their interactive box and ends when students start doing the hands-on activity or talking off-topic or do nothing and so forth.
- If students do the hands-on activity a few times, there can be another T_Prep in between.

Helpful Indicators/ Example

- Students explore the chemicals and materials inside of the box.
- Students plan the experimental setup.
- Students prepare the experimental setup.
- Students talk about how they can perform the hands-on activity again.

Hands-on activity

T_activity	Is defined as students do the hands-on activity.

In- and Out-Points

- T_activity starts when students do the hands-on activity and ends when students start to analyse the phenomenon (→ T_AN) or talk off topic or do nothing (→ T_off) or clean (→ T_clean) or talk about how to perform the hands-on activity another time (→ T_Prep).

Helpful Indicators/ Example

- Students observe the phenomenon.

- Students do experimental measurements.
- Students put the zinc nail into the copper sulphate solution.
- Students put the metal plates in the metal sulphate solution.

Explanation

T_AN	Is defined as students explain the phenomenon.

In- and Out-Points

- T_AN starts when students are finished doing the hands-on activity and start to explain orally or to write down their observation and explanation in their lab journal.

Helpful Indicators/ Example

- Students take their lab journal and their pen.
- Students write something down.
- Students talk about what happened and why it happened.

Information Cards

T_Info	Is defined as students pay attention on the information card.

In- and Out-Points

- T_Info starts when students watch the information card explicitly and stops when they change their view or start a new activity.
- Short breaks (<3 sec) in between are not additionally coded.

Helpful Indicators/ Example

- Students hold the information card in their hands.
- The eyes move from left to right and back.
- Students read the text of the information card out loud.

Prompts - Students

T_Prompts_Students	Is defined as **students** pay attention on the prompts.

In- and Out-Points

- T_Prompts_Students starts when students explicitly watch the prompts and stops when they change their view or start a new activity.
- Short breaks (<3 sec) in between are not additionally coded.

Helpful Indicators/ Example

- Students hold the prompt card in their hand.
- The eyes move from left to right and back.
- Students read out loud.

Prompts - Teacher

T_Prompts_teacher	Is defined as **teacher** reminds the students to use the prompts.

In- and Out-Points

- T_Prompts_teacher starts when teacher starts to interrupt students in their hands-on activity or another activity and starts to talk about the prompts and ends when teacher stops talking.

Helpful Indicators/ Example

- The teacher speaks out loud.
- "Und jetzt auch noch Mal aufgepasst, ihr habt besondere Info-Karten, die weißen. Da sollt ihr noch Mal an die drei Ebenen erinnert werden." [Teacher/UEGY48/ Box1 09:02.0-09.12.8]

Exercise

T_Exercise	Is defined as students pay attention on the exercise card.

In- and Out-Points

- T_Exercise starts when students explicitly watch at the exercise card and stops when they change their view or start a new activity.
- Short breaks (<3 sec) in between are not additionally coded.

Helpful Indicators/ Example

- Students hold the exercise card in their hand.
- The eyes move from left to right and back.
- Students read out loud.

Cleaning

T_Clean	Is defined as students remove all materials and chemicals from their table.

In- and Out-Points

- T_Clean starts when students remove chemicals and/or materials and ends when they start another activity.

Helpful Indicators/ Example

- Students put all materials/chemicals in the box.
- Students have towel in their hand.
- Students go to the basin.

Off Topic

T_off	Is defined as students talk about non-related chemical aspects or do nothing.

In- and Out-Points

- T_off starts when students talk about not content related things more than 5 seconds and stops when they start a new activity.
- T-off starts when students do nothing for more than 5 seconds and stops when they start a new activity.

Helpful Indicators/ Example

- Students stare out of the window.
- Students talk about their plans in the afternoon.
- Students talk with other students about their homework or other school related things.

Surface Structure of Inquiry

In- and Out-Points

- The following codes are related to statements. A statement can be one sentence or a few sentences, which form a sense unity.
- There should be no break (<3sec) between two sentences; otherwise two statements must be coded.

Planning

P_Inq	Is defined as students talk about what they are going to do.

Helpful Indicators/ Example

- Students plan what to do in the following steps.
- [UEGY64/Box1: "Also erst Mal durchlesen, was für Material wir da haben."]

Designing

Designing	Is defined as students talk about how to perform the hands-on activity.

Helpful Indicators/ Example

- Students talk about which material they need.
- Students talk about how the experimental setup must be look like.
- [UEGY54/Box2 04:43.4-04.45.9: "Wir tauschen die Dinger gleich noch Mal und gucken was dann passiert"]

Analysing – Explanatory Approach

EX_APP	Is defined as students communicate chemical knowledge in a non-scientific way. Students communicate wrong chemical knowledge.

General Considerations

- Domains of representations are coded in addition to *Ex_App*.
- If students communicate their chemical knowledge in a scientifically correct way, the statement is coded as *Conceptual Knowledge.*

Helpful Indicators/ Example

- [UEGY59/Box1 02:58.6-03:02.5: "Das Kupfer lagert sich am edleren Zink-Ion ab."]

Surface Structure of Descriptive - Terms

General considerations

- They speak often terms out loud while writing or structure their lab journals.
- These codes are coded if they are not embedded in a broader context or a sense unity.

In- and Out-Points

- The following codes are connected to single words which students use.

Observation

Term_OL	Is defined as students' use of the term *"Beobachtung"*

Experimental Setup

Term_ES	Is defined as students' use of the term *"Versuchsaufbau"/ "Versuchsdurchführung"*.

Hypothesis

Term_VH	Is defined as students' use of the term *"Vermutung"/ "Hypothese"*.

Materials/ Chemicals

Term_MC	Is defined as students' use of the term *"Materialien"/ "Chemikalien"*.

Analysis/ Explanation

Term_AN	Is defined as students' use of the term *"Deutung"/ "Erklärung"*.

(Chemical) Equation

Term_EW	Is defined as students' use of the term *"Reaktionsgleichung"*

Experienced World

Term_EW	Is defined as students' use of the term *"Erfahrungswelt"/ "Erfahrbare Ebene"*.

Modelled World

Term_MW	Is defined as students' use of the term *"Modellwelt"/ "Modellebene"*.

Submicroscopic Domain

Term_SL	Is defined as students' use of the term *"Atomare Ebene"*

Formal Domain

Term_FL	Is defined as students' use of the term *"Formale Ebene"*

Surface Structure of Descriptive Statements

General considerations

- All statements are descriptive rather than explanatory.

In- and Out-Points

- The following codes are related to statements. A statement can be one sentence or a few sentences, which form a sense unity.
- There should be no break (<3sec) between two sentences; otherwise two statements must be coded.

Des_MC	Is defined as students describe the material/ chemicals.

General considerations

- Students describe just the material/ chemicals before they do the hands-on activity; otherwise *Des_OL/EW* is coded.

Helpful Indicators/ Example

- [UEGY59/Box3 01:20.9-01:27.2: “1-Molare Kupfersulfatlösung und 0,01-Molare Kupfersulfatlösung.”

Des_ES	Is defined as students describe the experimental setup they have used.

General considerations

- Students have already done the hands-on activity and describe the experimental setup retrospectively; otherwise *Designing* is coded.

Helpful Indicators/ Example

- [UEGY08/Box2 12:11.4-12:16.6: “Zink in Zink und Kupfer in Kupfer.”

Des_OL/EW	Is defined as students describe their observation they have made.

Helpful Indicators/ Example

- Students describe an entity which is directly accessible to the senses.
- Students describe the result of measurement.
- Students use colors to describe their observation.
- [LGGY39/Box1 05:21.5-05:23.4: “Oh er wird schwarz.”

Des_VH	Is defined as students generate a hypothesis about what happened or what will happen. A hypothesis is a testable statement.

General Considerations

- Students construct a hypothesis about the results of a hands-on activity.

Helpful Indicators/ Example

- Students formulate causes why something is effected
- Students use words like “I think”, “before”, “perhaps”, “probably”
- “Ich werde dir vorher sagen, da wird Schwefel dran haften bleiben” [LGGY39/Box1: 04:59.6-05.03.3]

Special Considerations

- A predictive explanation is also coded as *Hypothesis*.

Scientific Representation Domains

General Considerations

- Every statement in addition to conceptual knowledge and to the explanatory approach is coded by one representation domain.
- The representation domain refers to the specific chemical language (“Copper” (EW); “Copper-atom” (SL); “Cu” (Cu))

Experienced World

Rep_EW	Is defined as students use a statement, which refers to macroscopic aspects that are “directly” accessible to the senses.

Helpful Indicators/ Example

- [LGGY39/Box1 06:58.8-06:59.8: “Das ist rot.”]

Submicroscopic Domain

Rep_SL	Is defined as students use a statement, which refers to submicroscopic aspects like atoms or molecules.

Helpful Indicators/ Example

- [LGGY39/Box1 26:46.0-26:48.2: “Sauerstoff-Atom hat immer minus 2.”]

Formal Domain

Rep_FL	Is defined as students use a statement, which refers to chemical formulae language like Fe or Cu.

Helpful Indicators/ Example

- [JKGY20/Box1 13:33.3-13:35.3: “SO_4^{2-} or not”]

Mixing:

Submicroscopic & Formal Domain

Rep_SLFL	Is defined as students use submicroscopic and formal aspects in one statement.

Helpful Indicators/ Example

- “Cu^{2+} gives two electrons” [LGGY39/Box1 27:40.1-27:46.7]

Experienced & Modelled World

Rep_EWMW	Is defined as students use macroscopic, submicroscopic and formal aspects in one statement

Helpful Indicators/ Example

- “That 2e^- are going that way and give it away” [JKGY20/Box3 20:37.2-20:43.7]

Experienced World & Formal Domain

Rep_EWFL	Is defined as students use macroscopic and formal aspects in one statement.

Helpful Indicators/ Example

- [LGGY38/Box2 09:47.0-09:48.7: “Rot ist Plus”]

Experienced World & Submicroscopic Domain

Rep_EWSL	Is defined as students use macroscopic and submicroscopic aspects in one statement.

Helpful Indicators/ Example

- “[LGGY39/Box1 06:58.8-06:59.8: Zinknagel wurde reduziert”]

Deep Structure – Meta-conceptual Awareness

In- and Out-Points

- The following codes relate to statements. A statement can be one sentence or a few sentences, which form a sense unity.
- There should be no break (<3sec) between two sentences; otherwise two statements must be coded.

Conceptual knowledge	Is defined as students communicate the knowledge of a chemical concept in a scientifically correct way.

Conceptual Knowledge

General Considerations

- Domains of representations are coded in addition to conceptual knowledge.

Helpful Indicators/ Example

- Explanations for natural phenomena often involve unseen entities such as atoms.
- Conceptual knowledge refers to scientific laws, theories and models.

Meta-Representational Knowledge

Meta-Representational Knowledge	Is defined as students communicate their knowledge of scientific representations.

General Considerations

- The meta-representational competence includes the understanding of the nature and different modes of external representations like verbal, concrete/ material, visual, gestural or symbolic.
- Students' ability to translate different representations, to construct a representation and to solve problems by using suitable representations.

Helpful Indicators/ Example

- "Als erstes beschreiben wir nur... also Erfahrungswelt" [UEGY28 Box1 04:06.6-04:13.0]
- "Jetzt müssen wir eine Reaktionsgleichung aufstellen. Also die formale Ebene…" [UEGY08 Box 1: 11:28.9-11:31.3]

Meta-Modelling Knowledge

Meta-Modelling Knowledge	Is defined as students communicate their knowledge of scientific models

General Considerations

- This epistemological knowledge relates to understanding how models are built as well as how and why they are used.
- Meta-modelling knowledge focuses on the nature and purposes of models, strengths, and limitations of different models, the evidence-based nature of models, and the importance of change and revision in modelling

Helpful Indicators/ Example

- "Dass ein Atom als Kugel dargestellt wird, ist ja nur eine Modellvorstellung."

Procedural Knowledge - Planning

Planning	Is defined as students plan the externalisation of their knowledge related to the representation domain.

General Considerations

- Students talk about which representation domains they need while writing their lab journals.

Helpful Indicators/ Example

- "Als erstes zeichne ich es" [JKGY10 Box2 22:56.6-22.58.5]
- "Denk an die Ebenen" [UEGY48 Box1 13:20.3-13:22.5]
- "Lass uns die Beobachtung aufschreiben" [UEGY08 Box3 10:01.2-10:01.6]
- "Lass uns als erstes das hier [zeigt auf den Versuchsaufbau] abzeichnen" [UEGY54 Box2 03:39.0-03:41.3]
- "Und jetzt was mit der Modellebene" [UEGY33 Box3 09:54.1-09:57.6]
- "Ich habe erst Beobachtung geschrieben und jetzt würde ich die Deutung aufschreiben" [LGGY22 Box1 09:27.9-09:31.4]

Procedural Knowledge - Monitoring

Monitoring	Is defined as students talk about how to monitor the chemical content related to the representation domain and the externalisation of the representations.

General Considerations

- Students talk about which aspects belong to the experience-based world or to the observation.
- Students talk about which aspects belong to the modelled world or to the submicroscopic or the formal domain.

Helpful Indicators/ Example

- “Mehr kannst du doch nicht beobachten” [UEGY34 Box 1 11:52.5-11:55.4]
- “Aber das ist doch die Modellwelt” [UEGY64 Box1 13:29.6-13:30.9]
- “Das ist nicht die Beobachtung, das ist die Deutung” [UEGY34 Box 1 18:21.3-18:25.1]
- “Ja, aber du must das hier aufschreiben [zeigt auf die Erfahrungswelt” [UEGY26 Box1 10:55.1-10:57.9]
- “Wir haben beobachtet, wir haben die atomare Ebene und die formale” [UEGY28 Box1 21:11.0-21:17.9]
- “Das ist nicht mehr Beobachtung” [JKGY07 Box1 13:40.1-13:42.1]

Procedural Knowledge - Evaluating

Evaluating	• Is defined as students talk about how to evaluate their knowledge about representations.

General Considerations

- It is important that students build the link between the representation domains explicitly.

Helpful Indicators/ Example

- “Ich habe gesehen das Kupfer entstanden ist. Elementares Kupfer wird auf der submikroskopischen Ebene als Atom dargestellt”
- “Auf der atomaren Ebene habe ich ein Ion, dass sehe ich an der Ladung auf der formalen Ebene”
- “Aber das stimmt gar nicht [points her finger at the formal domain]… dass das dann immer fest ist, weil die Kupfersulfatlösung ist ja immer noch flüssig [LGGY03 Box 1 26:44.1-26:52.2]

IV. Lab Journal

i. Self-Constructed External Representations (Lampe, 2016)

General Considerations

- Each phenomenon is coded only once per document
    - Types of particles are coded once per document even if one occurs as more than one material
    - Particles are fourfold coded:
        - Representation domain
        - Form of representation
        - Type of particle
        - Colour
- The coding is drawn covering the whole coded element
- Codings only refer to the manner of drawing and do not consider scientific correctness

In a first step the representation domain of students' drawings is coded.

Representation Domains

Macroscopic

Repe_Mak_Kupfer	Is defined as the students' macroscopic drawing of copper precipitate.

Helpful Indicators/ Example

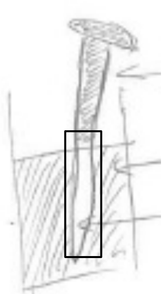


Figure 1. Macroscopic drawing of copper precipitate (JKGY07 - Box 1).

Special Considerations

- Repe_Mak_Kupfer is only coded if students do not draw any atoms in it
- The coded element is the area of the copper precipitate on the nail

Repe_Mak_Nagel	Is defined as the students' macroscopic drawing of a nail.

Helpful Indicators/ Example

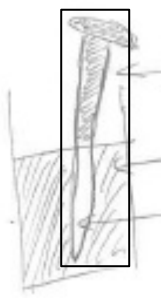


Figure 2. Macroscopic drawing of a nail (JKGY07 - Box 1)

Special Considerations

- Repe_Mak_Nagel is always coded if students draw a nail
- The coded element is the whole nail

Repe_Mak_Mess	Is defined as the students' macroscopic drawing of a meter.

Helpful Indicators/ Example

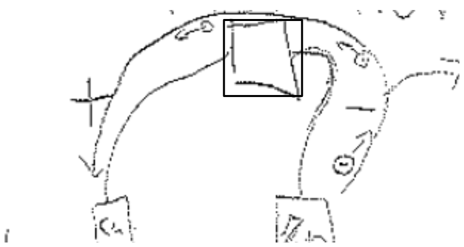


Figure 3. Macroscopic drawing of a meter (JKGY17 - Box 2)

Special Considerations

- Repe_Mak_Mess is always coded if a device is drawn that is integrated in the electric circuit even if it is drawn as a voltage source or not especially marked as a meter
- The coded element is the area around the drawn device

Repe_Mak_Kabel	Is defined as the students' macroscopic drawing of a power cord.

Helpful Indicators/ Example

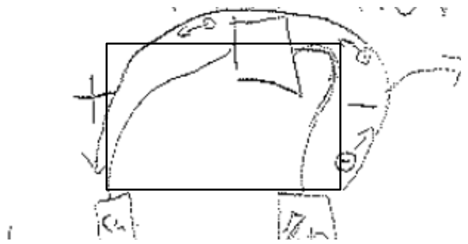


Figure 4. Macroscopic drawing of power cords (JKGY17 - Box 2)

Special Considerations

- Repe_Mak_Kabel is coded if the power cords are drawn arbitrary
- The coded element is the area around both power cords

Repe_Mak_Metall	Is defined as the students' macroscopic drawing of a metal plate.

Helpful Indicators/ Example

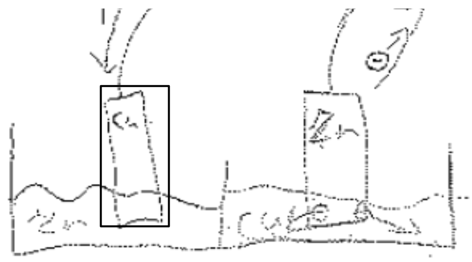


Figure 5. Macroscopic drawing of metal plate (JKGY17 - Box 2)

Special Considerations

- Repe_Mak_Metall is coded if a quadrangular element is drawn – either shaped by lines or by circles that add to a quadrangle
- The coded element is one quadrangle, even if two made of different material are drawn

Repe_Mak_Flüssig	Is defined as the students' macroscopic drawing of a liquid.

Helpful Indicators/ Example

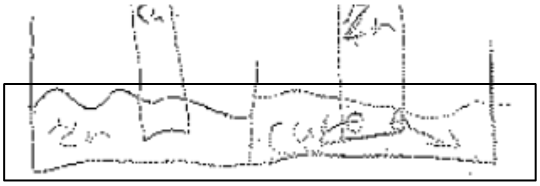


Figure 6. Macroscopic drawing of liquid (JKGY17 - Box 2)

Special Considerations

- Repe_Mak_Flüssig is always coded if students draw a (curved) line within the container
- The coded element is the area limited by the container and the line representing the liquid surface

Repe_Mak_Glas	Is defined as the students' macroscopic drawing of a container.

Helpful Indicators/ Example

Figure 7. Macroscopic drawing of container (JKGY - Box 2)

Special Considerations

- Repe_Mak_Glas is always coded if students draw any device to contain the nail or the metal plates and the liquid
- The coded element is the area around the whole container

Submicroscopic

Repe_Subm	Is defined as the students' submicroscopic drawings.

Helpful Indicators/ Example

Figure 8. Submicroscopic drawing of an electron (JKGY17 - Box 2)

Special Considerations

- Repe_Subm is coded if students draw not visible particles
- The coded element is the circle/dot/etc. representing the particle

Formal

Repe_Form	Is defined as the students' formal drawings.

Helpful Indicators/ Example

Figure 9. Formal drawing of a negative charge and an arrow (JKGY17 - Box 2)

Special Considerations

- Repe_Form is coded if students draw elements on the formal domain such as mathematic or chemical symbols
- The coded element is the area around the formal element

Form of Representation

Repf_Pun	Is defined as the students' drawings of dots.

Helpful Indicators/ Example

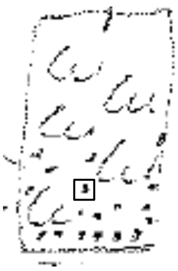


Figure 10. Drawing of a dot (UEGY64 - Box 3)

Special Considerations

- Repf_Pun is coded if students draw a tiny round object
- The coded element is the area around one of those dots

Repf_Git	Is defined as the students' drawings of a lattice.

Helpful Indicators/ Example

Figure 11. Drawing of a lattice (UEGY48 - Box 1)

Special Considerations

- Repf_Git is coded if students draw several dots or circles that are connected through lines
- The coded element is the area around one dot or circle and its four lines

Repf_Diff	Is defined as the students' exact drawings of a molecule.

Helpful Indicators/ Example

Figure 12. Exact drawing of a molecule (UEGY26 - Box 1)

Special Considerations

- Repf_Diff is coded if students draw a molecule containing all atoms belonging to that molecule
- The coded element is the area around the whole molecule

Repf_Kreis	Is defined as the students' drawings of a circle.

Helpful Indicators/ Example

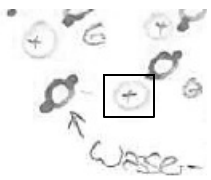


Figure 13. Drawing of a circle (UEGY26 - Box 1)

Special Considerations

- Repf_Kreis is coded if students draw a circle representing a particle
- It is not coded for other circles
- The coded element is the area around the circle

Repf_Phys_Kab	Is defined as the students' physical drawings of power cords.

Helpful Indicators/ Example

Figure 14. Physical drawing of power cords (JKGY19 - Box 2)

Special Considerations

- Repf_Phys_Kab is coded if students draw straight lines for power cords
- The coded element is the whole area around the power cords

Repf_Phys_Strom	Is defined as the students' physical drawings of a meter.

Helpful Indicators/ Example

Figure 15. Physical drawing of a voltmeter (JKGY28 - Box 2)

Special Considerations

- Repf_Phys_Strom is coded if students draw physically any device that either produces electricity or measures it
- The coded element is the area around the physical drawing of the electric device

Repf_e$^-$	Is defined as the students' physical drawings of e$^-$.

Helpful Indicators/ Example

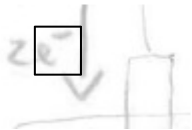


Figure 16. Drawing of electrons as e$^-$ (JKGY19 - Box 2)

Special Considerations

- Repf_e$^-$ is coded if students draw electrons as e$^-$
- The coded element is the area around the e$^-$

Repf_Gleich	Is defined as the students' physical drawings of an equal sign.

Helpful Indicators/ Example

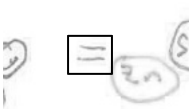


Figure 17. Drawing of an equal sign (UEGY48 - Box 1)

Special Considerations

- Repf_Gleich is coded if a mathematic equal sign is drawn
- The coded element is the area around the equal sign

Repf_Pfeil	Is defined as the students' physical drawings of an arrow.

Helpful Indicators/ Example

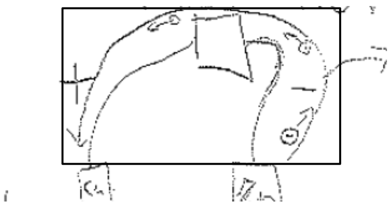


Figure 18. Drawing of an arrow (JKGY17 - Box 2)

Special Considerations

- Repf_Pfeil is coded if students draw an arrow
- The coded element is the whole area around the arrow

Repf_Minus	Is defined as the students' physical drawings of a minus.

Helpful Indicators/ Example

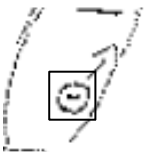


Figure 19. Drawing of a minus within a particle (JKGY - Box 2)

Special Considerations

- Repf_Minus is coded if students draw a minus either representing an electron or an anion or as mathematic symbol
- The coded element is the area around the minus

Repf_Plus	Is defined as the students' physical drawings of a plus.

Helpful Indicators/ Example

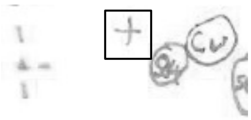


Figure 20. Drawing of a plus as mathematic symbol (UEGY48 - Box 1)

Special Considerations

- Repf_Plus is coded if students draw a plus mathematically or chemically
- The coded element is the area around the plus

Repf_Elem	Is defined as the students' physical drawings of a chemical symbol.

Helpful Indicators/ Example

Figure 21. Drawing of a chemical symbol (UEGY48 - Box 1)

Special Considerations

- Repf_Elem is coded if students draw a chemical symbol to tag or represent a particle
- The coded element is the area around the chemical symbol.

Type of particle

T_Undefiniert	Is defined as a type of particle that is not defined.

Helpful Indicators/ Example

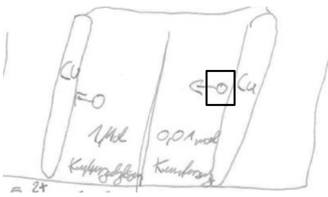


Figure 22. Drawing of a particle that is not definable (UEGY28 - Box 3)

Special Considerations

- T_Undefiniert is coded if students draw a particle that is not definable by a label or key and not deducible from its context
- The coded element is the area around the particle

T_Molekül	Is defined as the drawing of a molecular particle.

Helpful Indicators/ Example

Figure 23. Drawing of a water molecule (UEGY26 - Box 1)

Special Considerations

- T_Molekül is only coded if students draw a water molecule
- The coded element is the area around the whole water molecule

T_Elektron	Is defined as the drawing of an electron.

Helpful Indicators/ Example

Figure 24. Drawing of an electron (JKGY17 - Box 2)

Special Considerations

- T_Elektron is coded if students draw an electron in either way
- The coded element is the area around the electron

T_Atom	Is defined as the drawing of an atom.

Helpful Indicators/ Example

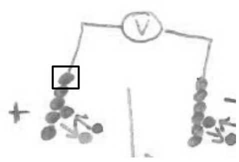


Figure 25. Drawing of an atom (JKGY28 - Box 2)

Special Considerations

- T_Atom is coded if students draw zinc or copper atoms in either way
- The coded element is the area around only one atom of zinc or copper per document

T_Kation	Is defined as the drawing of an cation.

Helpful Indicators/ Example

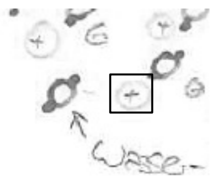


Figure 26. Drawing of a cation (UEGY26 - Box 1)

Special Considerations

- T_Kation is coded if students draw zinc or copper cations in either way
- The coded element is the area around one cation of zinc or copper per document

T_Anion	Is defined as the drawing of an anion.

Helpful Indicators/ Example

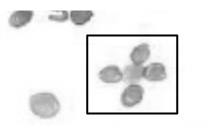


Figure 27. Drawing of a sulfate anion (LGGY24 - Box 2)

Special Considerations

- T_Anion is coded if students draw sulfate anions in either way
- The coded element is the area around the whole anion

Colour

F_Makr	Is defined as a macroscopic choice of colour.

Helpful Indicators/ Example

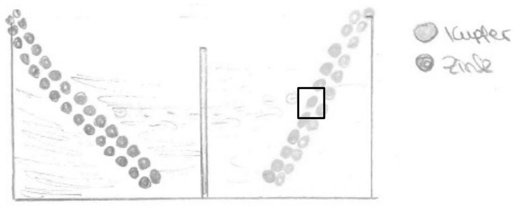


Figure 28. Drawing with a macroscopic choice of colour (UEGY07 - Box2)

Special Considerations

- F_Makr is only coded if students use colours for their drawing
- It is coded if the particle is drawn in the same colour as the macroscopic object
- The coded element is the area around one colourful particle

F_Willk	Is defined as an arbitrary choice of colour.

Helpful Indicators/ Example

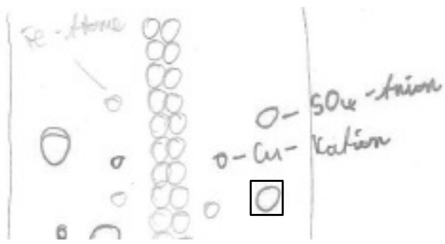


Figure 29. Drawing with an arbitrary choice of colour (UEGY54 - Box1)

Special Considerations

- F_Willk is only coded if students use colours for their drawing
- It is coded if the particle is drawn in a colour differing from the macroscopic object
- The coded element is the area around one colourful particle

Labelling

Be_Neb	Is defined as a label next to the object.

Helpful Indicators/ Example

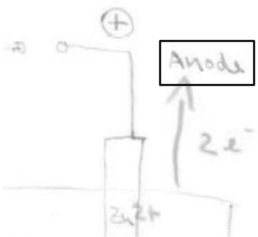


Figure 30. Drawing with label next to the concerning object (JKGY19 - Box 2)

Special Considerations

- Be_Neb is coded if students write a label next to the concerning object
- The coded element is the area around the written label

Be_Leg	Is defined as a legend.

Helpful Indicators/ Example

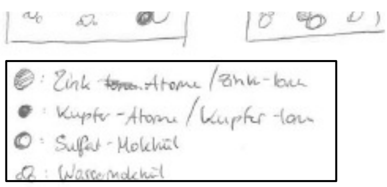


Figure 31. Drawing with an added legend (JKGY26 - Box 1)

Special Considerations

- Be_Leg is coded if students add a legend about the drawn objects
- The coded element is the area around the whole legend

Be_In	Is defined as an integrated label.

Helpful Indicators/ Example

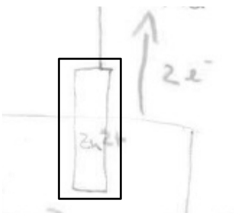


Figure 32. Drawing with a label that is integrated in the object (JKGY19 - Box 2)

Special Considerations

- Be_In is coded if students write a label within the object
- The coded element is the area around the integrated label

Be_An	Is defined as a tied label.

Helpful Indicators/ Example

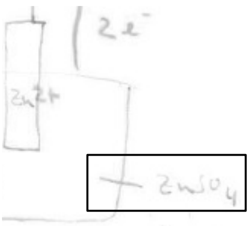


Figure 33. Drawing with a label that is tied to the object (JKGY19 - Box 2)

Special Considerations

- Be_An is coded if students write a label next to the object and tie it to the object with a line
- The coded element is the area around the tied label

ii. Concept-Related Statements

Wichtige Kodierregeln:

! Pro richtige Aussage und Zeichnung 1 Punkt geben – wenn Zeichnung durch Aussage erklärt wird, NICHT doppelt werten!

Zeichnung: Zn_ox und Cu_red gewertet, wenn z.B. „Reduktion: …“ „Oxidation…“ geschrieben wurde.

Box	Description	Code SPSS
1	Zink ist ein unedleres Metall als Kupfer.	B1_Zn_unedler
	Zink-(Atom) gibt (gerne) (zwei) Elektronen ab.	B1_Zn_eAbgabe
	Zink-(Atom) wird oxidiert.	B1_Zn_ox
	Es entstehen Zink-(Kat)ionen.	B1_Zn_Ionen
	Die Zink-(Kat)ionen gehen in Lösung.	B1_Zn_Kat_Lsg
	Kupfer ist ein edleres Metall als Zink.	B1_Cu_edler
	Kupfer-(Kation) nimmt (gerne) (zwei) Elektronen auf.	B1_Cu_eAufnahme
	Kupfer-(Kation) wird reduziert.	B1_Cu_red
	Es entsteht Kupfer-(Atom).	B1_Cu_Atome
	Daher ist eine kupferfarbene Schicht am Zinknagel zu beobachten.	B1_Cu_Schicht
	Die Reaktion läuft spontan und freiwillig ab.	B1_Rkt_spontan
	Es handelt sich um eine Redoxreaktion.	B1_Redox
	Eine Redoxreaktion ist eine Elektronenübertragungsreaktion.	B1_Redox_eÜbertrag
	Oxidation/Elektronenabgabe und Reduktion/Elektronenaufnahme laufen gleichzeitig ab.	B1_Ox_zeitgleich_Red
	Oxidation/Elektronenabgabe: $Zn (s) \rightarrow Zn^{2+}(aq) + 2 e^-$	B1_Ox_Gleichung
	Reduktion/Elektronenaufnahme: $Cu^{2+}(aq) + 2 e^- \rightarrow Cu (s)$	B1_Red_Gleichung
	Gesamtreaktion: $Zn (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu (s)$	B1_Ges_Gleichung

Hinweis: Zwei mögliche Erklärungsansätze je nach Aufbau des Experiments		
Box	**Description**	**Code SPSS**
2.1	Zink ist ein unedleres Metall als Kupfer.	B2.1_Zn_unedler
	Zink-(Atom) gibt (gerne) (zwei) Elektronen ab.	B2.1_Zn_eAbgabe
	Zink-(Atom) wird oxidiert.	B2.1_Zn_At_ox
	Die Zink-Kationen gehen in Lösung.	B2.1_Zn_Kat_Lsg
	Die Elektronen bleiben im Metallgitter zurück.	B2.1_e_in_Gitter
	Es entsteht ein Elektronenüberschuss.	B2.1_e_Überfluss
	Kupfer ist ein edleres Metall als Zink.	B2.1_Cu_edler
	Kupfer-(Kation) nimmt (gerne) (zwei) Elektronen auf.	B2.1_Cu_eAufnahme
	Kupfer-(Kation) wird reduziert.	B2.1_Cu_Kat_red
	Kupfer-Atome entstehen am Metallgitter.	B2.1_Cu_At_Gitter
	Die notwendigen Elektronen werden aus dem Metallgitter entzogen.	B2.1_e_aus_Gitter
	Es entsteht ein Elektronenmangel im Metallgitter.	B2.1_e_Mangel
	Durch die Unterschiede in der Elektronendichte/ in den Ladungen an den beiden Metallblechen ist eine Spannung messbar.	B2.1_Erklär_Spannung
	Das Kupferblech stellt den Pluspol und das Zinkblech den Minuspol dar.	B2.1_Cu_Plus B2.1_Zn_Minus
	Elektronen fließen vom Punkt hoher Elektronendichte/Minuspol zum Punkt niedriger Elektronendichte/Pluspol.	B2.1_e_Min_zu_Plus
	Oxidation/Elektronenabgabe: $Zn (s) \rightarrow Zn^{2+}(aq) + 2 e^-$	B2.1_Ox_Gleichung
	Reduktion/Elektronenaufnahme: $Cu^{2+}(aq) + 2 e^- \rightarrow Cu (s)$	B2.1_Red_Gleichung
	Gesamtreaktion: $Zn (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu (s)$	B2.1_Ges_Gleichung
	Es handelt sich um eine Redoxreaktion.	B2.1_Redox
	Oxidation und Reduktion laufen räumlich voneinander getrennt aber gleichzeitig ab.	B2.1_OxRed_getr

Box	Description	Code SPSS
2.2	Zink ist ein unedleres Metall als Kupfer.	B2.2_Zn_unedler
	Zink-(Atom) gibt (gerne) (zwei) Elektronen ab.	B2.2_Zn_eAbgabe
	Zink-(Atom) wird oxidiert.	B2.2_Zn_ox
	Es entstehen Zink-Kationen.	B2.2_Zn_Ionen
	Die Zink-Kationen gehen in Lösung.	B2.2_Zn_Kat_Lsg
	Kupfer-(Kation) nimmt (gerne) (zwei) Elektronen auf.	B2.2_Cu_eAufnahme
	Die Kupfer-Ionen werden reduziert.	B2.2_Cu_red
	Es entstehen Kupfer-Atome.	B2.2_Cu_Atome
	Daher ist eine kupferfarbene Schicht am Zinknagel zu beobachten.	B2.2_Cu_Schicht
	Die Reaktion läuft spontan und freiwillig ab.	B2.2_Rkt_spontan
	Es handelt sich um eine Redoxreaktion.	B2.2_Redox
	Eine Redoxreaktion ist eine Elektronenübertragungsreaktion.	B2.2_Redox_eÜbertrag
	Oxidation/Elektronenabgabe und Reduktion/Elektronenaufnahme laufen gleichzeitig ab.	B2.2_Ox_zeitgleich_Red
	Oxidation/Elektronenabgabe: $Zn (s) \rightarrow Zn^{2+}(aq) + 2 e^-$	B2.2_Ox_Gleichung
	Reduktion/Elektronenaufnahme: $Cu^{2+}(aq) + 2 e^- \rightarrow Cu (s)$	B2.2_Red_Gleichung
	Gesamtreaktion: $Zn (s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu (s)$	B2.2_Ges_Gleichung
	Auf der Seite des Kupferblechs passiert nichts, da Kupfer edler ist als Zink.	B2.2_Cu_keine_Rkt
	Kupfer-(Atom) gibt **nicht** (gerne) (zwei) Elektronen ab.	B2.2_Cu_keine_eAbg
	Zink-(Kation) nimmt **nicht** (gerne) (zwei) Elektronen auf.	B2.2_Zn_keine_eAufn
	Es kann keine Redoxreaktion stattfinden.	B2.2_keine_Redox
	Es ist eine Spannung messbar, da die Ladungsträger unterschiedlich verteilt sind.	B2.2_Erklär_Spannung

Box	Description	Code SPSS
3	In der Lösung mit $c = 1\frac{mol}{l}$ liegen mehr Kupfer-Teilchen vor als in der Lösung mit $c = 0{,}1\frac{mol}{l}$.	B3_Teilchenanzahl
	Wenn ein Kupferblech in eine Kupfersulfat-Lösung getaucht wird, können sich Kupferatome aus dem Metallgitter lösen.	B3_Teilch_Gitt_lös
	Die gelösten Kupfer-Ionen können Elektronen aus dem Kupferblech aufnehmen und sich als Kupfer-Atome am Metallgitter ablagern.	B3_Cu_Ion_eAufn B3_Cu_Gitt_Ablag
	In der Lösung mit $c = 1\frac{mol}{l}$ nehmen mehr Kupfer-Kationen Elektronen auf.	B3_1M_mehr_eAufn
	In der Lösung mit $c = 1\frac{mol}{l}$ werden mehr Kupfer-Kationen reduziert.	B3_1M_Red
	Dort lagern sich Kupfer-Atome am Metallgitter ab.	B3_1M_mehr_Ablag
	In der Lösung mit $c = 0{,}1\frac{mol}{l}$ lösen sich mehr Kupfer-Atome aus dem Metallgitter.	B3_01M_mehr_Lös
	In der Lösung mit $c = 0{,}1\frac{mol}{l}$ werden mehr Kupfer-Atome oxidiert.	B3_01M_Ox
	Diese liegen dann als Kupfer-Ionen in Lösung vor.	B3_01M_gelö_Ionen
	Am Kupferblech der höher konzentrierten Lösung entsteht ein Elektronenmangel.	B3_1M_eMangel
	Am Kupferblech der niedriger konzentrierten Lösung entsteht ein Elektronenüberschuss.	B3_01M_eÜbersch
	Es entsteht eine Ladungsdifferenz.	B3_Ladungsdiff
	Das Kupferblech der höher konzentrierten Lösung ist positiv geladen.	B3_1M_pos
	Das Kupferblech der niedriger Konzentrierten Lösung ist negativ geladen.	B3_01M_neg
	Die Ladungsdifferenz wird ausgeglichen. (Dadurch ist eine Spannung messbar).	B3_Ldiff_Ausgleich
	Oxidation/ Elektronenabgabe (0,1 mol/L) Cu (s) →	B3_Ox_Gleichung

	Cu^{2+}(aq) + 2 e	
	Reduktion/ Elektronenaufnahme (1mol/L) Cu^{2+}(aq) + 2 e^- → Cu (s)	B3_Red_Gleichung
	Es findet eine Redoxreaktion statt.	B3_Redox
	Oxidation und Reduktion laufen räumlich voneinander getrennt aber gleichzeitig ab.	B3_OxRed_getr

iii. Structure

In order to answer the research question in what way do students structure their lab journal and in what way do they pay attention on the different representation domains the following coding scheme is used.

In a first step, the surface structure of students' lab journal is coded.

Surface Structure

Table	Is defined as students' use the structure of a table to describe and explain the experiment.

Helpful Indicators/ Example

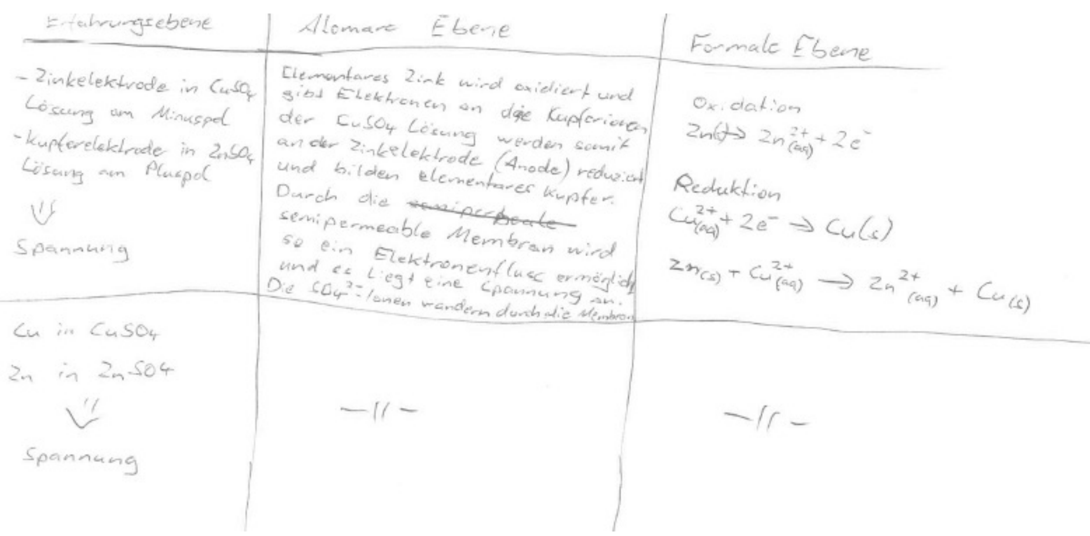


Figure 34. Table in lab journal (UEGY01/ Box 2)

Special Considerations

- Table is also coded if students use different terms in their table compared to the table used in the meta-conceptual training.
- The coded element is the whole area of the table.

General Considerations:

- The specific term in front of a statement can indicate the code of the following statement.

In- and Out-Points

- Codes of terms (Term_XX): The coded element is just a single word or a short form of it
- Descriptive codes (Des_XX): It depends on the content students use. The coded element can be a single word, a sentence, a few sentences, a bullet point or a few bullet points.
- Codes of externals (EX_XX): The coded element is the whole area of the drawing.

Rules

- Codes of terms are single coded
- Descriptive codes are connected to codes of representation domains
- Codes of externals are single coded

Observation

Term_OL	Is defined as students' use of the term "*Beobachtung*".

Indicators/ Example

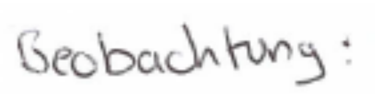


Figure 35. The term observation in lab journal (UEGY58/ Box 2)

Des_OL	Is defined as students describe the *observation* they have made. A description of an observation includes all sensory and experience-based statements.

Helpful Indicators/ Example

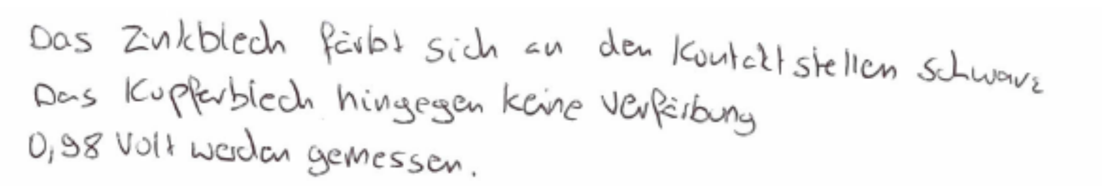


Figure 36. The description of the observation in lab journal (UEGY58/ Box 2)

Special Considerations

- The statement "Es bildet sich Kupfer" can be coded as a description of an observation because students already know the experiment.
- The term "experienced world" indicates the use of the code Des_EW.

EX_OL	Is defined as students draw the *observation* they have made. A drawing of an observation is not the same as a drawing of the experimental set up. A drawing of an observation includes additional information.

Helpful Indicators/ Example

- A drawing of an experimental set up, which includes the measured voltage shown on the display of the voltmeter, can be coded as EX_OL.

Figure 37 .A drawing of an observation in lab journal (JKGY06/ Box 1)

Analysis/ Explanation/ Inference

Term_AN	Is defined as students' use of the term *"Deutung"/ "Erklärung"*.

Helpful Indicators/ Example

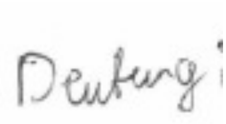


Figure 38. The term „Deutung" in lab journal (UEGY56/ Box 3)

Des_AN	Is defined as students describe the *analysis/ explanation* of the experiment. The description of the analysis includes all information, which correspond to scientific knowledge.

Helpful Indicators/ Example

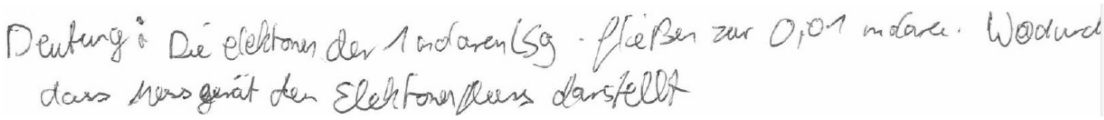


Figure 39. The description of the analysis in lab journal

EX_AN	Is defined as students draw some aspects to explain the phenomenon.

Helpful Indicators/ Example

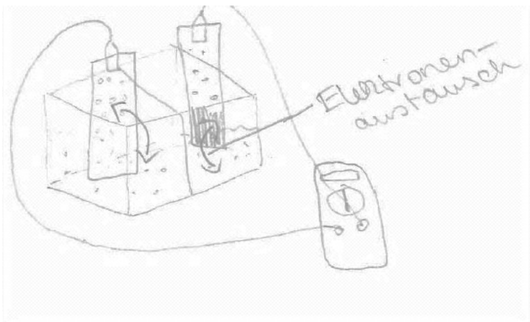


Figure 40. A drawing of an ***inference approach*** *in lab journal (UEGY13/ Box 2)*

Special Considerations

- If a drawing includes detailed information about the submicroscopic structure, it is coded as EX_SL.

Experimental Setup

Term_ES	Is defined as students' use of the term *"Durchführung"/ "Aufbau"*.

Indicators/ Example

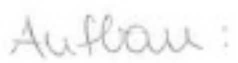


Figure 41. The term ***'experimental setup'*** *in lab journal (UEGY10/ Box 1)*

Des_ES	Is defined as students describe the *experimental setup*.

Helpful Indicators/ Example

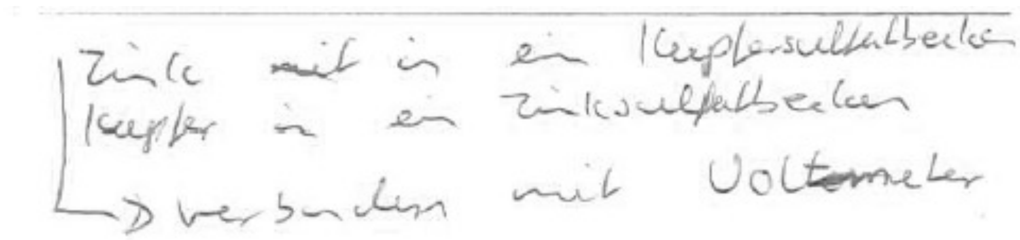


Figure 42. The description of the observation in lab journal (UEGY20/ Box 2)

Special Considerations

- If a statement about the experimental setup is included in a statement of the observation, than the statement is coded as Des_OL.

EX_ES	Is defined as students draw the *experimental setup*. A drawing of an observation is not the same as a drawing of the experimental set up. A drawing of an experimental setup excludes information about changes during the experiment.

Helpful Indicators/ Example

- A drawing of an experimental set up, which includes the measured voltage shown on the display of the voltmeter can be coded as EX_OL.

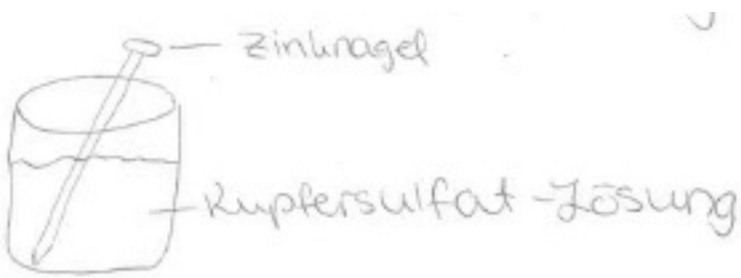


Figure 43. A drawing of an experimental setup in lab journal (UEGY10/ Box 1)

Material/ Chemicals

Term_MC	Is defined as students' use of the term *"Material"/ "Chemikalien"*.

Indicators/ Example

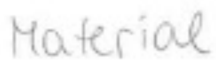


Figure 44. The term ***"Material"*** *in lab journal (UEGY10/ Box 1)*

Des_MC	Is defined as students describe the *materials*/ *chemicals* used in the experiment.

Helpful Indicators/ Example

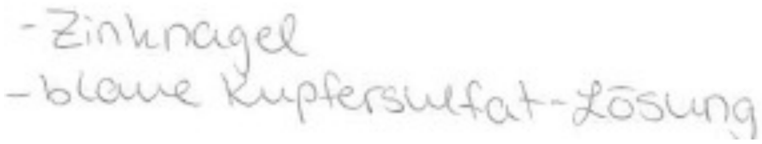


Figure 45 .The description of the observation in lab journal (UEGY10/ Box 1)

EX_MC	Is defined as students draw the *materials* separated.

Helpful Indicators/ Example

- A drawing of the material shows no information about the experimental setup. The materials or chemicals are drawn separated.
- A drawing of the materials is probably not used.

Hypothesis

Term_VH	Is defined as students' use of the term "*Vermutung*"/ "*Hypothese*".

Indicators/ Example

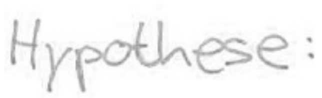


*Figure 46. The term **"Hypothese"** in lab journal (JKGY32/ Box 1)*

Des_VH	Is defined as students describe the *hypothesis*. A description of hypotheses does not have to be scientifically right.

Helpful Indicators/ Example

- Hypotheses are often written in conditional tenses.

EX_VH	Is defined as students draw the *hypothesis*.

Helpful Indicators/ Example

- A drawing of a hypothesis can be similar to a drawing of the analysis.

Special Considerations

- A drawing of a hypothesis is probably not used.

(Chemical) Equation

Term_CE	Is defined as students' use of the term *"Reaktionsgleichung"/ "Redoxreaktion"/* "Oxidation"/ "Reduktion"

Indicators/ Example

*Figure 47. The term **"Reaktionsgleichung"** in lab journal (JKGY08/ Box 1)*

Des_CE	Is defined as students describe the *chemical equation* in symbols or as a word equation.

Helpful Indicators/ Example

- To describe a (chemical) equation symbols are often used.

Figure 48. The description of a chemical equation in lab journal (UEGY10/ Box 1)

EX_CE	Is defined as students draw the *chemical equation*.

Helpful Indicators/ Example

- A drawing of the chemical equation can include submicroscopic visualizations of the molecules, atoms or ions.
- A drawing of the chemical equation can include macroscopic visualizations of the chemicals used in a chemical equation.

The following codes need a special consideration. For example, if students mark a part as experienced world, the following statements are coded as Des_EW independent of the content of these statements. Consequently, all descriptive codes are coded, if the connected term is in front of. This decision was made to investigate students' ability to differentiate between the different representation domains. All descriptive codes are additionally connected to the representation domains. In addition, if drawings are connected to a specific term, for example "submicroscopic domain", the drawing is coded as EX_SL.

Term_EW	Is defined as students' use of the term *"Erfahrungswelt"/ "Erfahrbare Ebene"*.

Indicators/ Example

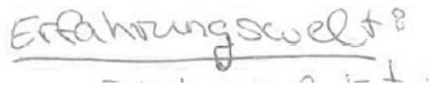


*Figure 49. The term **"Erfahrungswelt"** in lab journal (JKGY08/ Box 1)*

Des_EW	Is defined as students describe or think to describe the *experienced world*

Helpful Indicators/ Example

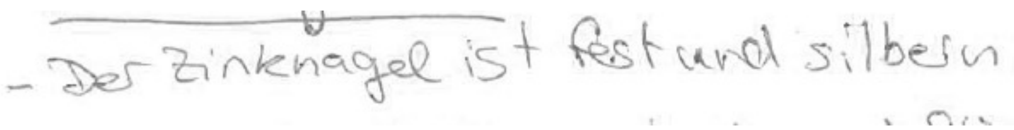


Figure 50 .The description of the experienced world in lab journal (JKGY08/ Box 1)

Special Considerations

- If a statement about the experimental setup is included in a statement of the observation, than the statement is coded as Des_OL.

EX_EW	Is defined as students draw the *experimental setup*. A drawing of an observation is not the same as a drawing of the experimental set up. A drawing of an experimental setup excludes information about changes during the experiment.

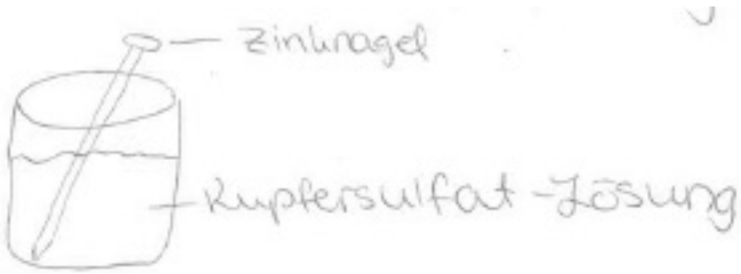


Figure 51 A drawing of an experimental setup in lab journal (UEGY10/ Box 1)

Modelled world

Term_MW	Is defined as students' use of the term *"Modellwelt"/ "Modellebene"*.

Indicators/ Example

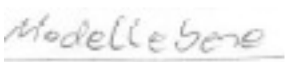


*Figure 52. The term **"Modellwelt"** in lab journal (UEGY01/ Box 3)*

Des_MW	Is defined as students describe or think to describe the *modelled world*

Helpful Indicators/ Example

- Statements at the modelled based domain correspond to the submicroscopic and/or formal domain.

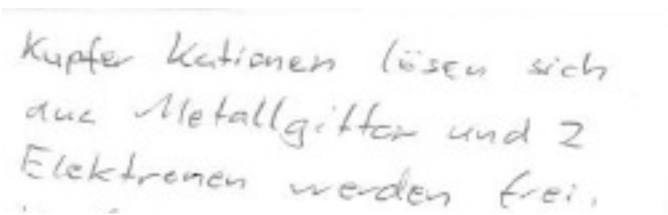


Figure 53. The description of the modelled world in lab journal (UEGY01/ Box 3)

EX_MW	Is defined as students draw aspects of the *modelled world*. A drawing at the modelled world can include aspects of the submicroscopic and formal domain.

Helpful Indicators/ Example

- A drawing of the modelled world should be connected to the term "Modelled world"

Submicroscopic Domain

Term_SL	Is defined as students' use of the term *"Atomare Ebene".*

Indicators/ Example

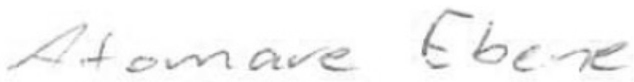


*Figure 54. The term **"Atomare Ebene"** in lab journal (UEGY01/ Box 3)*

Des_SL	Is defined as students describe or think to describe the *submicroscopic domain.*

Helpful Indicators/ Example

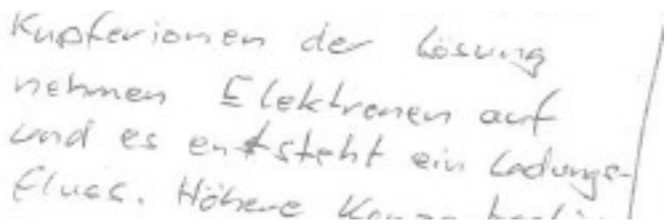


*Figure 55. The description of the submicroscopic **domain** in lab journal (UEGY01/ Box 3)*

EX_SL	Is defined as students draw aspects of the *submicroscopic domain*. Drawings can include visualizations of atoms, molecules or ions.

Helpful Indicators/ Example

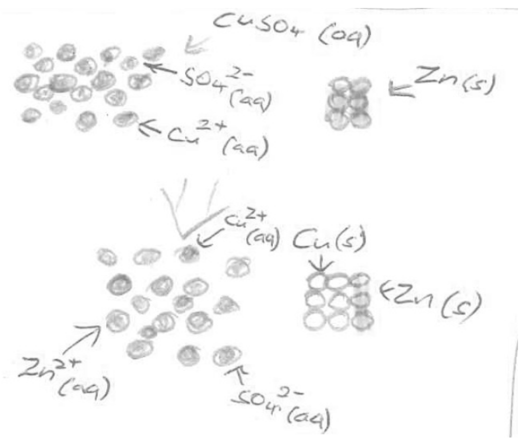


Figure 56. A drawing of aspects oft he submicroscopic ***domain*** *in lab journal (UEGY01/ Box 1)*

Formal Domain

Term_FL	Is defined as students' use of the term *"Formale Ebene"*

Indicators/ Example

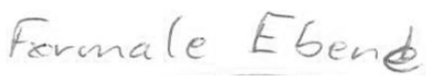


Figure 57. The term ***"Formale Ebene"*** *in lab journal (UEGY01/ Box 1)*

Des_FL	Is defined as students describe or think to describe the *formal domain.*

Helpful Indicators/ Example

Figure 58. The description of the formal ***domain*** *in lab journal (UEGY01/ Box 1)*

EX_FL	Is defined as students draw aspects of the *formal domain*. Drawings can include visualizations of atoms, molecules or ions, but also symbols like +, →.

Representation Domains

General Considerations:

- Every statement is coded by one representation domain.
- The representation domain refers to the specific chemical language (“Copper” (EW); “Copper-atom” (SL); “Cu” (Cu))

In- and Out-Points

- A statement can be a single world, a bullet point or a (main) sentence
- If a sentence can be split up in two sentences, both parts of the sentence are coded (“anions are negative **and** cations are positive”).

Experienced World

EW	Is defined as students use a statement, which refers to macroscopic aspects. It is a sensory- and experience-based statement.

Helpful Indicators/ Example

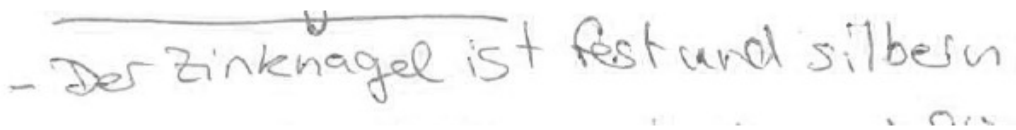


Figure 59. A experience-based statement in lab journal (JKGY08/ Box 1)

Submicroscopic Domain

SD	Is defined as students use a statement, which refers to submicroscopic aspects like atoms or molecules.

Helpful Indicators/ Example

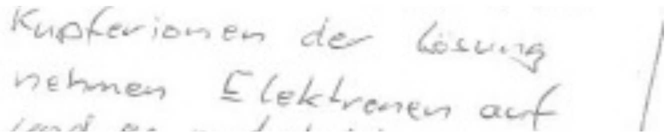


Figure 60. A sumicroscopic-based statement in lab journal (UEGY01/ Box 3)

Formal Domain

FD	Is defined as students use a statement, which refers to chemical formulae language like Fe or Cu.

Helpful Indicators/ Example

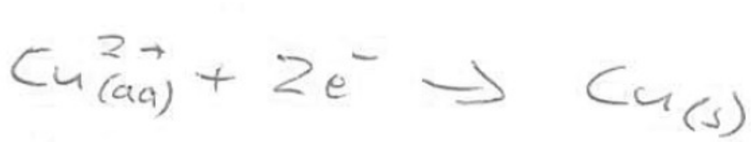


Figure 61. A formal-based statement in lab journal (UEGY01/ Box 1)

Mixing

EWSL	Is defined as students use macroscopic and submicroscopic aspects in one statement.

Helpful Indicators/ Example

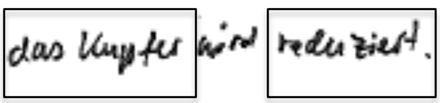


Figure 62. A mixing statement in lab journal (UEGY24/ Box 1)

EWFL	Is defined as students use macroscopic and formal aspects in one statement.

Helpful Indicators/ Example

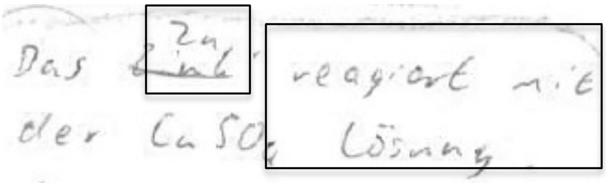


Figure 63. A mixing statement in lab journal (UEGY02/ Box 1)

SLFL	Is defined as students use submicroscopic and formal aspects in one statement.

Helpful Indicators/ Example

- Student connects a chemical formula to a submicroscopic property like Cu^{2+} is reduced.

EWMW	Is defined as students use macroscopic, submicroscopic and formal aspects in one statement.

Helpful Indicators/ Example

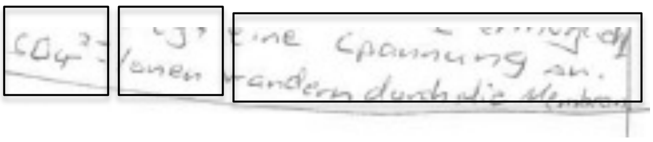


Figure 64. A mixing statement in lab journal (UEGY01/ Box 1)

Connecting Different Representation Domains

E_connect1	Student connects explicitly/ visually the observation and the analysis.

Helpful Indicators/ Example

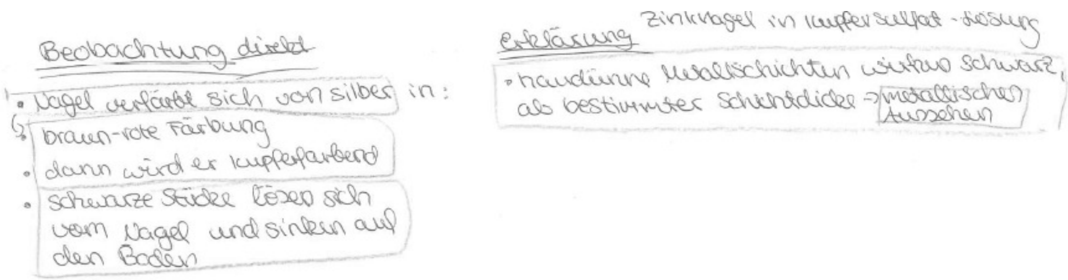


Figure 65. ***Visual connec****tion between observation and analysis in lab journal (UEGY07/ Box 1)*

E_connect2	Student connects explicitly the observation, analysis and chemical equation.

Helpful Indicators/ Example

- Student use different colours to show which aspects at observable, analysis and formal domain are connected.

E_connect3	Student connects explicitly experienced and modelled domain.

Helpful Indicators/ Example

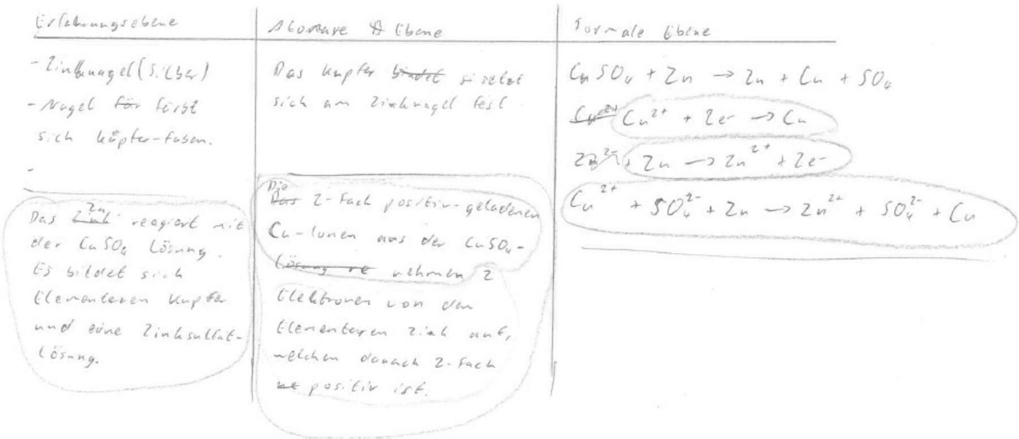


*Figure 66. **Visual connec**tion between experienced and modelled world in lab journal (UEGY02/ Box 1)*

E_connect4	Student connects explicitly experienced and submicroscopic domain.

Helpful Indicators/ Example

- Student use different colours to show which aspects at experienced and submicroscopic domain are connected.

E_connect5	Student connects explicitly submicroscopic and formal domain.

Helpful Indicators/ Example

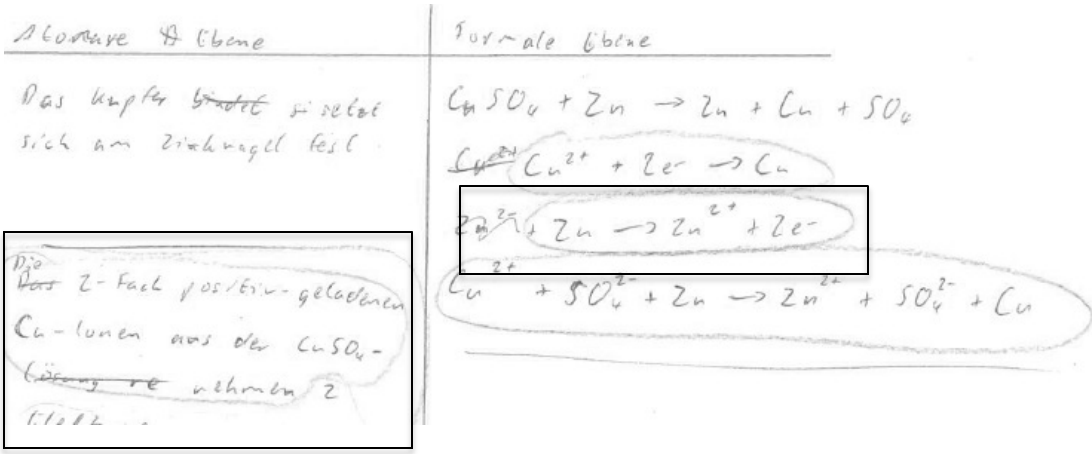


*Figure 67. **Visual connec**tion between experienced and modelled world in lab journal (UEGY02/ Box 1)*

E_connect6	Student connects explicitly experienced and formal domain.

E. Further Analyses

I. Factor Analysis (Attitudes, Interest & Motivation)

Rotierte Komponentenmatrix[a]

	Komponente									
	1	2	3	4	5	6	7	8	9	10
ES_12_rec	,907									
SAI_42_rec	,880									
GTA_41_rec	,879									
ES_08_rec	,855									
GTA_72_rec	,850									
Sbk_02	,849									
SAI_20	,838									
Sbk_01	,822									
Sbk_05	,822									
Sbk_04	,809									
ES_33	,795									
ES_05	,794	,308								
SAI_20_rec	,769									
ES_01	,766									
ES_19	,765									
Swe_02	,752									
ES_40	,749								,379	
Sbk_6	,734									
Sbk_3	,728			,329						
Swe_3	,722				,350					
Swe_1	,675			,340						
Kos_05_rec	,659									
GTA_35_rec	,642	,309								
FGN_39	,581			**,452**						
Kos_05		**,829**								
Kos_04	,352	**,762**								
Kos_02		**,594**								
Kos_01		**,585**					-,356			
SI_03			**,831**							
SI_50.			**,789**							
SI_10_rec			**,635**							
SI_24_rec			**,583**		,313			-,489		
FGN_78	,339			**,744**			,301			
FGN_91.	,457			**,717**						
SAI_18	,331				**,715**					
SAI_26	,406				**,713**					
Koop_01						**,843**				
Koop_02						**,713**				
Koop_04					-,385	**,592**				
FBF_82							**,744**			
FBF_80							**,741**			
FBF_75								,759		
Koop_03									,860	
Kos_03										,841

II. Factor Analysis (Situational Interest S1)

Rotierte Komponentenmatrix[a]

	Komponente			
	1	2	3	4
Exin_04	,866			
Koop_04	,792			
Koop_01	,765			
Exin_01	,695			
Exin_03	,693			
Exp_exin5_rec	,682			
Koop_02	,641			
Koop_03	,557			
Exin_06	,533			
Her_01		,795		
Her_03		,660		
Her_04		,543		,430
Tosi_05		,511	,490	
Tosi_03			,661	
Tosi_04		,525	,626	
Her_02			,547	
Tosi_06			,509	
Tosi_02				,718
Exin_02			,431	,572
Tosi_01		,408		,463

Extraktionsmethode: Hauptkomponentenanalyse.
Rotationsmethode: Varimax mit Kaiser-Normalisierung.[a]
a. Die Rotation ist in 6 Iterationen konvergiert.

III. Correlation Matrix Video Analysis

i. Box 2

		(1)	(2)	(3)	(4)
(1)	Planning		.18	-	.24
(2)	Monitoring			-	.43**
(3)	Evaluating				-
(4)	Conceptual Knowledge				

ii. Box 3

		(1)	(2)	(3)	(4)
(1)	Planning		.31*	-	.1
(2)	Monitoring			-	.33**
(3)	Evaluating				-
(4)	Conceptual Knowledge				