Stockholm University

# Bringing Chemistry to Life

Exploring how drama can support students' learning in upper secondary chemistry education

Kerstin Danckwardt-Lilliestrom



Doctoral Thesis in Science Education at Stockholm University, Sweden 2024

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## Exploring how drama can support students' learning in upper secondary chemistry education

**Kerstin Danckwardt-Lilliestöm**

Academic dissertation for the Degree of Doctor of Philosophy in Science Education at Stockholm University to be publicly defended on Friday 13 December 2024 at 13.00 in Hörsal 3, Hus B, Södra huset, Vån 3, Universitetsvägen 10B and online via Zoom, public link is available at the departments website.

### Abstract

The aim of this dissertation is to advance knowledge about how different forms of drama in upper secondary chemistry education can support students' learning in chemistry, spanning from disciplinary to humanistic perspectives, and how the drama may be designed to achieve that purpose. Teaching and learning are understood as complex processes of social interaction drawing on sociocultural and social-semiotic perspectives. The dissertation is based on two design-based research projects in upper secondary chemistry education. Project 1 focuses on disciplinary learning, and was conducted in three cycles in two different schools in collaboration with one teacher. Project 1 seeks to answer the first overarching research question: (1) In what ways can creative drama support students' conceptual learning of electronegativity and chemical bonding in upper secondary chemistry education? Project 2 focuses on humanistic approaches, and was conducted in two cycles in two different schools in collaboration with three teachers. Project 2 seeks to answer the second overarching research question: (2) In what ways can process drama support students' learning about wicked problems in upper secondary chemistry education? In both projects, research lessons were designed in an iterative process of collaboration with teachers and the lessons were implemented during ordinary teaching. The research lessons were video- and/or audiotaped. Findings from the dissertation are presented in four papers. Paper I shows, based on a social semiotic analysis, how creative drama may afford student meaning-making of abstract non-spontaneous chemical concepts related to chemical bonding. The creative drama supported different types of transductions and transformations which may afford student exploration of intra- and intermolecular forces, in particular when students use bodily mode in combination with other semiotic resources. Paper II reveals, based on a qualitative content analysis, that the creative drama activities enabled the students to bodily move between chemistry's sub-micro and macro levels, and link the electronegativity and polarity of molecules to formations of molecular grid structures to represent how molecules are organised in different states of matter. Paper III shows, based on a qualitative content analysis, how a process drama dealing with the wicked problem of plastic waste/use enabled students and teachers to talk about plastic pollution and plastic use while drawing on perspectives of science as well as values and social science. Paper IV reports, based on a qualitative content analysis, how the use of imaginary transitions in time – in the form of historying and futuring in process drama – can afford nuanced understandings of wicked problems and a readiness to act for the future. Taken together, this dissertation contributes with knowledge about the bodily position as a semiotic resource, the importance of how the roles and the fictional situations are crafted for student learning, as well as how different features in the design of drama promote students' collaborative engagement in chemistry. Based on the findings, design principles for designing creative drama and process drama in chemistry education are proposed.

**Keywords:** *Chemistry education, upper secondary school, creative drama, process drama, social-semiotics, agency, chemical bonding, electronegativity, wicked problems, sustainability, imaginary transitions in time.*

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To my Family
in the past, present
and future

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# List of Papers

I. Danckwardt-Lilliestöm, K., Andrée, M., & Enghag, M. (2018). Creative drama in chemistry education: a social semiotic approach. *Nordic Studies in Science Education, 14*(3), 250-266. https://doi.org/10.5617/nordina.5869

II. Danckwardt-Lilliestöm, K., Andrée, M., & Enghag, M. (2020). The drama of chemistry – supporting student explorations of electronegativity and chemical bonding through creative drama in upper-secondary school. *International Journal of Science Education, 42*(11), 1862-1894. https://doi-org.ezp.sub.su.se/10.1080/09500693.2020.1792578

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# TACK

Samtidigt som jag skriver på min avhandlings sista delar lyser solens strålar på höstlöven utanför mitt fönster så att de gnistrar i allsköns färger. Jag har svårt att förstå att avhandlingen som varit någonting långt borta i framtiden faktiskt närmar sig nutiden. Det känns som om trådarna från både dåtiden och framtiden knyts samman till detta nu.

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*Kerstin Danckwardt-Lilliestöm*

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# 1. Introduction

This dissertation takes its departure from my experiences as a science teacher in upper secondary school where I have used drama in various ways in my teaching to support student learning in chemistry. I have, for example, used drama as a follow-up activity after demanding theory reviews. In doing so, I have experienced how students tend to become more engaged in the teaching. During my chemistry lessons, my students and I have visualised atoms and molecules with our bodies and dramatised chemical reactions. The dramatisations have then sparked discussions among the students and I have enjoyed listening to their spontaneous reactions, such as "Aha, now I understand much better! Was that what you meant!" In my experience, drama activities have tended to generate constructive questions and talk about the chemistry dramatised (e.g., "But why does he place the arm like that?"). In my experience as a teacher, my uses of drama have contributed to a productive and positive classroom atmosphere. However, not all chemistry teachers share my experiences. I have sometimes encountered a view that although drama certainly can be used to make teaching more enjoyable, the student interest might have more to do with the pleasure of the novelty, raising questions about how the drama activity can enable the learning of chemistry. Also, utilising drama in chemistry teaching is sometimes seen as a frivolous use of valuable teaching time in light of a demanding chemistry curriculum.

In spite of my experiences of scepticism towards drama, there is research suggesting that drama can be a useful support to science learning (e.g., Dorion, 2009; Yoon, 2006; Ødegaard, 2003). However, research in science education is limited and the potential for using drama to facilitate students' learning, particularly in chemistry, needs be investigated further. There is also a need to develop curriculum resources that can make forms of drama more accessible to chemistry teachers. This dissertation seeks to describe ways in which drama can be used to support different aims of chemistry education and to explore what happens when drama is incorporated into chemistry teaching. Although Drama and Science may be combined as separate school subjects in a subject-boundary crossing (cf. Raphael et al., 2021), in this dissertation, drama is primarily discussed as a pedagogy for teaching chemistry. The overall aim is to explore the ways in which and for what purposes drama may be used to support students' learning of chemistry in upper secondary school.

# Relevancing chemistry education

Today's societies face major sustainability challenges – problems as climate change, disaster risk, biodiversity loss, poverty, consumption, and global injustice. Action at many levels of society is needed and education is of crucial importance. Knowledge of chemistry can contribute with important and central insights that enable societies to meet these challenges (Matlin et al., 2022). Chemistry is interconnected with other disciplines and from a sustainability perspective, applications of chemistry practices that focus on the analysis, synthesis, and transformation of substances have the potential to both cause problems and improve the quality of life (Mahaffy et al., 2019a).

In schools, however, students from Europe and other Global North countries show a low interest in the science commonly found in science curricula and textbooks (Sjøberg & Schreiner, 2019). Many students tend to view science education (Gilbert, 2006; Hofstein et al., 2011; Stuckey et al., 2013) and chemistry education as disconnected or unrelated to their own lives and the world around them (Cartrette & Mayo, 2011); these topics are often seen to be lacking in creativity, emotions, and moral issues (e.g., Stuckey et al., 2013). Research into science education has repeatedly pointed to limitations of "traditional frontal forms of chemistry teaching" in relation to student learning (Sevian & Talanquer, 2014; Sjöström et al., 2015; Vilches & Gil-Pérez, 2013). These challenges include passive learning, limited experimentation, a narrow curriculum, and lack of student engagement. There is need for research that seeks to better understand students' learning and that contributes to developing ways of teaching to tackle issues of learning and relevance in chemistry education (e.g., Broman, 2015; Stuckey et al., 2013) – partly in relation to current and future societal challenges, partly in relation to student groups who feel that the subjects are not "for them".

## Scientific literacy

An overarching goal of science teaching is to enable students to become scientifically literate (Schwartz et al., 2023). Although there is no consensus on the exact definition of scientific literacy, several scholars suggest that scientific literacy is achieved by understanding the nature of science, scientific inquiry, and science content knowledge (Lederman & Lederman, 2010). Roberts (2007) has distinguished two overarching ways of relating to scientific literacy in science education research: Vision I and Vision II, that focus on different aspects and goals of teaching and learning in science. Vision I emphasises the acquisition of scientific facts and the development of essential scientific skills. The main purpose of Vision I is to introduce students to science and to nurture them into being future scientists. Vision II, according to Roberts, is about learning from the natural sciences in society by problematising the role of the natural sciences in the student's everyday life, to promote

citizenship. It encourages students to understand science as a human endeavour and to make informed decisions about issues related to science. Vision I and Vision II can be understood as two different curricular orientations of citizenship representing a tension between preparing future scientists ("pipeline science") and educating everyone about science ("science for all"; Aikenhead, 2006). One of the challenges of upper secondary school is to develop a science teaching that will provide students with a knowledge base for further studies in science as well as critical citizenship education for all.

Based on a recognition of current and future societal challenges, suggestions for expanding Roberts's visions have been elaborated. For example, Sjöström and Eilks (2018) propose a third vision, Vision III. For Vision III, the goal in science education is to prepare students for political participation in a increasingly complex world that enables them to critically reflect on the role of science in society. While Vision II prioritises relevance in everyday life, Vision III places more emphasis on relevance in relation to critical citizenship and sustainability (Sjöström & Eilks, 2018). In a similar vein, Sund (2016) proposes a distinction between a Vision IIA and a Vision IIB. Whereas Vision IIA, concerning the applications of scientific knowledge to inform everyday life, was somewhat similar to the idea of the Vision II originally suggested by Roberts (2007), Vision IIB, emphasises that the role of science education should not be to solve practical problems in everyday life. Rather, the important contribution of a science education for citizenship lies in enabling students to critically reflect on the role of science in society (cf. Wiblom, 2020).

Hence, Vision III (Sjöström & Eilks, 2018) and Vision IIB (Sund, 2016) share a striving to contribute to humanising science in general (Sund, 2016) and chemistry in particular (Sjöström & Eilks, 2018) by providing students with opportunities to face societal challenges in chemistry by integrating values and moral reasoning into science classrooms. In chemistry education there are challenges that relate to all the visions: to make disciplinary chemistry knowledge relevant from a Vision I perspective; to make chemistry relevant for students' ability to lead a good life and to participate in everyday life from a Vision II perspective (cf. Wiblom, 2020); to make chemistry relevant for the nurturing of a critical citizenship required to meet the challenges of today and the future, focusing on Vision III (Sjöström & Eilks, 2018; or IIB, Sund, 2016).

## A disciplinary challenge – making sense of the invisible and untouchable

One of the specific challenges to understanding chemistry is making sense of things that are invisible and untouchable because chemistry is mainly concerned with the molecular level and particles on a scale that cannot be seen with the naked eye or touched (cf. Airey et al., 2023; Kozma & Russel, 1997). The consequence of this is that students are expected to interpret a variety of

symbolic representations to develop their understanding of chemistry concepts (Taber & Coll, 2002).

In addition to handling particles on the molecular level, students have to handle "multilevel thought" in the teaching, which means they have to deal with different types of concepts at different levels, simultaneously. Relationships between levels or representations of macroscopic properties and submicro and symbolic representations have been described in Johnstone's triangle (Johnstone, 1982). The macro level is the observable or perceptible phenomenon and describes what we can see, hear, or measure. The sub-micro level describes arrangements of particle units such as atoms, molecules, ions, and electrons, and the symbolic level is the language of chemical formulas and symbols that describe the substances and particles. Several studies have revealed that students struggle to switch between the different levels of representation (De Jong et al., 2013; Gilbert & Treagust, 2009; Harrison & Treagust, 2002; Seifeddine Ehdwall & Wickman, 2018). They often use one form of representation, usually macro, for describing what they can measure, hear, or see, and do not move between modes of representation when they are asked to describe and explain a chemical phenomenon (Hultén et al., 2020; Kozma & Russel, 1997).

The multilevel thought becomes particularly crucial in the field of chemical bonding that serves as a foundation for learning other topics in chemistry. Students need to learn about the arrangement of atoms and electrons, even though they cannot physically see these things. If students do not grasp the key concepts and ideas concerning chemical bonding, it may affect their ability to understand other related topics (Othman et al., 2008). In addition, lack of understanding of chemical concepts can have a negative effect on their interest in chemistry as a whole, and the students might not be motivated to engage in chemistry as citizens and may not consider further studies in chemistry (Johnstone, 2010; Taber, 2009). Introducing drama into chemistry teaching could be one way to make molecular bonding at the sub-micro level accessible and visible to students and work as a means of describing chemical observations at the macro level with models of chemical bonding at the sub-micro level.

## Challenges related to humanistic approaches to chemistry education

In addition to the challenges sketched above related to grasping the concepts of chemistry, it is not enough that the students can move between the different levels of representations. They must also be able to handle the knowledge in relation to daily life and societal challenges. Making connections to daily life is frequently advocated as a way to increase students' interest in science education in general (Aikenhead, 2006; Andrée, 2005) and chemistry education in particular (Broman, 2015; Cartrette & Mayo, 2011; King, 2012;; Mahaffy, 2004). Integrating societal challenges into chemistry education aligns with Education for Sustainable Development, an educational approach adopted by

the United Nations (UN). The goal of this approach is to provide students with the tools and knowledge they need to transform both themselves and the societies they live in. To achieve this goal, the UN suggests that education for sustainable development incorporate a holistic approach, focusing on the development of students' creativity and cooperation skills. It should also encourage critical thinking and systemic thinking, which means students should be able to analyse complex problems and understand the interconnectedness and interdependence of different global challenges. By helping students make these connections, education for sustainable development aims to foster a sense of responsibility towards addressing these challenges today and in the future (UNESCO, 2017). As a response to these sustainability challenges, several scholars advocate including *systems thinking* approaches in chemistry education (MacDonald et al. 2022; Mahaffy et al., 2018; Orgill et al., 2019; Talanquer et al., 2020) where chemical processes are not seen as isolated but as part of larger systems, such as the environment – promoting a humanistic and holistic understanding of chemistry.

A particular challenge for developing humanistic approaches to chemistry education concerns the nature of complex sustainability issues, dealing with problems and challenges that are inherently complex and open to discussion (Simonneaux, 2008), which also can be called *wicked problems*. More specifically, wicked problems can only be understood in a context of complexity, uncertainty, and diversity of values and because many of these wicked problems require a radical change in our lives, they also become political in nature (Block et al., 2019). These wicked problems thus require knowledge of both science and actions based on values (Bazzul, 2015). In addition to the complex, interdisciplinary content, teaching for sustainable development that addresses wicked problems also requires that teachers deal with emotions concerning value conflicts and future perspectives (Österlind, 2012). Moreover, the teaching also poses a challenge, because facts about development can arouse feelings of anxiety, guilt, and hopelessness in students (Ojala, 2012). This makes teaching about wicked problems a challenging subject for science education compared to more traditional knowledge areas, and teachers tend to express insecurity about how to deal with students' uncertainties and emotions towards complex sustainability issues (Bursjöö, 2014).

If chemistry education is to become relevant in relation to wicked problems, previous research suggests that teaching should be organised so that students are provided opportunities to participate in conversations about questions related to the social implications of chemistry (cf., Block et al., 2019; Hauge and Barwell, 2017; Lundegård & Caiman, 2019; Mamlok-Naaman et al., 2015; Osborne 2010). Knowledge of chemistry could be important for helping students understand, handle, and take a stand on these wicked sustainability challenges (Zuin et al., 2021), both as citizens and/or prospective higher education students and professionals in the field of chemistry. However, these issues are often missing in traditional chemistry teaching (Sjöström, 2013; Vilches & Gil-Pérez, 2013).

## Integrating humanistic approaches into chemistry education

To promote scientific literacy and the two different curricular orientations of citizenship – preparing future scientists and educating everyone about science – finding a balance between them in chemistry education is required. However, as aforementioned, previous research shows that teaching traditionally focuses more on the former (e.g., Talanquer, 2013; Talanquer et al., 2020). Freire et al. (2019) note that "Historical, philosophical, and sociological studies of chemistry highlight critical aspects of the discipline that teachers and instructors must recognize to avoid presenting a mono-faceted view of the discipline" (p. 675). In line with Freire et al. (2019), Sjöström (2019) emphasises the importance of cultivating a *metaperspective* – in addition to the disciplinary side of chemistry education and research, attention must also be paid to the humanistic, social science, and environmental science perspectives, to promote a *Bildung-oriented* chemistry teaching (e.g., Sjöström, 2019; Sjöström et al., 2020). More specifically, Sjöström (2019) suggests that "metachemistry" includes both knowledge about the nature of chemistry, i.e., NOS (Nature of Science) and knowledge of humanistic dimensions, i.e., STSE (Science-Technology-Society-Environment).

Research on chemistry education has elaborated different approaches for integrating chemistry into aspects of daily life concerning environmental and sustainability issues, proposing humanistic approaches. Figure 1 shows how Johnstone's triangle (Johnstone, 1982; 1991, see also Chapter 2 and Figure 2) has been adopted by various authors to include humanistic dimensions in chemistry education. Mahaffy (2004) stresses the importance of the "human learner and the web of human connections" (p. 229) in chemistry education and includes a human element in Johnstone's triangle. Mahaffy's tetrahedron has been further developed by Sjöström (Sjöström & Talanquer, 2014), adding a relevance dimension by proposing three levels of humanistic science education with growing complexity, moving from disciplinary chemistry education in the bottom triangle towards increasing humanistic approaches at the top (see Figure 1).

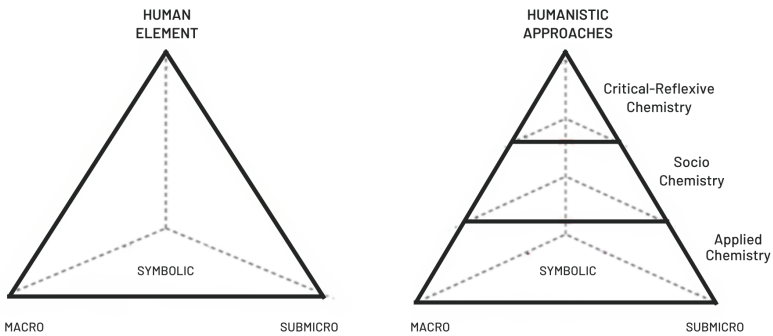



Figure 1. Mahaffy´s tetrahedron (to the left) and Sjöström´s tetrahedron (to the right) adding a relevance dimension. Adapted from Sjöström & Talanquer (2014).

The different levels of complexity in Sjöström's tetrahedron (Figure 1) can be described by focusing on various parts of chemistry knowledge for teaching (see also Sjöström & Talanquer, 2014). *Pure Chemistry* at the tetrahedron's triangular base, represents methods for teaching and learning chemistry that are primarily concerned with the advancement of fundamental disciplinary knowledge. *Applied Chemistry* focuses on making the chemistry subject relevant by connecting the content to applications in the students' daily life in line with context-based education (cf. Broman, 2015). However, the underlying chemistry concepts, ideas, and practices are often uncritically and partially explored, remaining unproblematised (Sjöström & Talanquer, 2014). In *Socio Chemistry,* the role of chemistry in society is stressed, and its advantages, disadvantages, and risks are addressed. Several educational activities at this level can be considered Education for Sustainable Development initiatives. At the top of the tetrahedron *Critical-Reflexive Chemistry,* students are encouraged to critically reflect on the role of chemistry in society, which highlights uncertainties in knowledge generation and application, and emphasises wicked problems. Further, it gives students the opportunity to gain a better understanding of the interrelationships between science, history, and humanity.

Later, Sjöström and Eilks (2018) addressed the different levels of complexity in the humanistic approaches in relation to different visions of scientific literacy. Pure and Applied Chemistry (see Figure 1) are connected to Roberts's (2007) Vision I, while Socio Chemistry relates to Vision II, and Critical-Reflexive Chemistry at the top of the tetrahedron in Figure 1 is related to Vision III. A chemistry education which acknowledges all visions and addresses complexity related to humanistic dimensions may give students more options for dealing with sustainability issues in chemistry teaching.

In sum, chemistry education faces a complex challenge. Although there is a need to develop teaching methods that can make chemistry more vivid and tangible concerning conceptual understanding related to Vision I, there is also a need to develop teaching methods that address complex sustainability issues in chemistry education (Herranen et al., 2021; Sjöström et al., 2016; Yavuzkaya et al., 2022) related to visions II and III. Hence, for chemistry teaching to become more meaningful and provide conditions for further studies in science as well as citizenship education for all, and a critical-reflexive approach to chemistry in society, a balance between the visions is required.

## Drama as a way to challenge conventional chemistry teaching practices

In the field of chemistry education there have been many initiatives to develop chemistry teaching to make chemistry more meaningful to students. For example, approaches such as context-based learning (Broman, 2015; King, 2012), inquiry-based learning (Jegstad, 2023), socioscientific issues (Çalık, &

Wiyarsi, 2021), and argumentation (Erduran, 2019) as well as integrating sustainabile chemistry and green chemistry (Zuin et al., 2021). In this dissertation, I investigate another way of developing chemistry teaching - through educational drama. Educational drama can be used in teaching to address all visions of scientific literacy (cf. Ødegaard, 2003), supporting learning from a disciplinary as well as a humanistic perspective. Further, "drama activities used in science focus less on the dramatic process and more on the process of developing scientific literacy" (Ødegaard, 2023 p. 74).

Although there was limited empirical research connecting drama and science in the past, the interest in its use in science classrooms has increased in recent years. One expression of the increased interest is the anthologies that have been published with examples of how drama can be used in science education (McGregor & Anderson, 2023; White et al., 2021). However, research is still limited and the potential for using drama in science education and particularly in chemistry education needs further scrutiny and development (Dorion, 2009; Namyssova et al., 2023; Raphael et al., 2021; Yoon, 2006; Ødegaard, 2003). Taken together, this dissertation seeks to contribute to challenge conventional chemistry teaching practices to enable student engagement in explorations of how chemistry knowledge may come to matter through the use of drama.

## Why use drama for learning in science education?

Drama for learning can be used in different ways in science teaching, such as watching a performance about science, performing a play with a manuscript, or improvising a subject-related drama activity in the classroom (Baskerville et al., 2023). When subject content is integrated into the drama activity, the focus is often on the latter, also called learning *through* drama, and priority is given to learning through engagement in the process rather than a performative result (cf. Clark-Fookes & Henderson, 2021).

One of the most powerful reasons for using drama in science is that it provides students and teachers with an opportunity to "step into someone else's shoes" and see things from a different perspective. Here and now, another person – or animate and inanimate entities (Metcalfe et al., 1984) – are brought to life for a moment. The role and the fictitious situation mean that the person has to act, gets a reason, a motive to do something from the perspective of the role, which according to Bowell and Heap (2001) is an imperative for learning. The interaction between fiction and reality is the pedagogical potential of drama pedagogy (Bolton, 1984). By using drama in science teaching, students are given the opportunity to participate in "serious playfulness". To be in the fiction while being aware of reality, is referred to in drama pedagogy as *aesthetic doubling* (Heikkinen, 2016; Østern & Heikkinen, 2001) or *metaxis* (Boal, 1995), and can provide an expanded opportunity for experience and reflection. Heikkinen (2016) explains the learning potential of aesthetic doubling:

> [Y]ou have to devote yourself to the construction of the fiction, you make it conditionally (not for real, 'for play' – you bracket the demands of 'reality' for a certain amount of time and then you leave it) and you are not obligated to anything else than to obey the rules of the play (p. 33).

According to Heikkinen (2016), aesthetic doubling allows for the exploration of different roles, places, times, and plots and the term serious playfulness refers to the way humans naturally engage in playful activities that involve reinterpreting symbols and their conventional meanings. This kind of playfulness helps us think about the meaning of our own lived experiences, in line with the concept of drawing on personal funds of knowledge (cf. Andrée & Lager-Nyqvist, 2013). However, serious playfulness, which could have great potential for learning, is commonly an overlooked teaching resource in chemistry education (cf. Waermö, 2019).

Exploring the relationship between fiction and reality and the awareness of both at the same time, thus holds great potential for learning, not only in social sciences as argued for by Heikkinen (2016) but also in other school subjects such as science (cf. Verhoff, 2023). Hallgren (2018) describes, with reference to Davis (2014) and Bolton (1984), that in metaxis a small gap or space occurs "where I do something in the role while seeing myself doing it" (p. 22). In this gap, "an impulse to self-reflection" can arise and an opportunity to ask one of the most important questions, according to Davis (2014): "Why did I do that in role when I might do it in a different way in reality?" (p. 22). According to Hallgren (2018), this process of aesthetic doubling is embodied and gives rise to the emergence of meaning in the spaces or gaps that are created. These gaps can be between a participant and the role they are playing, between different participants, and between the fictional situation being portrayed and the real-world situation.

Several scholars emphasise that drama in science education is a means to add emotional and creative elements to the teaching which can help deepen students' understanding and allow them to delve more deeply into scientific concepts and ideas (Clark-Fookes & Henderson, 2021). A central concept in drama research related to emotions is *perezhivania*, a Russian term used by Vygotsky (see Davis, 2015). Perezhivania is described by Ferholt (2010) as the emotionally lived experience, carried in the heart and that such experiences are rarely forgotten. Perezhivanie underscores the significance of the subjective, emotional dimension of human experience, suggesting that our emotions are integral to how we understand, interact with, and learn from the world around us. Hallgren (2018) emphasizes that the concept of perezhivanie is useful in the creation of drama processes in relation to learning and that "it is about opening up problems, gaps and spaces where perspectives can be broken, tension can arise and commitment can be awakened, which metaxis and aesthetic doubling through role-taking can make even more visiblev" (p. 45, my translation).

To promote aeasthtic doubling in chemistry teaching could involve, for example, letting the students oscillate between assuming roles as atoms and molecules in the invisible sub-micro world of chemistry and then stepping out of their role and explaining and reflecting on their visualisations concerning conceptual understanding related to Vision I. But also, letting the students assume roles where they act as human characters and move between the fictional situation and the real-world situation. This favours a Vision II and III perspective in chemistry teaching. An important implication for science education is that the teacher provides space for the students' reflection during and/or after a drama activity – to compare their enacted roles, movements, or conversations with real-life and the scientific discourse (cf. Braund, 2015; Verhoff, 2017).

One way to challenge traditional forms of chemistry teaching may thus be to introduce drama and allow students to explore the subject of chemistry in a playful format, that can expand opportunity for experience and reflection, promoting learning in chemistry. Depending on the purpose, drama can be used in different ways in chemistry teaching, as described in the following section.

## Different forms of educational drama in science education

Two main strategies in teaching science through drama have emerged in the literature - to teach science concepts and to explore the uses and implications of science in social practices. These two main strategies have been labeled *physical simulations* and *social simulations* (Abed, 2016; Dorion, 2009), although they are often used together in a drama activity. In this dissertation, physical and social simulations are used in such a way that they open up a multitude of activities that can be interpreted in different ways without being right or wrong.

The first strategy, physical simulations*,* provides a way for students to experience non-human entities. This strategy is often employed to explain abstract physical processes that otherwise are not visible in the classroom (Dorion, 2009; Ødegaard, 2003) in line with Vision I (Roberts, 2007). For example, students visualise atoms, molecules, and chemical processes with their bodies (e.g., Hendrix et al., 2012; Najami et al., 2019) or assume the roles of lungs, alveoli sacs, red blood cells, and body cells (Aubusson et al., 1997). Physical simulations can also involve visible non-human entities such as organisms in a food chain or animals in a park (Cokadar & Yılmaz, 2010).

In the second strategy, activities are categorised as social simulations, where students act as human characters (e.g., scientists) engaged in roleplays designed to teach topics related to emotions and cultural and intellectual discourses that are situated in science contexts (Ødegaard, 2003). Social simulations occur in a variety of forms and can be applied with a variety of different dramatic techniques.

Dramatic activities in the classroom can take various forms related to various purposes. In this dissertation, I have chosen to focus on two particular forms of educational drama used in science teaching – *creative drama* (Arieli,

2007) and *process drama* (Hallgren, 2018). In this dissertation, creative drama relates to the category of physical simulations where the students are enabled to visualise different abstract objects such as atoms and molecules, and process drama relates to social simulations, where the students have the opportunity "to be" different subjects.

### Creative drama

Creative drama is a form of educational drama that can be used to explore the conceptual dimension in science teaching and a form of drama that primarily focuses on physical simulation (according to Namyssova et al. [2023] creative drama may also include social simulations). Creative drama is an improvised, non-performance, process-oriented form of drama in which participants are guided by an instructor to imagine, perform, and reflect on human experience (Davis & Belm, 1978). Integrating creative drama into science teaching thus means that the teacher guides the students so that they can dramatise a story, a concept, or a phenomenon that is current in the ongoing teaching. Creative drama is a form of improvised imaginative play in which the participants have no script. The students receive oral and/or written instructions on the spot, and even if the drama is not rehearsed in advance, the students are often given a moment to discuss with each other how to dramatise the concepts. This process allows students to analyse and synthesise information and transfer scientific concepts and processes into a personally meaningful form. The process students go through in the creation and presentation of the concepts enables them to think about the concept in a way that is meaningful – they own their idea (Arieli 2007).

Some studies maintain that students' conceptual understanding can be developed through creative drama (e.g., Arieli, 2007). However, there is a lack of research focusing on older students and more complex subject content. In addition, research has mainly been based on pre-and post-test methodologies. Thus, there is a lack of research that zooms in on the process of students' participation in drama activities in the chemistry classroom to explore what opportunities for conceptual learning may arise.

### Process drama

Process drama is a form of educational drama in which teachers participate and take on a role in a fiction created together with the students on site based on a predetermined theme. Students and teachers take part as both observers/audience and participants in role (Warner & Anderson, 2004). The overall aim of process drama is to deepen students' understanding of a subject and support them in making connections between different areas of knowledge, ethics, and emotions. Process drama has been proposed as a powerful way to enhance students' active participation because it allows them to face authentic problems and issues, but from a safe position (Österlind & Hallgren, 2014). A role in a process drama may be seen as a safe position in that the students can

assume roles as politicians and activists, where conflicting issues can be explored without having to reveal personal opinions or stances.

In process drama, the teachers and students move in and out of roles, exploring certain subjects or themes using sets of drama pedagogy conventions (Hallgren, 2018). Conventions or strategies are "the different performance forms that, when combined, build and make the process drama happen in action" (Bowell & Heap, 2013 p. 80). Various strategies are used in process drama, such as *still image* or *tableau* to momentarily "freeze the body" in a position, aforementioned *creative drama*, *improvisation* in a group or whole class, *writing in role* (a writing work motivated by the role and experiences in the drama in the form of diaries, letters and short messages), and many more strategies. (For additional information, see Bowel & Heap, 2013; Hallgren, 2018; Heggstad, 2014).

A powerful strategy in process drama is *teacher-in-role (TiR),* a drama technique developed by UK-based drama educator Dorothy Heathcote (Johnson & O'Neill, 1984). This strategy provides the teacher with an important leadership role for influencing the students' learning (Berggraf Saebo, 2011). In process drama, the teacher's opportunity to step in and out of role enables them to be flexible – to both let go of authority and to take control, depending on what unfolds in the drama activity (Heggstad, 2014). In addition, Ødegaard (2003) emphasises that the science teacher does not need to have acting skills to use drama in teaching, the value lies in the teacher's opportunity to guide the students, for example, in their reflections after an episode of drama activity, to enable them to explore what they have experienced and connect science to their everyday life.

Introducing process drama into chemistry teaching may promote teaching for sustainable development where students have the opportunity to participate in activities addressing wicked problems. Letting the students step into a role and experience complex environmental problems, become entangled in the related values and attitudes, and explore the problems from different perspectives, may, according to Berggraf Sæbø, (2011), contribute to new insights and transformed understandings. In addition, Hallgren (2018) argues that from the perspective of drama pedagogy, there is a lack of knowledge regarding how process drama can be used in teaching various school subjects, but there is also a need from the teaching and school viewpoint to discover novel approaches for teaching and fostering a deeper level of learning.

Although several studies have acknowledged the value of using process drama in teaching about sustainability issues (Lethonen et al., 2020; McNaughton, 2008; Ødegaard, 2023; Österlind, 2018), there is a lack of peer-reviewed literature that has examined its potential in chemistry education at upper secondary level. According to Namyssova et al. (2023), between 2000 and 2020, only two scientific journal articles investigating drama focusing on students as active participants in science in upper secondary school were published, and one of these is included in this dissertation (Paper II). The other study addressing chemistry was a quantitative study, investigating how the use

of drama for learning chemistry affected student achievement and motivation in a group of tenth-grade students in Israeli schools. The topics were about conceptual understanding dealing with chemical reactions, light, and photosynthesis, based on pre- and post-intervention (Najami et al., 2019).

### Summary

In drama activities in science education, students may be enabled to process subject content together with their peers and teachers in a playful format. By bringing scientific knowledge to life through drama in line with Vision I (Roberts, 2007) and environmental issues in line with visions II and III (Roberts, 2007; Sjöström & Eilks 2018), teachers may create a more engaging and immersive learning experience for students. This approach thus holds the potential to help students develop a more nuanced understanding of the subject matter and gives them a sense of ownership and agency in their learning journey. However, using drama for teaching science in general and chemistry in particular has not been thoroughly investigated in upper secondary school.

## Aim and overarching research questions

The aim of this dissertation is to advance knowledge on how different forms of drama in upper secondary chemistry education can support students' learning in chemistry, spanning from disciplinary to humanistic perspectives, and how the drama may be designed to achieve that purpose. More specifically the dissertation targets how creative drama and process drama can support students' learning in relation to visions I, II, and III. It encompasses two overarching research questions targeting learning of non-spontaneous chemical concepts (Vygotsky, 1934/1999) in the context of teaching electronegativity and chemical bonding, and students' learning of wicked problems in the context of teaching about plastics:

- In what ways can creative drama support students' conceptual learning of electronegativity and chemical bonding in upper secondary chemistry education?

- In what ways can process drama support students' learning about wicked problems in upper secondary chemistry education?

The overarching research questions are addressed in papers I-IV and investigated in two different design-based research projects: Project 1 and Project 2.

## Outline of the dissertation

After the introduction, Chapter two provides an overview of previous research on chemistry education followed by Chapter three that presents previous research on drama in science education relevant for this dissertation.

In Chapter four, the theoretical framework are presented, where a mutimodal perspective are connected with a sociocultural perspective. The theoretical concepts that have been used in the analyses of the data are also described.

Chapter five delves into the methodology and research design for the empirical analysis underpinning this thesis. This chapter outlines the details of the two projects, including the specific empirical settings, the participants engaged in the research, the cyclic process employed in the projects, and the various forms of participation throughout the research process. Furthermore, this chapter describes how the data was generated, transcribed and analyzed as well as reflections on the methodological and ethical considerations taken into account throughout the research process.

Chapter six provides a summary of the four papers in the dissertation. In Chapter seven, the overall findings of papers I–IV and how they relate to the main goal and research questions of the dissertation are discussed, followed by implications for learning through drama in upper secondary chemistry education. Chapter eight is a summary of the dissertation in Swedish.

# 2. Previous research on learning in chemistry education

In this chapter I provide an overview of previous research on learning in chemistry education spanning from research on conceptual understaning in chemistry education to humanistic approaches to teaching chemistry, relevant for this dissertation.

## Previous research on conceptual understanding in chemistry

Previous research reveals that students experience the subject of chemistry as abstract and difficult to understand (Gräber, 2011). One reason for this has to do with challenges regarding students' conceptual learning. In particular, the nature of the language of chemistry has received attention in the research on chemistry education. In fact, the language of chemistry is considered to be so multifaceted that it has even been given its own term – "chemish" (Markic & Childs, 2016) – which can be compared to Rundgren's (2006) Swedish equivalent of "talking biochemish". Markic and Childs (2016) emphasise that the problem with "chemish" is that it differs markedly from the mundane language students use in their everyday lives. For example, in "chemish" many words originate from Greek or Latin and seem foreign to the majority of students (e.g., electrolysis, synthesis). In addition, the same words can have different meanings in everyday life compared to when they are used in a specific scientific context (e.g., matter, solution, element). However, the challenges of learning chemistry do not only pertain to the learning of new words, students are also expected to be able to use and interpret a variety of models and symbolic representations to develop their conceptual understanding (Taber & Coll, 2002). Another reason learning chemistry is challenging for many students is that the subject involves what Johnstone (1982; 1991) describes as multilevel thought.

## Multilevel thought in chemistry

According to Johnstone (1982; 1991), multilevel thought in chemistry refers to the handling of different types of chemical concepts at different levels, simultaneously. For example, students are expected to learn to move between *sub-micro level* and *macro level* to explain which bonds are broken when water boils (changes from liquid to gas). Johnstone illustrated his idea with a simple figure showing a triangle with vertices labelled "macro", "sub-micro" and "symbolics" (see Figure 2). The macro level represents the properties and phenomena of chemical substances that can be observed with our senses (e.g., phases and colours), the sub-micro level represents what we cannot observe with our senses (e.g., particle units such as atoms, molecules, ions, and electrons), and the symbolic level includes symbols for describing substances and particles (e.g., chemical formulas and chemical reactions). Johnstone (1991) argued that rather than focusing teaching on one point, or even along one side of the triangle, chemistry teaching often ends up inside the triangle where students are expected to master all three levels at once. The review of research in the field by Harrison and Treagust (2002), in line with Johnstone, shows that students have particular difficulties in moving between the different levels of organisation.

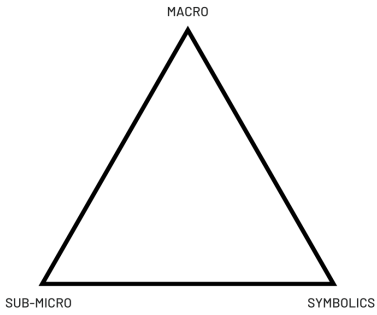



Figure 2. The chemistry triangle, multi-level reasoning required to learn chemistry. Adapted from Johnstone (1991, p. 78).

Over the years, Johnstone's model has been developed and reconceptualised in various ways. Taber (2013) developed the model in two ways. First, by adding an experiential level to the model, representing what we experience with our senses that can be explained with everyday words. Second, the symbolic level is integrated into the other two levels because the symbolic language is used to represent and communicate concepts and models both on the macro and sub-micro level. Figure 3 shows Taber's (2013) developed variant of the chemical triangle where reconceptualisation (represented by the arrows) between the everyday language and formal representations of conceptual understanding of the subject takes place at two different levels: sub-macro level and sub-micro level.

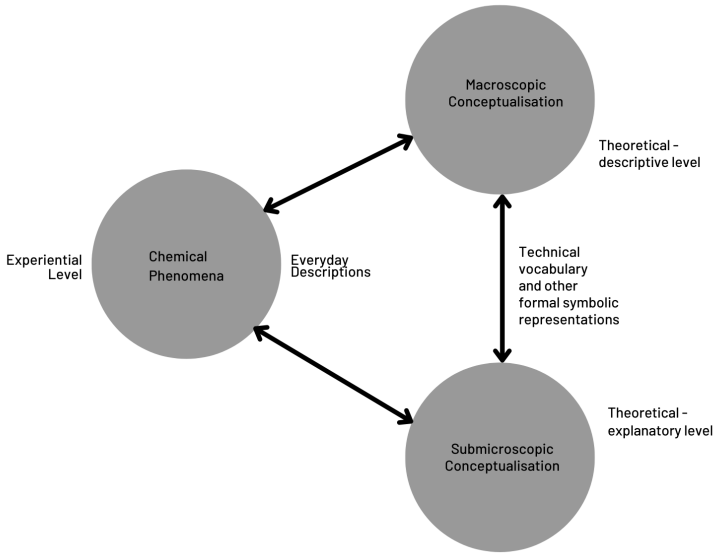



Figure 3. Taber's developed variant of the chemical triangle. Adapted from Taber (2013).

Students often use one form of representation, usually macro, for example, by describing what they can measure, hear, or see, and have difficulty moving between different forms of representation when asked to describe and explain a chemical phenomenon (Kozma & Russel, 1997). To make sense of macro-level chemical observations, they have to use sub-micro-scale models (Oversby, 2000). Such models are needed to make "the invisible arrangements of atoms and molecules visible", that is, the models need to describe or explain macro-level observations with sub-micro models (De Jong et al., 2013; Harrison & Treagust, 2002; Wu, 2003). In chemistry teaching, transitions between sub-micro and macro representations should be explicitly conveyed to students (Othman et al., 2008) and visualised in different ways (Gilbert & Treaugust, 2009). Often, the sub-microscopic level is represented by models in the form of pictures of molecules and atoms in textbooks, digital simulations (Chamberlain et al., 2014; Patron et al., 2024), and other visual representations in the classroom, as well as physical molecular models representing atoms and bonds, which in turn are used to explain phenomena at the macro level of chemistry. In particular, in the area of chemical bonding, a variety of models are used where students are expected to interpret and use different types of symbolic representations (Taber & Coll, 2002) and mastery of chemistry in this area can be understood as students' ability to move between different levels of organisation (Hultén et al., 2020).

## Chemical bonding and electronegativity

A substantial amount of research in chemistry education has examined students' ability to construct explanations and express their understanding of core chemical concepts (e.g., Taber, 2009; Taber & Coll, 2002; Coll & Treaugust, 2003; Qian et al., 2023), where some of the most central concepts are related to chemical bonding and electronegativity (e.g., Hunter et al., 2022; Unal et al., 2006).

Learning chemical bonding involves multilevel thought where the students are expected to move between different forms of representation. To develop an understanding of the relationship between the particulate nature of matter and the macroscopic properties of the substances, the students need to distinguish between intra- and intermolecular bonding (for example, that intermolecular bonds are broken when substances melt or boil) on a sub-micro scale. To understand intermolecular bonding, students need to master, distinguish, and relate to various concepts concerning chemical bonding such as how intramolecular covalent bonding and ionic bonding differ from intermolecular bonding, and understand what is meant by electronegativity, the polarity of the bond, and how the polarity of the bond is determined (Henderleiter et al., 2001).

Several studies from different countries describe students' difficulties understanding chemical bonding (Bergqvist & Chang Rundgren, 2017; Nahum et al., 2010; Nicoll, 2001; Taber & Coll, 2002). Taken together, these studies reveal that students who have not understood chemical bonding in upper secondary school are likely to have difficulty understanding chemical bonding in higher education (Burrows & Reid Mooring, 2015; Nahum et al., 2010; Nicoll, 2001).

In this dissertation, I have chosen to focus on the basic tenets of chemical bonding for upper secondary chemistry: the *particulate nature of matter*, *distinguishing between intra and intermolecular bonding*, *hydrogen bonding*, *electronegativity,* and *polarity.*

*The particulate nature of matter.* Othman et al. (2008) showed in a research review that students' difficulties in understanding the particulate nature of matter is due to the fact that they do not understand the relationship between the particulate form of matter and the macroscopic properties of the substances. As described above, several studies discuss students' difficulties in switching between different levels of representation (De Jong et al., 2013; Gilbert & Treagust, 2009; Harrison & Treagust, 2002; Seifeddine Ehdwall & Wickman, 2018). For example, students describe the boiling of water as a change from a liquid to gas phase on a macroscopic level, but they cannot describe what happens on a sub-micro level.

*Distinguishing between intra- and intermolecular bonding.* The students' difficulty in understanding the difference between intra and intermolecular bonding is expressed at the symbolic level. De Jong et al. (2013) describe, for

example, how students often represent the water molecule as a diatomic molecule of hydrogen and an atom of oxygen or that the water molecule is symbolised as three separate atoms. Othman et al. (2008) showed, in a study of diagnostic tests on students aged 15–16, that many of the students had difficulty distinguishing between intra- and intermolecular bonding, because, for example, they did not show that intermolecular bonding was broken when substances melt or boil, and that the students perceived the covalent bond as weak, which is consistent with several studies regarding chemical bonding in upper secondary school (Henderleiter et al., 2001; Peterson & Treagust, 1989; Schmidt et al., 2009).

*Hydrogen bonding.* Schmidt et al. (2009) examined German high school students' knowledge of intermolecular forces and their ability to use these to predict the relative boiling points of organic compounds. The most prominent explanation among the students was that boiling involved breaking covalent bonds. Schmidt et al. (2009) found that students used alternative models for hydrogen bonds, which limited hydrogen bonds to bonds solely between oxygen and hydrogen atoms. Henderleiter et al. (2001) revealed in a study of second-year undergraduates in a two-semester organic chemistry course at a US university, that the students still held concepts about hydrogen bonding that did not match the scientific discourse. For example, that when substances boil, it is covalent bonds not hydrogen bonds that are broken.

*Electronegativity and polarity.* The difficulties in distinguishing between intra- and intermolecular bonds have been interpreted as a lack of understanding of the concept of electronegativity – the ability of atoms to attract electrons from other atoms (Harrison & Treagust, 1996; Nahum et al., 2008; Taber & Coll, 2002). Nicoll (2001) revealed in an interview study that chemistry students in their first year at university had difficulties explaining the concepts of electronegativity and polarity in line with the scientific discourse. Students linked electronegativity primarily to ionic compounds – the ability to accept or give up electrons instead of attracting electrons. Some students seemed to know the concept of polarity but did not associate it with electronegativity. The results showed that some of the students could explain the concepts of electronegativity and polarity in line with the scientific discourse, but they could not situate them in a context. This is in line with findings in Burrows and Reid Mooring's (2015) study where students' conceptual connections regarding the concepts of electronegativity and polar covalent bonding were examined. Using concept maps and interviews where students in the United States were asked to "think aloud" in their first general chemistry course at university, they revealed the students' lack of understanding of electronegativity and polar covalent bonding. For example, students emphasised that the number of valence electrons determined the atom's electronegativity, that the larger the atom, the greater its electronegativity, and that electronegativity had no effect on chemical bonding. In addition, the low-achieving students made no or incorrect connections between the concepts of electronegativity and polar bonding.

In sum, previous research reveals that students have difficulty moving between the different organisational levels of chemistry, especially in the field of chemical bonding and electronegativity. Chemical bonding has proven to be a topic in upper secondary school that students have difficulty understanding. The students tend to confuse the central concepts, which makes it hard for them to grasp the basic tenets of chemical bonding. Consequently, new educational approaches are required to enhance students' learning of chemical bonding and electronegativity.

# Previous research on humanistic approaches in chemistry education

In this dissertation, I also explore the challenges related to the humanistic approaches of chemistry education, which have developed in slightly different directions within science education. The research literature on the humanistic dimensions of chemistry education emphasises slightly different aspects of humanistic approaches in chemistry education –problem-oriented approaches, socioscientific issues (SSI), systems thinking, sustainability and green chemistry etc. Taken together, all these issues involve humanistic approaches to chemistry education and are chosen as topics because they are controversial in nature and have the potential to impact on students' lives and society (e.g., Chang Rundgren & Rundgren, 2010). Hence, a goal in chemistry education is to understand how society deals with these issues and to encourage individuals to participate in societal debates and decisions around them (Eilks et al., 2013; Sjöström & Eilks, 2018).

## Socio-Critical and Problem-Oriented Approaches to Chemistry Teaching

Over 20 years ago, Eilks (2002) presented a new conceptual approach to chemistry teaching that promotes a humanistic approach in line with Vision III, which he called a *socio-critical and problem-oriented approach to chemistry teaching*. This approach has been used, through Participatory Action Research (Eilks, & Ralle, 2002), to develop and refine lesson plans in Germany for several years. Most studies have used a pre- and post-test methodology and have been conducted with students in grades 10 or 11 (15–16 year olds) in secondary school chemistry classes and deal with a variety of issues such as biodiesel (Eilks, 2002), light crisps (Eilks et al., 2008), shower gels (Marks & Eilks, 2009), bioethanol (Feierabend & Eilks, 2011), plastics (Burmeister & Eilks 2012), doping (Stolz et al., 2013), and tattoos (Stuckey & Eilks, 2014). In brief, the refined teaching approach follows five steps: (1) textual approach with problem analysis; (2) clarification of the chemistry background in a lab environment; (3) resuming the socio-scientific dimension; (4) discussing and

evaluating different points by debating; and (5) conducting a meta-reflection exercise (see Marks & Eilks, 2009).

Experience from the various lesson plans shows that it is pivotal that "the teaching approach must start with societally-relevant, current, authentic and controversial issues from within society", and simultaneously "must have the potential to allow the learning of basic chemistry content knowledge" (Marks & Eilks, 2009, p. 234). To facilitate group discussions and promote open decision-making processes (step 4, above), roleplays were used in several of the studies. For example, in the form of "talk shows" (Eilks et al., 2008; Stolz et al., 2013) and decision-making processes in parliamentary committees (Feierabend, & Eilks, 2011). Overall, results from the studies revealed that students perceived school chemistry as being relevant for the different contexts, and especially the controversial and authentic debates (where the intensive discussions continued even after the lessons) was very motivating (cf. Anker-Hansen & Andrée, 2015; Marks & Eilks, 2009). In brief, this teaching approach has the potential to increase students' interest in chemistry teaching as well as improve their argumentation skills (Eilks et al., 2008), thus promoting both scientific literacy (Marks & Eilks, 2009) and understanding of sustainability issues (Burmeister & Eilks, 2012).

There is also research in the area of sustainability issues where students' argumentation skills and critical thinking have been explicitly examined in relation to chemistry-focused socio-scientific issues. For example, Suephatthima and Faikhamta (2018) conducted classroom action research in a secondary school in Thailand, and investigated chemistry students' argumentation skills in relation to a Thai oil fund that had caused controversy. Suephatthima and Faikhamta (2018) argue that debating on topics related to this issue was beneficial for the students because it allowed them to practise and enhance their ability to reason. They also highlighted the significance of using evidence to construct a strong and trustworthy argument. In Spain, López-Fernández et al. (2022) introduced sustainability issues regarding plastics into chemistry teaching in Grade 8. Through critical analysis of information, argumentation, and decision-making about plastics, which also included a roleplay about the use or non-use of disposable plastics and the adoption of a hypothetical law, the students developed their critical thinking skills.

There is also research focusing on relevance within the area of sustainability in chemistry education. For example, in addition to using a lesson plan based on the socio-critical and problem-oriented approach to chemistry teaching framework, Stuckey and Eilks (2014) also used a relevant framework (Stuckey et al., 2013) to develop lesson plans in chemistry teaching about tattoos. Pernaa et al. (2022) developed a context-based learning activity through a contemporary research context involving ionic liquids in the dissolution of cellulose, using a relevant framework (Stuckey et al., 2013). Pernaa et al. (2022) conducted design-based research with future chemistry teachers that included practical laboratory work, and found that the ionic-liquids context offers great possibilities for supporting sustainable chemistry education and

students' individual, vocational, and societal levels of relevance (see Stuckey et al. (2013).

Research has also examined contexts where methods similar to authentic community approaches have been used by chemistry students and teachers. For example, Vogelzang et al. (2020) used a scrum methodology increasingly used in educational contexts. This method aims to support students in their learning when working on complex, real-world tasks. The teacher takes on the role of the "product owner" and presents a complex, real-world question to their students in a formal manner. The students then work collectively in small groups through specific exercises and assignments to answer the real-world question. The authors suggests that this approach, using chemistry-focused socio-scientific issues, offers opportunities for teachers to enhance and enrich their teaching practice.

Further, Çalık, & Wiyarsi, (2021) conducted a systematic review of the research papers on chemistry-focused socio-scientific issues that included 65 theoretical as well as interventionist and descriptive research papers published between 2008 and 2020. In brief, their review revealed that the research created "a need-to-know" among the students to make abstract chemistry concepts meaningful and relevant for daily life. A significant percentage of the research papers in the research review focused on chemistry-related issues that have societal, environmental, economic, and health impacts. However, although these papers touch on important ethical, moral, and emotional aspects, only a few of them specifically addressed these dimensions within the context of chemistry.

## Complex sustainability issues

In Sweden, Dudas et al. (2018; 2023) examined students' discussions about complex sustainability issues in secondary chemistry education. The students worked with sustainability issues concerning batteries and organic environmental toxins in everyday products. Dudas et al.'s (2018) found that students' ability to pay attention to the complexity of sustainability issues increased if the activity explicitly requested conflicting perspectives and values, included chemistry content knowledge based on frontier research, and that knowledge of chemistry was requested in the students' reasoning. These findings are in line with Marks and Eilks's (2009) study. Based on the implications of the aforementioned study, Dudas et al., (2023) conducted another study in secondary chemistry education where students' discussions about metabolism and how different factors affect the level of sugar in the blood were investigated. Dudas et al. (2023) revealed that two different kinds of considerations emerged in the students' discussions: factual and exploratory. They suggest that it may be beneficial to design chemistry teaching about complex sustainability issues around real-life problems. This approach allows students to face the unpredictability needed to help them better understand the complexity and exploratory nature of chemistry, and might also increase student participation

in chemistry education. Additionally, the activity was not explicitly designed to focus on the societal or moral perspectives related to metabolism, such as the concepts of obesity or diabetes. Dudas et al., (2023) suggest that this lack of consideration of moral aspects might explain the absence of discussions in that area in the study. However, they propose expanding the activity to include these moral perspectives in the future.

In a theoretical paper, Yavuzkaya et al. (2022) highlight the importance of working with what they call controversial socio-chemical issues in chemistry education, and suggest the concept *ChemoKnowings*, which they describe as "knowings that matter meaningfully to the student and connect the student to themselves and to the world, and as a consequence confer ethical compass and promote an ethics-oriented agency" (p. 15). They argue that ChemoKnowings may also be connected to and develop a critical stance on modern society focusing on an eco-reflexive approach, described by Sjöström et al. (2016) as "a critical stance towards the modern risk society, an understanding of the complexity of life and society and their interactions, and a responsibility for individual and collective actions towards socio-ecojustice and global sustainability" (p. 321). Similarly, Guerrero and Sjöström (2024) emphasise the necessity of acknowledging the political, ethical, emotional, cultural, and economic aspects that are intertwined with environmental and science-education-promoting critical scientific and environmental literacies – a prerequisite for tackling global sustainability challenges.

## Systems thinking

Finally, recent research advocates the introduction of systems thinking – to connect chemistry and society in a holistic perspective – which can be considered to embrace humanistic approaches in chemistry education and research (cf. Dessen Jankell, 2023). Orgill et al. (2019) emphasise that as a response to our unsustainable society, there is a need to educate

> "future chemists to be able to think holistically and systemically about chemistry in order to maximise resource efficiency while minimising hazards and pollution. We also need citizens who can make evidence-based decisions about science-related policy and about how they will interact in and with the planet" (p. 2721).

Orgill et al. (2019), like Mahaffy et al. (2018), compare systems thinking with "forest thinking" – studying the behaviour of a system as a whole rather than concentrating solely on its parts – where the forest represents the whole system, which is made up of its parts – the trees. A teaching that focuses on systems thinking goes beyond disciplinary and context-based learning (Mahaffy et al., 2018; Orgill et al., 2019; Talanquer et al., 2020) towards a more holistic approach where chemical processes are not seen as isolated but as part of

larger systems, including societal and environmental systems. In this way, students "can see the forest while not losing sight of the trees" (Mahaffy et al., 2018 p. 2).

There are several initiatives to promote systems thinking in chemistry for sustainability. MacDonald et al. (2022) created an interactive digital learning tool (https://planetaryboundaries.kcvs.ca) related to the Planetary Boundaries framework. This tool employs interactive visualisations to enhance students' comprehension of Earth system sustainability challenges and to link chemistry processes and chemistry concepts to sustainability science. For example, "the nature and quantities of novel entities such as plastics, CFCs [chlorofluorocarbons], and other anthropogenic pollutants introduced to the environment for the novel entities process" (p. 3532). The Planetary Boundaries interactive learning tool has been developed through several studies on both students and educators. For example, it has been used in introductory general chemistry courses and senior level environmental chemistry courses at an undergraduate university in Canada, at a Midwestern US university in a general chemistry class, and with chemistry educators in both secondary and postsecondary chemistry education in Australia and Taiwan. MacDonald et al. (2022), acknowledging the importance of systems thinking, emphasise that students and educators perceive the Planetary Boundaries interactive learning tool as encouraging and suggest further education research to discover its effectiveness on learning in sustainability chemistry. Another resource for teaching systems thinking in sustainability science chemistry education has been developed by Vuorio et al. (2024). They examined how concept maps based on authentic narratives can be structured to teach systems thinking. Based on interviews with chemists from academia or industry, involved in sustainability-related research, they conducted a qualitative content analysis which revealed key elements of systems thinking relevant for developing teaching modules concerning systems thinking in science education.

## Summary

Previous research reveals that chemistry teaching, in addition to including subject-specific content, should ackknowledge the roles of chemistry in society and its risks. Overall, previous research shows that teaching should include societally relevant, controversial issues that are current in society. Although several studies have enabled abstract chemical concepts to become meaningful and relevant for daily life, oftentimes important ethical, moral, and emotional aspects seem to be missing.

In sum, research on challenges in chemistry teaching suggest that students need support both in developing their conceptual understanding, and in understanding how chemistry resources can be useful from a broader holistic perspective – which includes ethical, moral, and emotional aspects. In this sense,

there is a need to develop chemistry teaching both from a disciplinary approach in line with a Vision I perspective, but also from a humanistic perspective that involves both visions II and III, acknowledging metachemistry (Sjöström, 2019), so that students "can see the forest while not losing sight of the trees" (Mahaffy et al., 2018). In this dissertation, I investigate possibilities for developing the teaching of chemistry in upper secondary school with the help of drama that can support students' learning in relation to "the trees (conceptual approach) *and* the forest (humanistic approach)".

# 3. Previous research on drama in science education

This chapter first gives a broad outline of previous research on drama in science education, followed by research on how drama in science education has been used in different ways depending on the purpose to be achieved: drama for teaching science with a *disciplinary approach*, for supporting learning of *scientific concepts,* and drama for teaching science with a *humanistic approach*, supporting learning of the *nature of science (NOS)* and *science in society*. However, to date, the literature in this field relating specifically to using drama in chemistry education for students in upper secondary school is notably limited, especially concerning the humanistic approach. Acknowledging this lack of research, and the similarities between science subjects, research in this chapter includes an overview of how drama has been used in science education.

## Overview of previous research on drama in science education

The use of drama in science classroom teaching was first documented by educators and scholars in England in the 1980s, most likely motivated by achievements in the humanities (Dorion, 2011). Already by the mid 1980s, Metcalf et al. (1984) had incorporated drama into science and had students in the role of atoms in various states of matter to teach particle physics. The authors concluded that the use of drama as a teaching method could help students gain a better understanding of scientific concepts and enhance their learning experience.

Over the last 20 years, three research reviews have been conducted that solely (Namyssova et al., 2023; Ødegaard, 2003), or partially (Lee et al., 2015) focus on the use of drama in science. Ødegaard (2003) conducted what she calls a non-conventional research review of different empirical science and drama projects. Some of the projects were Ødegaard's self-experienced activities not reported in written papers, internet-resources, or informal written pieces. The publications included in the review spanned the years 1984 to 1998 and Ødegaard (2003) summarised her overview in a model categorising different drama forms based on different approaches in the classroom that

could contribute to three dimensions of knowledge in line with the goals of science education, namely *products of science/scientific concepts*, *science practices/nature of science* (NOS), and *socio-scientific issues/science in society* (see also Ødegaard, 2023). She also presents them in order of increased dramatic freedom – structured, semi-structured, and exploratory. Figure 4 shows a developed version of Ødegaard's model (Ødegaard, 2003; 2015; 2023), which is widely used in today's educational research. The structured drama is essentially initiated and guided by the teacher and has more features of theatre, where something is to be communicated to an audience (e.g., a teacher, peers, or parents). The structured drama usually involves a small group of students dramatising a scientific concept or process. The exploratory drama is more initiated and controlled by the students where the participants are also the audience. The participants take on different roles with a certain motivation, opinion, or attitude. The semi-structured drama has elements of both structured and exploratory forms. Common to all categories is that the teacher's planning and guidance are pivotal for the activity to be meaningful for the students (cf. Braund, 2015).

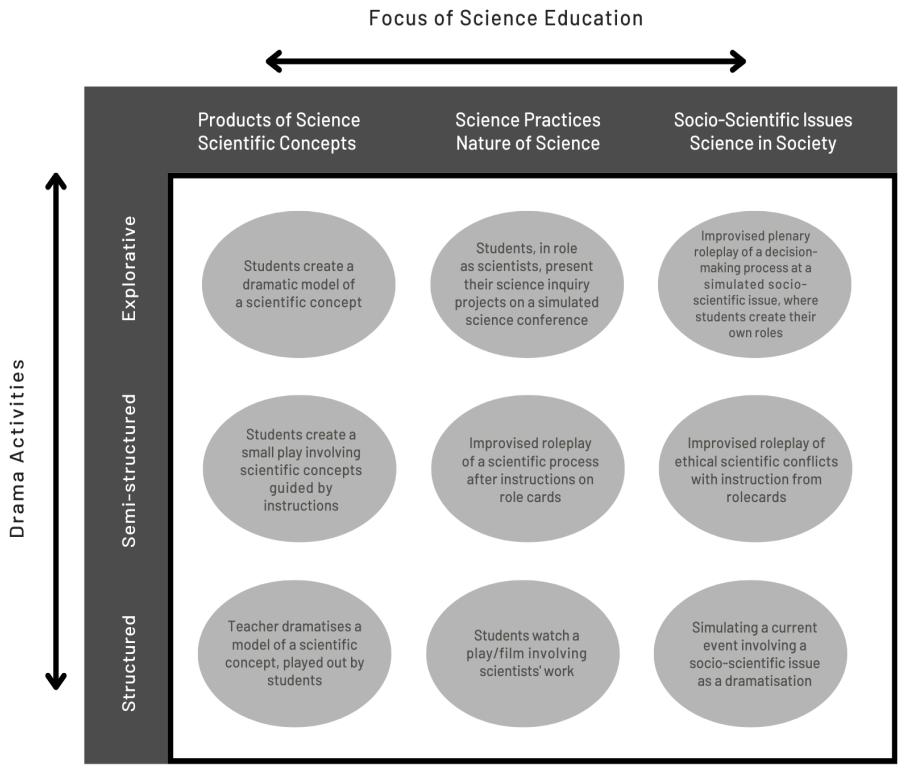



Figure 4. Ødegaard´s model of how drama can be used in science teaching. Adapted from Ødegaard, (2003, 2015, 2023).

Lee et al. (2015) conducted a meta-analysis using drama in science and other subjects covering 47 quasi-experimental or experimental research articles, published between 1985 and 2012. The findings revealed that drama-based pedagogy had a positive, significant impact on achievement outcomes in educational settings, especially when drama was integrated into English language arts or science curricula. However, few studies had been conducted in science education, and qualitative studies and case studies had not been included. They pointed out in their conclusion that instead of claiming that all drama-based teaching methods are effective, there is a need to develop ways to measure and understand the impact of specific drama approaches in the classroom.

Recently, Namyssova et al. (2023) conducted a review of empirical studies incorporating drama into science teaching published in peer-reviewed research journals (i.e., dissertations and book chapters were excluded) between the years 2000 and 2020. Like Lee et al. (2015) and Ødegaard (2003), they found that the majority of studies were carried out in pre-primary and primary school settings, and some in lower-secondary and upper secondary schools. This implies that the use of drama in secondary education may not be as well-established as it is in elementary education, indicating a need for additional study at the upper secondary levels.

In brief, the research reviews show that drama has been used in science teaching since the 1980s, but the research is scarce and has mainly been conducted in the lower grades. According to Ødegaard (2003), drama in science education can contribute to learning in three key areas with different purposes for science education: drama for teaching conceptual understanding, drama for teaching NOS, and drama for teaching science in society. Below, previous research concerning these different purposes for using drama in science education is presented, where NOS and science in society are described in the context of humanistic approaches.

## Previous research on drama for teaching conceptual understanding in science

When drama is used for the purpose of supporting students' conceptual understanding, the students are encouraged to dramatise scientific concepts (see Figure 4). Students, for example, create their own bodily scientific models, referred to as physical simulations where students visualise non-human entities. A distinctive feature of drama for teaching conceptual understanding in science education is that the activity enables students to learn from and with each other (Butler, 1989, Dorion, 2009: Hendrix et al., 2012). Letting the students in a drama activity use each other as learning resources can thus be a way to promote science learning (Abed, 2016; Hendrix et al., 2012). Previous

research (cf. Ødegaard, 2003) shows that the teacher guides the students during the drama activity to varying degrees – from very structured to more exploratory forms (see Figure 4).

In the physical sciences, Braund (1999) conducted a study on 37 undergraduate primary teacher trainees in environmental science dealing with energy and energy resources. The students improvised bodily visualisations of circuit electricity, its generation, and supply, which were presented to their classmates. The presentations were videotaped and used to analyse the drama techniques applied. In a questionnaire, almost all students (95%) answered that their understanding of science used in the research lesson had improved, and almost half (49%) reported that gains were major or significant. Further, the students expressed in interviews that they had not only learned from their own participation in drama , but also from watching others' enactments. Hendrix et. al. (2012) conducted a study on creative drama that focused on sound physics and solar energy in fourth and fifth grade elementary school. Students in the group that performed creative drama demonstrated higher learning gains than the students in the non-drama group, and the conclusions were that "[c]reative drama was an effective strategy to increase science conceptual learning" (p. 823).

Brandscombe (2019; 2023) conducted a case study in the classroom over a four-week period with third-grade students in the United States. The students had to bodily visualise concepts about the solar system in the form of an established drama convention tableau, described by Brandscombe (2023) as: "a silent image created by a group of people holding still gestures to express the *essence* of an experience or concept. The literary equivalent of this is a main idea, which summarises the key message of the text" (p. 137). After listening and reading a short informative text about the solar system, the students had to collaborate in groups and decide on a key concept which they then had to visualise in the form of a tableau. The students also had to write in role from the perspective of the role they had represented in the tableau. The collected data included audio recordings, photographs of the final tableau representations, and texts from writing in role. Brandscombe (2019) emphasises that "the visualisation of scientific concepts strengthened the understanding about the solar system for those who devised the representations *and* those who viewed them" (p. 7, italics in original).

In a biology education context, Cokadar and Yılmaz (2010) conducted a quasi-experimental study with pre- and post-tests in Turkey with 45 seventh-grade students, aged 12–13 years. The group that performed creative drama had significantly improved the scientific concepts of ecosystems, food chains, and matter cycles that had been covered in the research lesson. In South Africa, Braund and Ahmed (2019) conducted a quasi-experimental case study of two students' teachers using drama and non- drama (control-group) methods to teach Life Science (Biology) to students in grade 7, aged 12-13 years. Pre-tests (schools' examination) and post-tests were carried out with the students in both groups. The interventions were about the human ear and structure of

the cell nucleus, which were video and audio recorded. In addition the students' teachers were interviewed subsequent to the intervention. The findings revealed that in both cases test outcomes were in favor of drama interventions. Braund and Ahmed conclude that "over-directing students can limit their capacity to experience and make links from the drama to biological content" (p. 419), and to plan the role-play activity, a thorough knowledge of the topic is required, as well as the role play must be suitable to the content, and connections made clear between enacted actions and concepts, sequences or processes.

In a chemistry education context, the students have been offered, guided by the teacher, to visualize atoms, molecules and the different phases of the substances with their own bodies. For example, Arieli (2007) conducted a study in Israel with 130 students aged 11–12 years. The students in a control group and the students in the group that performed creative drama completed written-form and interview pre- and post-tests. The findings revealed that conceptual development in the group of students who performed creative drama had improved. In Abed´s (2016) study based on pre- and post-tests, 13-year-old seventh-grade students from a public boys school in Jordan bodily visualised the different forms of aggregation – what Abed (2016) called modelling – of substances, which resulted in the students improving their understanding of chemical concepts. In addition, the students who performed modelling displayed an increased positive attitude towards learning in science. Najami et al. (2019) conducted a study that dealt with conceptual understanding of chemical reactions, light, and photosynthesis. One hundred and eighty students aged 11 (middle school) participated in the study with a pre- and post-intervention. The students who were taught using drama were found to have higher scores on the post-tests than the control group. In addition, the results revealed higher motivation to learn chemistry in the group of students who performed drama. Saricayir (2010) investigated the effects of structured drama on the teaching of electrolysis of water to 40 students aged 12–13 (7th grade) in a Turkish school. Facilitated by the teacher, the students bodily displayed the formation and decomposition of water in a structural form. In the study, a randomised pre-test and post-test control group design was used with the results revealing that the drama group had significantly improved the scientific concepts that had been covered. Saricayir (2010) suggests that the drama "promoted student conversation and the use of language associated with chemistry" (p. 185).

Turkka and Aksela (2022), explored two cases in which pre-service teachers (without previous experience in using drama), facilitated drama activities with high school students (aged 16–18). The pre-service teachers designed an activity related to chemistry, which their students then had to perform. In both cases, the students were given non-human roles, and enacted physical simulations in a structural form, including mime, narrated by the pre-service teachers. In the first case, the students visualised protein structures related to a boiling egg, and in the second case they visualised atoms and ions in an enactment of galvanic cells. In-depth interviews with the pre-service teachers revealed

that they experienced learning opportunities for the students but also challenges when using drama. For example, the drama activity enabled the students' scientific talk about the topic, but a challenge was that the students in their spontaneity used bodily models not in line with the scientific discourse. The pre-service teachers tried to avoid this spontaneity by providing instructions that were as detailed as possible.

In England, Otter (2020) studied how A-level chemistry students' (aged 16–18) bodily visualisations of the particulate entities involved in organic chemical reactions, in what she called simulation roleplays, affected teaching and learning of organic reaction mechanisms. In a quasi-experimental intervention conducted in three phases, the participating students were divided into control groups using practice examination-style questions, and the other group using simulation roleplay. The drama group were tasked with playing out an organic reaction using written instructions and material provided by the researcher, which later were performed for the whole class. In the control group, the students worked on answering examination questions. A-level Chemistry exam questions were used as post-tests, and the results showed no statistically significant difference between the two groups' scores. However, analysis of the answers to a diagnostic question revealed a statistically significant difference in favour of the students' who performed roleplays. Otter (2020) suggests that, unlike traditional teaching methods, the use of simulation roleplay can contribute to a deeper learning of organic reaction mechanisms in chemistry education. This is in line with the aforementioned previous research of Metcalf et. al. (1984) which showed that students who had been allowed to use bodily visualisations of atoms were much better at explaining and understanding concepts than groups that had not.

In sum, previous research on drama for teaching conceptual understanding in science, reveals that physical simulations are referred to in different ways – such as creative drama, structured drama, roleplay, mime, improvisation, modelling, and simulation. In this dissertation, I have chosen, in line with previous research on drama in science education, to call these physical simulations *creative drama* (e.g., Abed, 2016; Arieli, 2007; Hendrix et al., 2012). Although research on using drama for supporting conceptual understanding in science education has mainly been conducted with younger students (Lee et al., 2015; Namyssova et al., 2023), the research overview shows that there have also been some studies conducted in chemistry education on students aged 16–18 (Otter, 2020; Turkka & Aksela, 2022). In addition, the research suggests that drama can provide students with opportunities to "talk chemistry" with each other while having the opportunity to both receive and use feedback in an interaction with the teacher. Hence, the teacher's role in linking the drama activity to the scientific discourse is very important, the students' learning can be made visible, and teachers get the opportunity to gain insight into the students' conceptual reasoning (Hendrix et al., 2012). The overview of research shows that creative drama may support students' conceptual understanding in science education and that the drama activities may also contribute

to deeper learning. Further, a strength identified in the research is that creative drama may increase the understanding of scientific concepts for both low-, average-, and high-achieving students (Abed, 2016; Aubusson et al., 1997). The majority of research has been based on a quantitative pre- and post-test methodology, in some cases supplemented with qualitative analysed interviews, which shows a lack in the research of investigations into what happens in the actual drama activity in the Chemistry classroom.

## Previous research on drama for teaching science with a humanistic approach

In addition to the disciplinary side of science education, drama is also used for the purpose of supporting learning about the humanistic dimensions in science education. Klopfer and Aikenhead (2022) emphasise the need for students to learn "content from the other domains of humanistic science education, including: the nature of science and scientists, cultural studies, and the multifarious interplay between science/scientists and society" (Klopfer & Aikenhead 2022, p. 490). When using drama for teaching science with a humanistic approach, students and teachers have taken on the roles of human characters, for example, as scientists. In this way, drama is used to promote learning about the nature of science as well as sustainability/controversial issues in science education.

### Drama for teaching about nature of science

To facilitate students' understanding of the nature of science, students are encouraged to take on different roles, such as historical persons or scientists (cf. McGregor, 2021; McGregor & Precious, 2015). Ødegaard, (2003) gives examples such as the trial of Galileo and a fictional trial for blasphemy of Charles Darwin. To date, several studies have investigated how drama could develop students' understanding of NOS through stories about science, and the experience of acting out the lives of scientists. By roleplaying these scenarios, students can better understand the historical context and the challenges faced by scientists during those times (Ødegaard, 2003), and gain better insight into scientific practice (Cakici & Bayir, 2012). For example, acting out the lives of Archimedes, Al-Hasan Ibn Al-Haitham, Newton, and Edison in relation to their work on the development of the concept of light (Boujaoude et al., 2005), and the life stories of Newton and Curie in relation to their scientific work (Cakici & Bayir, 2012). The former study was conducted in Lebanon with 14 students in grades 10 and 11. The latter was conducted in Turkey with younger children (10–11-years-old). Both studies used a pre- and post-test methodology, and the results showed that the use of drama activities gave rise to positive changes in students' NOS views.

Students may also take on the role of an expert and enact scientists conducting a scientific inquiry. This approach, often called process drama, and the *Mantle of the Expert*, was developed by UK-based drama educator Dorothy Heathcote (Heathcote & Bolton, 1994). The students and teachers collaborate as a team to complete a significant task, or mission, for a high-status (fictitious) client. They run into issues or conflicts along the way, either unplanned or instigated by the teacher (Aitken, 2013). Aitken (2013) emphasises:

> The fictional context allows the teacher and students to operate in a dual reality, where learning can be playful and serious, risky and safe, pretend and realistic. There are no real-world consequences for the actions students take, but there are plenty of real- world learnings (p. 42).

Several studies using Mantle of the Expert have been conducted in science education with younger children.

For example, Warner & Andersen (2004) conducted a study with 36 second-grade students (7–8 years-old) in Ohio, USA, to investigate how process drama affected their scientific enquiry and writing. In the study, pre-service teachers in the role of zookeepers and children in the roles of expert zoologists performed an investigation about snails and constructed a "snails manual". The results showed how the second-grade students in the drama-based inquiry group were more deeply engaged in their inquiry, and seemed to observe the snails more accurately than their peers in the traditional inquiry control group.

Through an action research approach in New Zealand and the UK, McGregor et al. (2019), drawing on the Mantle of the Expert framing, explored how children working in role as scientists in process drama could promote understanding of NOS. In the UK, the process drama, conducted with 22 (10-year-old) primary school students, was drawn from the historical and technological context of the work of the American inventor Margaret Eloise "Mattie" Knight (see also McGregor, 2017). It lasted for two hours and involved a series of tasks. For example, the students, in their role as technological scientists, were given the task of creating a bag of various objects using only materials from Victorian times. Data were collected through classroom observations, photographs, questionaries, and reflective focus group discussions with the students. In New Zealand, 27 children (aged 9–11) participated in four lessons where they worked in the role of atmospheric scientists in a company solving a local environmental issue, which concerned the impact of a racetrack on the community (see also Baskerville & Anderson, 2023). The atmospheric scientists had to work in teams and plan an investigation to collect data on greenhouse gases which they then had to use to design a new racetrack. In the study, data were collected in the form of audio-recordings, student artefacts, interviews with students and teachers, and field notes from observations. The findings from both cases revealed that "being in role as a scientist offered learners various opportunities to be agentive, to think and act

scientifically, better appreciate the nature of work that scientists do" (p. 171), which promoted the development of both scientific literacy and understanding of NOS.

Stagg (2020), focusing on learning and attitudes towards plants, investigated the effect of process drama on 108 students (aged 10–11) in four primary schools in the UK. The students took part in the roles of 18th century botany students and were guided by a professional actor acting as the biologist Carl Linnaeus, talking about his life history and his new classification system. Throughout the process drama, which lasted 90 minutes, the students also encountered challenges such as going on a fictional expedition to find a rare plant, but also to classify thirteen potted wild plants in small groups. In this mixed-method study, data from pre- and post-intervention tests indicated improvement in knowledge as well as positive attitudes towards plants. Further questionnaires and interviews revealed that the students' active involvement in the dramatic activities, physical drama games, authentic problem-solving, and their direct encounters with living plants served as important contributing factors to the successful outcomes observed in this research study.

In sum, previous research shows that drama aimed at supporting students' learning of NOS can be conducted productively in different ways – partly by a Mantle-of-the-Expert approach where the students take on roles as experts or researchers conducting scientific investigations, but also letting the students listen to and engage with a story, which then can inspire and motivate them to conduct an investigation linked to the story. However, to date, the research conducted on drama and NOS has mostly involed younger students.

## Drama for teaching about science in society

This section focuses on previous research on drama teaching about science in society. This research covers a range of approaches including different ways of conceptualizing the issues at stake. Notably, the research on drama in science education has framed science in society in terms of controversial and socioscientific issues, sustainability issues or challenges. In the following I provide an overview of the research on drama for teaching about science in society while acknowledging the variety of conceptual frameworks in that research.

### Controversial/Socioscientific issues

In the Netherlands, Verhoeff (2017; 2023) investigated how drama enhanced students' engagement in socioscientific issues by having students collectively design a drama activity which was then presented to their peers. In the first study (Verhoeff, 2017), 22 academic students from various science disciplines attending an elective graduate course on human enhancement participated in writing a script about (future) issues around neuroscience (e.g., memory chips, smart pills, and brain-computer interventions). Data were collected with questionnaires before, during, and after the intervention and class discussions and

enactments were videotaped. The findings revealed that the students viewed the socio-scientific issues primarily from a personal and ethical standpoint, rather than considering the technical and economic aspects. The findings, from the students' enactments which focused on every-day contexts, revealed that this "did not prompt students to consider the science aspects of SSIs or draw on science knowledge they had acquired earlier" (p. 124). Verhoeff (2017) interpreted this to mean that students had difficulty crossing the borders between science and drama education. Later, Verhoeff (2023) conducted a similar study in which 58 students (aged 13–14) from two secondary Biology classes participated, although this study was framed by environmental topics selected by the teacher. Several of the topics included chemical content, such as accumulation of pharmaceuticals in water, (micro) plastics in oceans, and the use of pesticides. Class discussions, group work, and enactments were video recorded, and short interviews were held during the intervention. The findings revealed that "involving learners in environmental drama via multiple roles as authors, actors, and audience can stimulate students to consider the complexities of the human impact on our environment and develop a personal and social action perspective for sustainable development" (p. 133). However, the findings also revealed that there was limited time for reflection after each enactment and therefore their peers watching the drama were quite passive. Further, the teacher's role as a guide to help students bridge the fictional and the real world was important for allowing access to a deeper level of knowledge of the science involved in the socio-scientific issue (cf. Verhoeff, 2017).

White and Raphael (2023) describe an interdisciplinary collaborative project about drama for teaching controversial issues in science that started in 2014 and was still active in 2021. The project followed a process drama approach focusing on biology education in the senior secondary years in Australia, and the controversial issue was about stem-cell science and the use of stem-cell therapies. They developed a teaching and learning sequence in collaboration with pre-service teachers, a stem-cell researcher and researchers in science and drama education. The sequence, which is available online (https://contemporaryvcebiology.com/stem-cells/sequence-two/) was developed as a pedagogy for pre-service teachers to apply in their own classrooms, but has also been used for in-service science teachers and academics, and in schools with secondary students. The drama pedagogies of the stem-cell inquiry were divided into different stages that contain a variety of drama conventions, such as creating a tableau to represent a photograph from stem-cell headlines in the media, and for the participants to create their own "as if" video advertisement for a particular stem-cell therapy. In a whole-class roleplay, the participants explore the complexity of the issue in a television debate in the role of different stakeholders with the teacher-in-role as the host of the debate, followed by an out-of-role reflection. The entire workshop ends with reflections and discussions about the learning. Raphael and White's (2023) conclusions from the project are that the social and dialogic nature of drama makes

it a useful pedagogy for teaching upper secondary students about controversial issues, which can promote both empathy and multiple ethical perspectives.

**Sustainability issues**

Based on her experience as a science and drama educator and researcher, Ødegaard (2023) proposes a pedagogical framework of drama for sustainability issues in relation to science education. Inspired by Leinweaver's (2015) storytelling for sustainability, Ødegaard (2023) suggests three levels of sustainability drama that can provide a context for practising key competencies in sustainability education. *Little personal dramas* involve roleplays where personal values and actions are explored, exercising normative and anticipatory competencies. *Middle plenary dramas* involve roleplays with experts negotiating cultural values and practising decision-making. As well as anticipatory competencies, middle dramas deal with systems thinking, and problem-solving competencies. *Big symbolic dramas* involve reflexive presentational plays where sustainability stories are told at a symbolic or mythical level, promoting important questions and imagination about the future. Ødegaard (2023) emphasises that drama facilitates a practice where students can negotiate values and make decisions at personal, interpersonal, and global levels, bringing real-life situations into the classroom.

McNaughton (2004; 2010) examined, over a period of 12 weeks, the use of process drama in sustainability education with students in primary school (students 10–11 years old) in Scotland. The students and teachers took on different roles during the process drama, which was divided into two phases that dealt with different themes. In the first phase, the students acted in role as residents (and later "dumpers") when dealing with illegal dumping of rubbish and waste and the effects this had on their local community. The teacher acted in role as one of the worried residents and as a local councillor. In the second phase, students acted as villagers whose homes were threatened by deforestation, addressing the global issue of destruction of the rainforests, and the consequences for the environment and locals. The data included observations, students' evaluation of their work and learning, audiotaped interviews and videotaped lessons. The author suggests that the process drama seemed to support learning in education for sustainability in many ways, such as the students' use of sympathy and empathy, and their exploration of values from different perspectives throughout the drama. They also displayed skills in communicating and collaborating, and expressing ideas and opinions. The drama gave the students a meaningful context and prompted them to engage with their learning:

> [t]o make a personal reconstruction of knowledge and thus, perhaps, to come to a fuller and more meaningful understanding (…) It is this experience of inhabiting both the real world and the imagined world, and being aware of both, which allows a deep level of cognition, and thus learning, to take place (p. 153–154).

The findings also revealed that the drama conventions and associated teaching strategies of *teacher-in-role*, the *fictional context*, *still and moving images,* and *in-role improvisation and presentations* of ideas, were particularly valuable for facilitating the students' explorations and development of their learning in education for sustainability issues.

Lehtonen et al. (2020) explored the potential of using drama as an arts-based method for sustainability education, particularly focusing on climate change. Lethonen et al. (2020) conducted a case study with 16 students, experienced in drama in education, attending a university course on drama in education for a sustainable future in Finland. Various types of qualitative data were gathered during three workshops. The first workshop involved individual and collective reflection on sustainability challenges, still images, and a process drama of a fictive environmental conference with the teacher-in-role (TiR) as the hostess, where the students had the opportunity to explore climate change from different stakeholders' perspectives. The drama workshop was originally designed for student teachers with no previous drama experience. The second workshop took place in a forest and featured activities such as embodied self-reflection exercises and group improvisations, including non-verbal poetry and participatory enactments. The third workshop focused on reflecting on the experiences from previous workshops through drama activities, writing, and discussions. The findings indicate that the drama fostered a sense of interconnectedness and promotes transformative learning, and enhanced the ability to understand, critique, initiate change, embody values, and care (see also Wals, 2015). Further, the students' reflections revealed that drama was perceived as a powerful tool, with the experiences during the course having a lasting impact on their behaviours and attitudes. In conclusion, Lethonen et al. (2020) emphasise that the integration of embodiment, emotions, and cognition, along with the blending of individual and collective efforts in creative collaboration, through the use of drama, significantly enhanced participants' awareness of interconnectedness.

Österlind (2020) conducted a study with 60 student teachers in Athens where the participants explored sustainability issues and how drama can be used in education for sustainability (ESD). The collected data consisted of the student teachers responses to questionnaires with open-ended questions after the workshop. The results showed that more than three-quarters of the students appreciated drama as part of teaching and learning The student teachers expressed three approaches to the use of drama: The *optimistic* approach, where the student sees no disadvantages whatsoever in implementing drama in ESD teaching. The *realistic* approach, where the student is very positive about implementing drama in ESD teaching, but sees some obstacles – for example, that drama is time-consuming, requires extensive preparation, and is hard to manage with a large group of students. The *pessimistic* approach, where the student is positive about using drama in ESD, also foresees many obstacles and problems in implementing drama– for example, lack of time, fear of

drama being perceived as a kid's game, need for extensive preparation, and fear of not having sufficient training, or not feeling comfortable in conducting drama in their own teaching.

Fries and Österlind (2020) integrated drama elements into regular teaching in a lower secondary school in Sweden, with the aim of developing interdisciplinary teaching around various aspects of sustainable development. A drama teacher collaborated with the students' teachers in a class for two years (grades 8 and 9) and implemented process drama with different themes. One theme was about climate change and climate refugees, where subject such as Geography, Swedish and English were involved, in collaboration with one teacher. Another sustainability theme dealt with electronic waste and involved both Science and Social Science in collaboration with three teachers. The study was conducted as a small-scale qualitative study based on student questionnaires and focus group interviews, where the students had to reflect on drama in teaching based on their experience after the interventions. The results showed that the students were extremely positive about drama in the teaching and that the students' experiences of the drama interventions contributed to an understanding of the interaction between drama and subject content in terms of: *different learning* – fun and motivating, i.e., because it involved movement and interaction; *integrated learning*, where theory and practice were brought together; and *extended learning*, that "describes how the students' experiences of drama extend from the personal and bodily, by way of compassion and empathy, to a social commitment" (p. 347, my translation). Fries and Österlind (2020) emphasise that the teachers and drama pedagogues in their study needed more planning time, especially on the topic of climate refugees, where three teachers were involved, and that there are great benefits when the teacher themself can integrate the drama into the teaching. Fries and Österlind (2020) conclude that process drama is a resource in teaching about sustainable development and there is a need for "insight into what is required for drama to become a working method among others and thus a completely common element in teaching" (p. 353, my translation).

**Roleplay in teaching about science in society**

Although research on drama for teaching about science in society is sparse, particularly in chemistry education, there is research on the use of roleplay in science education resembling decision-making processes. Although this research may not be anchored in drama pedagogy, the results of the research may still be of relevance to the uses of drama in science education. In such roleplays, the conversations between different stakeholders are often structured, focus on a given problematic situation where a decision is to be reached on an issue involving conflicts between different stake-holders and require students to prepare by reading about and discussing the topic (see for example, Anker-Hansen & Andrée, 2015). When roleplay takes place in a drama context such as process drama, however, students and teachers step in and out of

roles, and together build a narrative by using a range of different drama strategies. This enables an exploration of the content from many different perspectives, which may provide a more complex learning experience (Österlind, 2020; Österlind & Hallgren, in press). For example, roleplays not anchored in drama pedagogy have been used in several of the studies mentioned in Chapter 2; these promote open decision-making processes in secondary education and are situated within the socio-critical and problem-oriented approach to chemistry teaching (e.g., Feierabend, & Eilks, 2011). Also, at university level, Smythe and Higgins, (2007) had students in an environmental chemistry course roleplay in a "mock congressional hearing" debate on environmental issues resembling debates that occur in committee meetings of the U.S. Congress. To show how science and policy interact in decision-making, Stokes and Selin, (2016) developed a negotiation simulation called the "mercury game". Based on the global mercury treaty negotiations, students take on roles as different stakeholders.

In sum, previous research shows that drama for teaching about science in society involving sustainability and controversial issues has been conducted with varying subject content in a large age range from primary school to university level, with a focus on both students' and pre- and in-service teachers' experiences of drama in teaching. Data have been collected using various qualitative methods, where questionnaires and interviews predominate. Overall, research results show that students and teachers are very positive about using drama in teaching about science in society, and that the teacher's guidance of students between the fictional and the real world is of great importance for allowing access to a deeper level of knowledge of the science involved. Particularly, the process drama examined in research has proven to be a resource for teaching about sustainability and controversial issues involving different subjects, often using an interdisciplinary approach. Although sustainability issues are cross curricular, limited research has been conducted in science education, particularly in chemistry education, on process drama dealing with sustainability issues.

## Summary

Taken together, research shows that drama can support students' learning both in terms of conceptual understanding and the humanistic aspects of NOS and controversial/sustainability issues. Letting the students in a drama activity use their bodies as visual representations of chemical bonding can be a way to "make the invisible visible", that is, the bodily models can describe or explain macro-level observations with sub-micro bodily models, facilitating a movement between the different levels of organisation. Moreover, drama can be used as a pedagogy to teach controversial/sustainability issues in science, which may enhance the learning experience by promoting empathy, encouraging dialogue and collaboration, and fostering a deeper understanding of

multiple perspectives concerning the issue at stake (cf. White & Raphael, 2023). Some studies related to humanistic approaches in chemistry education have used roleplay to mimic decision-making processes (se also Chapter 2), which may not always be anchored in drama pedagogy. Questions could be asked about how a process drama that involves both teachers and students beyond a structured roleplay could enable exploration of controversial/sustainability issues in chemistry education. Research methodology shows that students indeed learn by using drama, but how and why they learn in the drama activity is less well known. Few studies that investigate conceptual understanding have collected data, for example, through video, and analysed what happens during the actual drama activity. Although research on drama aimed at developing the humanistic dimensions of science education has to a greater extent analysed the actual drama activity, pre- and post-test methodology and interviews predominate. To fill this gap in the research, I intend to zoom in on the drama activity itself to analyse the ways in which drama can support students' learning in the chemistry classroom.

# 4. Theoretical perspectives

This dissertation is underpinned by a sociocultural conceptualisation of learning. This theoretical perspective emphasises the role of social and cultural dimensions in the learning process. It recognises that learning is not an individual endeavour but occurs through active engagement with others and the cultural artefacts and tools available within particular practices. In the case of using drama in chemistry teaching, the sociocultural perspective highlights the social interactions and collaborative learning that takes place during the drama activity in the classroom. It also takes into account the cultural norms and values intertwined with students' engagement with chemistry and drama. Below, I describe how a sociocultural theoretical perspective on learning and human activity informs this dissertation and the theoretical concepts that have been used in the analyses of the data.

## Learning as a social, cultural, and historical endeavour

A starting point for a sociocultural perspective is that students learn by participating in the socially and culturally organised activities offered through interactions with others before learning is internalised and can become part of their concrete personal experience. According to Vygotsky, the social environment plays a crucial role in shaping an individual's mental functioning. Wertsch and Rupert (1993) discuss Vygotsky's claim, which they consider to be the starting point of his analysis of human mental functioning – "the social dimension of consciousness is primary in time and in fact. The individual dimension of consciousness is derivative and secondary" (Vygotsky, 1979, p. 30). Vygotsky emphasised that the social aspect of consciousness is the most important and develops before individual consciousness. These claims laid the foundation for his theories on the internalisation of speech (Vygotsky, 1934/1999), the "zone of proximal development" (Vygotsky, 1978), and the development of scientific concepts (Vygotsky, 1934/1999), discussed below in the context of sociocultural learning.

Vygotsky (1978; 1934/1999) proposed the importance of the zone of proximal development, or ZPD, which he described as the relationship between the student's actual and potential developmental level. According to Vygotsky, students can reach higher levels of problem-solving with the support of a teacher or a more knowledgeable peer. This means that a student can achieve

more with the help and guidance of others than what they are currently capable of independently. In the classroom, prior knowledge and skills should be connected to the specific situation in which the teaching occurs, and it is crucial to observe how students collaborate with peers and employ various intellectual and physical tools (Säljö, 2015; Vygotsky, 1978).

From a sociocultural perspective, the individual and the environment are seen as an inseparable unit and learning is understood as *action* situated in historical, cultural, and social practices (Leontev, 1981; Vygotsky, 1978). Within educational settings, various cultures coexist, and it is through the lens of cultural practices that the content and methodology of student learning are defined. However, it is crucial to acknowledge that culture is shaped and upheld by individuals in interaction, and as communities, through human action (Säljö, 2015). Hence, when people interact with their environment and take specific actions, they not only come into contact with their surroundings but also shape both their surroundings and themselves (Wertsch, 1993).

To understand the world around us and act in it, we use the intellectual and physical resources we have access to (Vygotsky, 1934/1999). According to Vygotsky (1934/1999), people are constantly developing and changing, and different environments offer different opportunities and access to intellectual tools. People are constantly in the process of *appropriating* new forms of intellectual and material tools with the support of what they previously could do and know (Säljö, 2005). By appropriating new conceptual tools, it is possible for us to learn to see new patterns and possibilities in the intellectual and practical tools that are already known to us (Säljö, 2015). In this sense, one aim in chemistry teaching is students' appropriation of new conceptual tools. An example in upper secondary school chemistry is the concept of electronegativity which is a concept that enables a more nuanced understanding of chemical bonding and how matter is composed than a simple grasp of chemistry's organisation levels. The appropriation of new conceptual tools has the potential to mediate new ways of understanding the world and ourselves as part of it in different ways.

From a sociocultural perspective, the learning process involves the use of various resources for communication such as language, bodily positions, and physical artefacts. These resources play a crucial role in mediating meaning, and can therefore be regarded as *mediating means* (Vygotsky, 1978; Wertsch & Rupert, 1993). Learning is an active process shaped by these mediating means (Säljö, 2015). This aligns with the aforementioned view that actions and learning are tied to the historical, cultural, and social context in which it takes place. By taking this approach to learning and communication, it becomes evident that the actions of students and teachers, as well as the mediating means they employ, cannot be separated and understood in isolation from one another (Wertsch, 1993).

# The role of verbal and bodily language in science learning

Vygotsky (1934/1999) discussed the role of language in learning scientific concepts and emphasised that scientific concepts do not come ready-made to the child/student but must be developed through the child's experience. Vygotsky proposed a model in which spontaneous concepts and scientifically abstract concepts, denoted abstract non-spontaneous concepts, develop simultaneously. The spontaneous concepts originate from the child's own personal experience but cannot initially be expressed through disciplinary scientific language. The non-spontaneous concepts are the product of teaching and are initially completely abstract in that there is a mediated relationship with the concept and its object.

With everyday language, chemistry teachers can say, for example, that water boils. In this case, boiling can be considered a spontaneous concept. However, when the chemistry teacher presents the concepts phase and phase transition to account for the changes in the water – in terms of transition from liquid phase to gas phase – when it boils, the teacher introduces non-spontaneous concepts. Vygotsky proposed that the spontaneous and non-spontaneous scientific concepts develop and converge in a concrete–abstract dimension:

> In working its slow way upwards, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality. Science concepts, in turn, supply structures for the upward development of the child's spontaneous concepts towards consciousness and deliberate use. Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upwards through scientific concepts (Vygotsky, 1962/1986, p. 194).

This quote demonstrates Vygotsky's view that everyday concepts, which are our basic understanding of the world around us, help pave the way for scientific concepts to develop. Scientific concepts, on the other hand, contribute to the growth and development of our everyday concepts. It is a two-way process where both types of concept support and build upon each other.

Chemistry in upper secondary school mainly deals with the kind of concepts that Vygotsky (1934/1999) called non-spontaneous scientific concepts, i.e., concepts that do not develop spontaneously in everyday life, such as electronegativity. For the understanding of non-spontaneous concepts to develop, teaching should enable the concepts to grow into students' concrete personal experience. According to Vygotsky, "the development process of a concept has not ended, but instead has just begun at the moment one acquires the new concept" (Vygotsky, 1934/1999 s. 389, my translation from Swedish).

Further, a prerequisite for students to develop a scientific language is that the teacher interacts with them and acts as a mediator to enable them to participate in a scientific discursive tradition (Schoultz, 2002). The teacher's work can be described, through dialogue with the students, as guiding them to the *turning point*, i.e., guiding them to go from an everyday language to a scientific language (Mortimer & Scott, 2003). In addition, it is important that teaching is facilitated by teachers in such a way that science resources become available to them on a social level and that they are enabled to reach a personal understanding of the content (Leach & Scott, 2003).

In this dissertation, questions are asked about how the drama can support the growth of non-spontaneous chemical concepts, especially regarding different organisational levels in the field of chemical bonding and how these can become part of the students' concrete personal experience. Through drama, giving students the opportunity to materialise abstract scientific concepts and processes using their own bodies as physical artefacts can be a way to promote their chemical reasoning and conceptual development. Drama in chemistry education may thus enable students to express themselves through bodily language in addition to verbal language.

This bodily/embodied nature of drama has the potential to spark learning through creative imitation in processes of *mimesis*, acknowledging the importance of social interaction and learning from others. Zlatev (2007) defines mimesis based on Donald (1991, p. 168): "Mimetic skills or mimesis rests on the ability to produce conscious, self-initiated, representational acts that are intentional but not linguistic." Reber (1992) describes how mimesis requires the ability to understand the context in which the activity takes place and that individuals position themselves as observing actors, who in turn generate and reproduce these behaviours and actions in practice with their own bodies. According to Wulf (2008), mimesis or *mimetic learning* constitutes one of the most significant forms of learning:

> *Mimetic learning does not, however, just denote mere imitation or copying: Rather, it is a process by which the act of relating to other persons and worlds in a mimetic way leads to an enhancement of one's own world view, action and behavior. Mimetic learning is productive, it is related to the body, and it establishes a connection between the individual and the world as well as other persons; it creates practical knowledge, which is what makes it constitutive of social, artistic, and practical action.* (p. 56, italics in original)

In drama, mimesis may enable a direct and vivid learning experience. Also, mimesis may assist students in forming mental images and models of abstract ideas, by stepping into the shoes of scientists or by taking on the roles of different elements, molecules, or chemical processes, thus promoting a deeper understanding and retention of scientific knowledge.

# Multimodal social semiotic perspective on science learning in drama

In this dissertation, the sociocultural theory of learning (Vygotsky, 1934/1999) is combined with multimodal social semiotic analysis (Kress & Bezemer, 2015). Social semiotics and sociocultural perspectives on learning are inherently interconnected, both emphasising the importance of various resources for communication and social interaction in the meaning-making. Thus, the interplay between social semiotics and sociocultural perspectives provides a comprehensive lens for examining the complexities of learning and meaning-making in the chemistry classroom.

Mortimer and Scott (2003) emphasise, in line with other researchers (Lemke, 1990; Mercer et al., 2010), that the conversation in the classroom – to "talk science" – is important for students' opportunities to create meaning in science teaching. In this dissertation, although the conversation is important for the students' meaning making, it is also seen as but one of all available semiotic resources. The resources that are available and how they are used in the classroom play a major role in students' meaning-making and are therefore interesting to study to understand the learning process. In drama, the bodily mode, with gestures, facial expressions, and movement become particularly significant. From a sociocultural perspective, bodily mode and physical artefacts are important for communication and learning, although language is considered to have a prominent place (Vygotsky, 1978). From a multimodal social semiotic perspective, all modes are considered equally significant (Kress, 2010).

The *social* in socio semiotics points to meaning being created in a social environment, with the semiotic resources available to the meaning maker. Thus, the creation of meaning is a result of the work done in a social environment with socially shaped cultural resources by socially shaped actors/agents (Kress, 2010; Kress & Bezemer, 2015).

*Semiotics* in socio semiotics points to meaning, that meaning-making is always functional, which means that people express meaning in many different ways with the resources that are available. This means that meaning and functional expression of these are not only limited to speech, but can take place in many other ways, such as with bodily language, gaze, images, and physical artefacts (Björkvall, 2009; Kress, 2010). Regardless of whether the communication is expressed in speech or text, the speech and text must have the resources to express the meaning that the creator of meaning intended to express. If no such resources are available within a communication mode, they are created, or the meaning is expressed using other communication modes (Björkvall, 2009; Danielsson & Selander, 2021). In chemistry education, the student thus participates both as an actor and creator of meaning. In the use of drama in chemistry teaching the range of available semiotic resources in the form of actions, materials, and artefacts used to communicate is potentially broadened through the introduction of drama conventions and new ways of

using the body as a semiotic resource. In this sense, the functional potential of the meaning may be expanded through the semiotic resources made possible in the drama activity.

The *multimodal* perspective means that attention points to several forms of communication working together to create meaning in a particular environment. Kress and Bezemer (2015) refer to semiotic resources as *modes*, which in this thesis, I denote as *semiotic modes*, which originates from the term Björkvall (2009) uses. According to Björkvall (2009), a semiotic mode is an organised set of semiotic resources, for example, the "building material" that is available when creating a text. Semiotic resources are thus meaning-making materials that can be used for communication, and when several resources are used in a more organised way, one can start talking about semiotic modes, such as the image mode (see also Danielsson & Selander, 2021).

Semiotic resources in all semiotic modes can be actualised in the teaching situation. This includes gestures and other types of actions beyond speech and text (Kress, 2010; Kress et al., 2001). Each semiotic mode can be used both separately and together with other semiotic modalities and contributes to the creation of meaning in that particular environment. All semiotic resources in the semiotic complex (multiple modes) function as *meaning potentials* (Björkvall, 2009), which are possible meanings that can be expressed in different contexts depending on the meaning maker's interest and purpose. A starting point in a multimodal social semiotic perspective is that students use the semiotic resources that are available and that best help them create the meaning they strive to achieve (Kress & Bezemer, 2015).

In semiotics, the semiotic resources are sometimes referred to as *semiotic signs*. Semiotic signs consist of both *the signified* (in Swedish, *det betecknade*), which refers to the sign's meaning or content, and *the signifier* (in Swedish, *det betecknande*) which stands for the form or expression of the sign (Björkvall, 2009). An example of a sign in chemistry is the term dipole. In dipole, the word represents the shape of the molecule. A model of the molecule can be represented by the shape of the bodily mode, *the signifier*, and the meaning of dipole can be a molecule with a partly negative side, *the signified*.

A sign's meaning and form in a social semiotic multimodal perspective is thus based on an important relationship. The semiotic sign, the form that is "chosen" in a specific situation, addresses the interest of the sign maker and is therefore never arbitrary. It is always justified, which means that the form represented by the meaning maker is the best possible with the most appropriate meaning for carrying the meaning of the meaning maker. The consequence is that all signs, on all occasions, are newly created, which is considered to apply to all signs (Kress & Bezemer, 2015).

The sign is the product of semiotic work and the semiotic sign is the unit in which the meaning-making becomes material and visible. In social semiotics, the learning process is understood as the interaction of people in a communicative act, of semiotic work. Learning is the result of interaction and/or engagement in sign making (Kress & Bezemer, 2015). According to Kress and

Bezemer (2015), a sign is produced by the first meaning maker for an intended receiver. This "sign-as-message" acts as a prompt to a receiver, who responds to selected elements of the prompt. By doing so, the meaning maker *transforms* the selected elements from the first message and produces a new sign.

When the meaning maker creates signs in social interaction with others, the meaning created in one semiotic mode or in a complex of modes is transformed into meaning in another semiotic mode or complex. Kress and Bezemer (2015) describe different types of transformation with the terms *transformation* and *transduction*. Transduction refers to *inter*-modal changes – when the units change from one semiotic mode to another; for example, when a student reads a text in a book and draws a picture (text to picture). Transformation refers to *intra*-modal changes. This means that units/elements within a particular semiotic mode are reshaped. For example, when a student writes a new text based on the reading of another text (text to text) – how the units, the words, are the same within the semiotic mode text, but how the words can be rearranged and gain a new meaning when the student writes a new text. No matter what change of mode – intra- or intermodal – change in meaning is produced. Such meaning production constitutes learning (Kress & Bezemer, 2015).

From a multimodal social semiotic perspective, drama provides students with the opportunity to process the chemistry content within different semiotic modes. For example, when students transfer a text-based model or description from the chemistry textbook to a three-dimensional bodily mode, they are enabled to reconceptualise the chemical content and create meaning in a new semiotic mode – the bodily (Kress & Bezemer, 2015). In drama, several semiotic modes could become significant, such as speech, text, image, bodily and physical artefacts. Body and text may function as "building blocks". As such, the bodily building blocks are made up of different bodily movements, in the same way as textual building blocks are made up of letters written in a specific order to create specific meaning. In the semiotic mode of speech, sounds are used to express meaning. In other words, meaning is created through various semiotic modes in addition to speech and writing, always in specific combinations, where speech and writing are not necessarily central (Kress & Bezemer, 2015).

## A sociocultural lens on agency and participation

In chemistry education practices, students and teachers participate in social knowledge building where structures and resources provide different conditions for student agency in learning. According to Vygotsky (1934/1999), students learn when participating in activities through interaction with people and cultural resources. Learning is thus seen as an integral and inseparable aspect of participating in a social practice. Lave and Wenger (1991) have theorised

learning as participation with the concept of *legitimate peripheral participation* and describe learning in terms of expanded repertoires for participation in communities of practice (cf. Wenger, 1998). Here, the notion of participation entails ways of being in and gaining access to communities of practice. In the course of growing engagement, ways of accessing and ways of being located in such communities expand. This dissertation focuses on how ways of participating in a community of chemistry education may be expanded through the incorporation of drama. More specifically, I take the perspective that agency is something students achieve (do) in a situation rather than something they own or have (Biesta & Tedder, 2007).

In this dissertation, I adopt the metaphor margin|centre *dialectic* as a framework for describing students' participation in chemistry education drama. I use the "Sheffer stroke '|' to combine two mutually excluding yet mutually presupposing manifestations of an overarching unit" (see also Roth et al., 2013, p. 10). The framework allows me to see learning as participation as a fluid process and to make sense of how transformation, development, and learning unfold within the classroom at individual and collective levels (Roth et al., 2013). Drawing on Goulart and Roth (2006), the margin|centre dialectic implies that each moment of participation constitutes both marginal and central participation, creating a flow of participation that is constantly changing in the classroom. They compare student participation with the physicist notion of light where light can be observed either as a wave or a particle but never at the same time. In parallel, margin and centre can only capture one dimension of the phenomenon – a student can be observed participating in the activities in the classroom, sometimes at the margin and sometimes in the centre. In line with Goulart and Roth (2006), I argue that changes and movements in activity cannot take place without an agent achieving some form of agency.

Furthermore, through a dialectical sociocultural lens, agency in this dissertation is understood in the two dialectical relationships, *agency*|*structure* and *agency*|*passivity* (cf. Goulart & Roth, 2010; King, 2012). Agency and structure are theorised as a dialectical relationship where structures in themselves include social arrangements, relationships, and practices that can exercise power and limit people's lives (Osterkamp, 1999). In the chemistry classroom, the material structure and resources (in the form of laboratory equipment, whiteboards, models, special furniture, etc.) in combination with social structures mediate what teachers and students can do (King, 2012), and provide the opportunity and space for student learning (cf. Andrée, 2020). The practice shapes the individual, but the individual also shapes the practice (Hewson, 2010; Sewall, 1992). However, the structures should not only be considered as limiting but also as opportunities (King, 2012, see Sewall, 1992).

Agency and passivity presuppose each other (Roth, 2007). Passivity does not mean that a student is inactive with the intention of being silent or doing nothing in the eyes of others. Every aspect of agency is accompanied by passivity. On the contrary, the student can be receptive to learning, which can be made visible with facial and bodily expressions (King, 2012; Roth, 2007). To

enable learning, students should thus be given space to enact agency and also be given space to be passive, observed through the students' willingness and openness to learning (Hwang & Roth, 2009).

Questions of agency concern how the material and social structures provide opportunity and space for students to transform their understanding of chemical concepts and processes related to chemical bonding and sustainability issues in chemistry teaching. In this dissertation, I use the notion *collective agency* to analyse students' participation when using drama in chemistry education. The notion of collective agency follows from the distinctive feature of the collaborative nature of the drama (Baldwin, 2021; Fries & Österlind, 2019) and viewing language as a collaborative and shared mediation tool that shapes the collective consciousness of interest groups (Goulart & Roth, 2010). Following Fu and Clarke's (2019) perspective, collective agency is understood to centre on two key elements: engagement/negotiation and shared interests/goals. In the classroom, students engage in negotiation and co-creation of shared meanings through activities and dialogue within groups. These shared meanings generated through interactions among students and teachers, in turn, empower individuals and collectively construct a space for science learning within the group (in small groups or a whole class). In this sense, when individuals cooperate (e.g., students in a chemistry classroom), the collective units become, as described by Hewson (2010), a collective form of agency.

Following Biesta and Tedder's (2007) perspective, agency in this dissertation is related to the present, past, and future, meaning that individuals' past experiences and future imaginations are reactivated in the present. To analyse and describe the students' imaginary transitions in time when participating in drama, I use the notion of *futuring* and *historying*. Historying, the active process of creating, interpreting, and engaging with the past (cf. Garnet, 2017) – "doing history" (Munslow, 2015), is fundamentally linked to the concept of agency. So is also futuring, the process of anticipating and imagining the future, which may empower students to take action in a joint activity in the present based on their vision of the future (cf. Levrini et al., 2021). In this sense, imagination of the future and imagination of the past can be understood as something one does in a shared activity where social and material structures mediate and provide the opportunity and space for students to exercise their agency.

# 5. Methodology and research design

This dissertation is based on two research projects conducted in upper secondary chemistry education. In Project 1, I started from challenges in my own practice and investigated how *creative drama* could support students' learning of non-spontaneous chemical concepts related to electronegativity and chemical bonding. In Project 2, I investigated how *process drama* could be used to afford students' agency when dealing with complex sustainability issues. The research in this dissertation is characterised as *close-to-practice research*[1] focusing "on issues defined by practitioners as relevant to their practice, and involves collaboration between people whose main expertise is in research, in educational practice, or both" (Wyse et al., 2021, p. 1470). In this chapter, I begin by describing educational design-based research and how this has guided my work with this dissertation. Thereafter, the research design for the two empirical projects that form the basis of the dissertation is described, where I explain the design of interventions, settings, participants, and the different cycles for each project. I describe how the data have been produced and processed, the choice of transcription representation, and how data have been analysed. I describe the forms and conditions for participation as well as the methodological and ethical considerations that permeated the entire research process

## Close-to-practice research with a design-based approach

In both projects, the close-to-practice research was conducted in the form of educational design research (EDR), which is to be understood as a genre of research rather than a specific method (McKenney & Reeves, 2018). EDR is based on an assumption that research on teaching and learning needs to be situated in the practices where teaching and learning actually take place (McKenney & Reeves, 2018), addressing challenges in practice. An important criterion that forms the basis for the choice of EDR is the collaborative character (McKenney & Reeves, 2012), where collaboration between researchers

[1] There are various concepts within educational research addressing research conducted in practice, for example, *praxis development research* used by Anker-Hansen (2015) and *participatory research* used by Wiblom (2020).

and practitioners is an important element. In both projects, I strove to achieve a kind of hybridisation (Hamza et al., 2018) between teacher practice and research practice – where the aim was for both practices to fertilise each other, thus bridging the gap between theory and practice (cf. Sensevy et al., 2013).

The EDR approach in this dissertation enables the study of various aspects of multiple domains in the complex environment of the chemistry classroom that can be understood as a learning ecology (Cobb et al., 2003). EDR is inherently iterative, involving cycles of designing, implementing, analyzing, and refining interventions based on evaluation and findings from each iteration. This process allows for continual improvement and adaptation to intermediate outcomes and changing contexts in educational settings (The Design-Based Research Collective, 2003). Within EDR, tentative design principles, based on both theoretical and practical knowledge in relation to the research and teaching goals are usually formulated as a starting point. The design principles can thus be anchored in theoretical knowledge regarding the research objective while at the same time open to new practical and theoretical insights (van den Akker, 1999). In an EDR research process, the tentative design principles are refined in a continuous process to reflect the knowledge gained about the relationship between teaching and intended learning. Through this process more robust design principles are formulated that make important aspects of learning visible, which can be useful for teachers to develop their teaching.

# Research design

## Project 1

In the first project, drama interventions in two municipal upper secondary schools were conducted in three cycles during the years 2015 to 2107. The first and second cycles were conducted during my own ongoing chemistry teaching. As a means of testing transferability, Cycle 3 was conducted at another school with another chemistry teacher. A total of four research lessons were conducted and an overview of Project 1 is provided in Table 1.

The students who participated had no previous experience of drama in chemistry education. The research lessons were implemented when the subject area of chemical bonding was covered in the chemistry courses and was part of the ongoing chemistry teaching in the Natural Science programme.

Table 1. An overview of Project 1

| **Cycle 1**<br>(Jan. 2015) | **Cycle 2**<br>(Nov. 2015) | **Cycle 3** (Feb. 2017, two research lessons in different classes carried out on two consecutive days) | |
|---|---|---|---|
| School A | School A | School B | School B |
| Research lesson 1<br>30 min | Research lesson 2<br>1 hour | Research lesson 3<br>1 hour | Research lesson 4<br>1 hour |
| 25 students aged 16–17 | 26 students aged 16–17, and my supervisors (Andrée and Enghag) | 26 students aged 16–17 and a Chemistry teacher | 28 students aged 16–17 and a Chemistry teacher |
| I participated as teacher/researcher. | I participated as teacher/researcher. | I participated as researcher. | I participated as researcher. |

**Setting and participants**

The schools were situated in local municipalities close to the university and had expressed an interest in exploring drama in upper secondary chemistry education. In one of the schools (School A), I worked as a teacher at the time of conducting the project. After informal enquiries in nearby municipalities, another school (School B) was selected for participation, where a chemistry teacher, nominated for participation from a colleague, also expressed interest in using drama in his teaching. The participating teacher and I both had extensive experience teaching upper secondary school chemistry.

The first and second cycles were conducted at School A with me as the teacher during the data collection. In Cycle 2, my supervisors (Andrée and Enghag) also participated, observing and video recording the students during the drama activity. After the research lesson, they conducted semi-structured interviews with the participating students. In Cycle 3 (including two research lessons with different classes on consecutive days), the study was conducted in collaboration with the Chemistry teacher at School B. In this cycle, I participated in the classroom as an observer and video recorded the activity. I also conducted three semi-structured group interviews with the students after the research lesson.

A total of 105 students in their first year of the Natural Science programme participated in the study. The students participated both in whole class and in small groups (with 3–6 people in each group), and had no previous experience of drama in chemistry education. The research lessons in all four cycles were video- and audio recorded.

## Designing the intervention

*Starting point*

At the beginning of my doctoral studies, I taught chemistry part-time at upper secondary school. In one chemistry class, we had, both in theory and practice, covered the area of chemical bonding, which included intramolecular bonding (ionic bonding, polar and non-polar covalent bonding), the concept of electronegativity, intermolecular bonding (dipole–dipole bonding, intermolecular hydrogen bonding, and Van der Waals bonding), and metal bonding. In a written test at the end of the teaching sequence, I discovered that several students had not understood the concepts and processes relating to hydrogen bonding. As a teacher and researcher, I wanted to investigate whether creative drama could contribute to developing students' understanding of the concept of hydrogen bonding. As described in previous research, the students' lack of understanding of intermolecular bonding (e.g., hydrogen bonding), may have been caused by the fact that they had not yet understood other concepts related to chemical bonding (Henderleiter et al., 2001). Allowing chemistry students to visualise atoms, molecules, and chemical processes with their bodies may be a way to illuminate the invisible material world of science, and develop their understanding related to chemical bonding. Therefore, my aim was to design a drama sequence where students were given the opportunity to explore chemical bonding, focusing on hydrogen bonding.

Based on my prior teaching experiences and previous research on the use of drama in science education, as well as research on specific chemical bonding (see previous research) I formulated two tentative design principles. The initial tentative design principles were:

- *To create opportunities for students to work symbolically at both the sub-micro and the macro levels (Johnstone, 1982) and enable reflections on the different organisational levels by offering the students different semiotic modes.* In the design, I also intended to emphasise the transitions between the symbolic, macro, and microscopic worlds, so that students would develop models of bonding on these three levels (Nicoll, 2001).

- *To create opportunities for the students to interact with each other and to make their bodily formations of molecules visible in the classroom.* By making students' bodily formations of molecules visible in the classroom, I intended to create richer opportunities for students' meaning-making via peer learning and opportunities for the teacher to gain insight into the conceptual reasoning in the student groups.

*Designing a research lesson*

An intervention in the form of a research lesson including creative drama activities focusing on hydrogen bonding was designed guided by the tentative design principles. For the research lesson, the following tasks were designed:

1. *Small-group task.* Form a hydrogen fluoride molecule with your own bodies where you show which of the atoms is most electronegative. Provide an oral account of the formations.
2. *Whole-class activity.* Form the liquid phase of hydrogen fluoride with a large group of students and alternate between the different phases of matter.
3. *Small-group task.* Form a water molecule with your bodies where you show which of the atoms is most electronegative. Provide an oral account of the formations.
4. *Whole-class activity.* Form the liquid phase of water with a large group of students and alternate between the different phases of matter.

During the research lessons, the students were randomly placed in small groups around tables, while a free space in the middle of the classroom was reserved for whole-class activities. My intention was to have enough students in each group so that students who might not want to act in the actual drama would have the opportunity to take part without participating in the enactment. To support the students' scientific reasoning and semiotic work, they were offered a range of semiotic resources (e.g., coloured paper, textbooks, computers, digital tablets, scissors, cloth pegs, and tape). The students, in small groups, were given the task of visualising molecules and electronegativity with their own bodies. After initial discussion in the group, the students had to enact their molecules through bodily formation, and provide an oral account of how they had reasoned. In the whole-class activity, the students then used their molecules and based on the electronegativity of the molecules, displayed bodily how the molecules interacted with each other, which offered them the ability to move between sub-micro and macro levels.

*Learning objective of the research lesson*

In the present chemistry syllabus for Swedish upper secondary school, chemical bonding is emphasised as a core content: "Chemical bonding and its impact on, e.g., the occurrence, properties and application areas of organic and inorganic substances" shall be covered together with "models and theories of the structure and classification of matter" (Swedish National Agency of Education, 2011). One goal of the syllabus is for the students to be able to link the electronegativity – understood as "[a] measure of the power of an atom or a group of atoms to attract electrons from other parts of the same molecular entity" (Muller, 1994, p. 1111) – to the appearance of the polarity of the bond and also to be able to mark the charge of the poles in the molecule by using

notations for delta plus [d+], and delta minus [d-]. A goal is for the students to recognize that shared electrons will be more frequent at the more electronegative atom, that two poles are created, and that the bond becomes polar. It is important for the students to understand that there are no sharp boundaries between the different types of bonding (i.e., non-polar covalent bonding, polar covalent bonding, and ionic bonding). A purpose for making the distinction is to be able to talk about how and why substances react (Taber & Coll, 2002).

It worth noticing that although covalent bonding, polar covalent bonding, and ionic bonding are to be understood as a continuum, most textbooks in Sweden (for an analysis of Swedish text-books see Bergqvist et al., 2013) and teachers around the world (Taber et al., 2012) present them as three distinct types of bonding. Also, the students in this study had previous experience of teaching which had dealt with bonding in terms of a division into separate units primarily relyingon Bohr's atomic model.

*Rationale for the choice of molecules*

For the intervention, hydrogen fluoride molecules were selected for Tasks 1 and 2, while water molecules were chosen for Tasks 3 and 4. The students in schools A and B were familiar with both molecules because they were used in their chemistry course and in their textbook. A rationale for the choice of molecules was primarily that the molecules are held together by hydrogen bonding. Starting with hydrogen fluoride the rationale was that the students' first bodily formation would be facilitated by the fact that the hydrogen fluoride molecule consists of two atoms and is straight, unlike the more complex water molecule where the angle becomes important for the molecule's polarity. In addition, models of hydrogen fluoride molecules are used in the research literature to investigate students' understanding of electronegativity (Burrows & Reid Mooring, 2015; Peterson & Treagust, 1989).

*Rationale for design of drama activities*

In the drama activity, Task 1, the students were expected to discern that fluorine has higher electronegativity than hydrogen and attracts electrons more than hydrogen does. The students were expected to explore, bodily visualise, and explain that this leads to a higher probability that the electrons will more often be attracted to the fluorine atom than to the hydrogen atom. On the fluorine atom, a partly negative pole is formed and on the hydrogen atom, a partly positive pole. The students are expected to discern that the whole molecule thus becomes polar and is called a dipole. With the water molecule, Task 3, the students were expected to explore, bodily visualise, and explain that the oxygen atom, which has the highest electronegativity, attracts the electrons more than the two hydrogen atoms, which results in the oxygen atom becoming partly negative and the two hydrogen atoms becoming plus poles. The students were also expected to discern and show that the two free electron pairs on the oxygen atom affect the geometry of the water molecule so that an

angle is formed, which causes the whole molecule to become polar and thus a dipole.

The second and fourth task, performed in whole class, was designed to focus on the enactment of the liquid phase of matter and transitions between the different phases of matter. The whole-class tasks were intended to provide students with opportunities to explore bodily interactions between several molecules. The students were expected to discern, bodily visualise, and explain that when the molecules are dipoles, they attract each other with the intermolecular dipole–dipole bond. The students were expected to explore and explain that in the case of hydrogen fluoride and the water molecule, an extra strong dipole–dipole bond arises, which in the literature is called intermolecular hydrogen bonding. Further, the students were more specifically supposed to explain and visualise that the hydrogen bonding emerges when a hydrogen atom bonded to a strongly electronegative atom exists in the vicinity of another electronegative atom with a lone pair of electrons. The students were also supposed to explore the fact that these bonds are stronger than ordinary dipole–dipole bonds, but weaker than true covalent and ionic bonds.

In sum, the tasks were intended to enable the students to move between the macro, sub-micro and symbolic levels to afford their meaning-making about the particulate nature of matter, electronegativity, chemical bonding, and how to connect these concepts to each other. The learning objective of the lesson was that the students would be able to distinguish between stronger intramolecular bonds and weaker intermolecular bonds and to be able to reason about molecular sub-micro level interaction in relation to macrolevel phenomena such as substances' different phases of matter. The whole-class tasks (tasks 2 and 4) were designed to provide students with opportunities to explore bodily interactions between several molecules. In addition, the students were given opportunities to talk to their peers and teacher about why they had positioned themselves as they did.

**Implementing the intervention in three cycles**

Interventions in the form of research lessons using creative drama were conducted in three cycles. In this section, I describe how each cycle was implemented in the classroom. Next, I describe how, after every cycle, we reflected and evaluated the student participation to form a basis for the redesign of the research lesson in the subsequent cycle. Through this process, the design principles were gradually refined to grasp important features of the design of creative drama with the objective of enhancing students' understanding of chemical bonding, electronegativity, and the particulate nature of matter. The empirical data produced in Project 1 are presented in papers I and II.

*Cycle 1*

The first cycle of interventions was conducted at School A with 25 students whom I taught chemistry. Hence, I participated as both teacher and researcher.

The previous teaching had covered chemical bonding in both theory and practice, which included intramolecular bonding (ionic bonding, polar and non-polar covalent bonding), the concept of electronegativity, intermolecular bonding (dipole–dipole bonding, intermolecular hydrogen bonding, and Van der Waals bonding), and metal bonding. The teaching had been completed with a written test, where I discovered that several students displayed a lack of understanding of hydrogen bonding in spite of the prior teaching. A research lesson was designed and implemented to target the displayed problems with understanding hydrogen bonding.

The research lesson of Cycle 1 was conducted during a subsequent Chemistry lesson and lasted about 30 minutes. After the drama tasks, the students were given a written task about hydrogen bonding to complete in small groups.

*Reflections, evaluation, and foundations for redesign*

After the implementation, I transcribed the video- and audio-recorded data verbatim. I then analysed the transcripts and obtained preliminary results, which my supervisors and I discussed and evaluated in several meetings.

Through my participation in the research lesson, I observed how the students had difficulties positioning themselves against the other bodily molecules during the phase transitions of the substances. Hence, the students' scientific reasoning and semiotic work in the creative drama activity revealed an inability to connect electronegativity to the molecule's polarity and intermolecular bonding. In Cycle 1, the main purpose of the intervention was to support the students' understanding of hydrogen bonding, but after analysing the results of the implementation we decided to expand the purpose of the drama activity to focus on explorations of electronegativity and chemical bonding. In addition, we observed in the transcripts that I (the teacher) did not act as a mediator or facilitator of students' bodily visualisations, but more like a director who used the student bodies as semiotic resources while simultaneously verbally explaining why I had placed the bodies as I had – thus, using drama as a means for demonstrating chemical bonding. In the drama activity, it became unclear whether the students and I worked together or whether it was just me who explored the intermolecular bonding. In redesigning the activity for Cycle 2, we decided to provide more space for student explorations of how electronegativity is linked to intermolecular bonding. In addition, the analysis revealed that the students had little time (30 minutes) to work with the tasks. To create more space for students to relate to electronegativity and chemical bonding in their semiotic work, we concluded that the time for the creative drama should be increased.

*Cycle 2*

The second cycle of interventions was conducted at School A, the same school as in Cycle 1 but in another class with 26 students taking Chemistry. I participated as both teacher and researcher, because, as in Cycle 1, I also taught

these students Chemistry when the research lesson was conducted. Prior to the research lesson, during the Chemistry course, I had covered chemical bonding, which included intramolecular bonds (as described in Cycle 1), the concept of electronegativity, and the class was in the middle of a teaching sequence regarding intermolecular bonds. Certain concepts (e.g., hydrogen bonding) that the students raised questions concerning in the research lesson had not yet been covered in lectures. In the research lesson, my supervisors participated during the drama activity to observe and video record. After the research lesson, they conducted semi-structured interviews with all participating student groups which lasted between 30 and 60 minutes and which were video- and audio recorded.

To create space for student conceptual reasoning, for reflection, and for bodily interaction both within and between the groups we decided to extend the creative drama from 30 minutes to 60 minutes. To support student interaction between groups, the students were asked to present and explain their molecular formations to the whole class. To additionally support student agency in discerning and evaluating the bodily formations, the students were instructed to document selected student molecules with their digital tablets. These photos were intended to be used in group discussions and a written individual assignment following the drama activity. When implementing Cycle 2, I added an unplanned final open task, where the students were to select and in groups design a molecule that, unlike in previous tasks, would not be a dipole but instead a non-polar molecule.

Cycle 2 was conducted during a full Chemistry lesson that lasted 60 minutes. The students were divided into five groups with 4–5 students in each group. The research lesson was recorded with five video cameras. One camera roved around the classroom with the other four stationary, placed with the four student groups. The discussions in the four student groups were recorded with audio recorders. After one week, the students had to submit an individual written task, in which they had to select a picture taken during the drama activity and describe what the picture showed related to chemical bonding. In the assignment, they also had to answer questions about how they had experienced the drama activity. The data collected in written forms and interviews constitute background material, and were not used in the analysis.

*Reflections, evaluation, and foundations for redesign*

During the research lesson, my supervisors, who had been involved in discussing and evaluating the results from Cycle 1, also participated. As in Cycle 1, I transcribed the video and audio recorded data verbatim. I then analysed the transcripts and obtained preliminary results, which I discussed with my supervisors in several meetings.

Our results from Cycle 2 revealed that the students, although they had more time for the tasks (1–4) and in some parts of the drama directed the visualisation themselves, mostly participated in a teacher-directed visualisation of

chemical bonding and electronegativity. We asked ourselves whether the chemistry content was too demanding for the students and whether the drama activity was too structured. Further, how would our drama design work with another teacher in another class? In redesigning the activity for Cycle 3, we decided that the basic design principles should be retained in the implementation of the next cycle but with an increased emphasis on giving the students more space to direct the visualisation themselves and encouraging them to use a variety of semiotic resources, including movement, to materialise concepts and processes. We also increased emphasis on creating affordances for increased student interaction in and between groups.

*Cycle 3*

The third cycle was planned and conducted at another school in collaboration with another Chemistry teacher. The teacher had previously been recommended by a colleague for involvement in the project and expressed interest in employing drama in his Chemistry teaching. The time for conducting the intervention was chosen so that it could be part of the ongoing teaching about chemical bonding. At the Chemistry teacher's request, the intervention was carried out in two consecutive lessons, with two different classes that he taught (26 students in the first class and 28 students in the second), for two consecutive days at the beginning of year 2017. Prior to the drama activity, the students had studied electronegativity and chemical bonding as described in Cycle 1. The teacher and I planned the implementation together in detail.

Based on our results from previous cycles, the teacher and I made the decision that he would use the same task instructions that had been used in the second intervention, but with a stronger emphasis on having the students justify to their peers why they had visualised the molecules or positioned themselves in a certain way during the drama activity. Additionally, he would urge students to try out various forms of semiotic resources and to verbally describe their rationale for how they created their bodily molecules. Furthermore, he would focus on facilitating the students in performing group semiotic work on intermolecular bonding by providing them with the opportunity to change phase multiple times (tasks 2 and 4). The research lesson lasted for 60 minutes and was audio- and video recorded with one roving camera, three stationary cameras, three audio recorders in the first class, and four in the second. I participated by observing and video recording the research lesson. I also conducted semi-structured interviews after the drama activity with one group in the first class and with two groups in the second.

*Reflections, evaluation, and foundations for design principles*

Directly after each research lesson, the teacher and I discussed and reflected on what we had experienced in the classroom. The recordings were then transcribed and analysed as in previous cycles. Our findings from Cycle 3 revealed that there were some variations in the implementation of the research lessons compared to Cycle 2. Unlike cycles 1 and 2, the teacher in Cycle 3 invited the

students to explain the concepts and acted more as a mediator. In all, the students in Cycle 3 were provided more space in the classroom to explore electronegativity and chemical bonding than the students in the previous cycles. These findings then formed the basis of revised design principles.

## Project 2

In the second project, drama interventions were conducted in two cycles during the year 2021, in two municipal upper secondary schools: schools A and C. An overview of Project 2 is provided in Table 2.

Table 2. An overview of Project 2.

| **Cycle 1** (September 2021) | **Cycle 2** (December 2021) |
|---|---|
| School A | School C |
| Research lesson 1<br><br>2 hours | Research lesson 2<br><br>3 hours |
| 14 students aged 17–18, a Swedish (mother tongue) teacher, and my supervisor (Andrée) participated. | 17 students aged 16–17, a Chemistry teacher, a Biology teacher, and my supervisor (Andrée) participated. |
| I participated as researcher, teacher-in-role, and drama facilitator. | I participated as researcher and drama facilitator. |

### Setting and participants

School A was the same school as in Project I, but with a different class. However, when the intervention was planned and conducted, I no longer worked there as a teacher. Like School A, School C was located in the same region as the university.

Three teachers participated in the planning and implementation of the research lessons, all of whom had previously expressed interest in using process drama in their teaching. In School A, 14 students participated. In School B, 17 students participated. The students who participated in the project attended the Natural Science programme (third and last year for students in Cycle 1, and second year for students in Cycle 2) and had no previous experience of working with process drama in upper secondary school.

### Designing the intervention

An intervention was designed in the form of a process drama plan that agreed with my overall purpose, to explore how process drama could be used in chemistry teaching to develop students' understanding of wicked problems.

*Starting point*

For the process drama intervention, plastic pollution and plastic use were chosen as the wicked sustainability issues to focus on. The rationale for the plastics choice is that today plastic is found everywhere on the planet, from oceans to human blood. The release of plastic into the environment today could have significant and long-lasting effects on a global scale in the future (MacLeod et al., 2021). Although there are numerous initiatives addressing the use of plastics and finding alternatives to them, there is no consensus on how to deal with the problem. Instead, possible solutions raise considerations about values such as social justice. Stopping the production and use of plastics and finding alternative solutions will also have economic and environmental consequences. In this sense, the complexity of plastic pollution – with a lack of clear-cut solutions and entanglement of disputed values – makes it a wicked problem.

In line with Heggstad (2014), the plastic problem can be considered a societal problem, where the opportunity for deepening exploration and gaining insight on many levels can be made possible in process drama. Letting students step into a role and experience and explore the consequences of our plastic consumption from different perspectives can, in line with Berggraf Sæbø (2011), create insights and a changed understanding:

> Process drama enables an open exploration and discussion of values and attitudes without the requirement to arrive at a certain attitude or a specific answer to a problem […] Process drama must be an open ideal of Bildung, which does not advocate a certain truth or a specific value base, but gives the participants the opportunity to discuss different points of view (Berggraf Sæbø, 2011, p. 12; my translation from Swedish).

The overarching learning objective of process drama is the opportunity provided to students to explore conflicts of interest and values at stake within complex sustainability issues from different perspectives by stepping into different roles; to see the problem from different perspectives, where chemistry knowledge can become relevant; to understand that these issues cannot be solved using mere factual knowledge.

Another rationale for choosing plastic, is that the plastic problem is an authentic subject that can be linked to the Chemistry curriculum and the three visions: visions I and II (Roberts, 2007) and Vision III (Sjöström & Talanquers, 2014). It is authentic in that our plastic waste and consumption is debated and discussed from a sustainability perspective both on an individual and global level in society. In addition, the students themselves are consumers and are surrounded by plastics in their everyday lives. Plastics can be connected to different levels of complexity in Sjöström and Talanquer's (2014) tetrahedron (see Figure 1) focusing on various parts of chemistry knowledge for teaching.

In the first Chemistry course at the upper secondary school in Sweden, students are expected to acquire basic knowledge in chemistry where "Chemical bonding and its impact on e.g. the occurrence, properties and application areas of organic and inorganic substances" are included (Swedish National Agency of Education, 2011). This lays the foundation for the next Chemistry course where, among other things, "Different categories of organic substances, their properties, structure and reactivity" will be covered (Swedish National Agency of Education, 2011), which can largely be considered chemistry learning for later application, where the students are expected to develop understanding of the chemical structure, properties, and applications of a variety of organic compounds. This focus in the Chemistry curriculum concerns pure and applied chemistry (see Figure 1) in relation to Roberts's (2007) Vision I.

One of the applications of organic chemistry which is often included in the textbooks (e.g., Danielsson Thorell & Johansson, 2016) is the use of polymers in the form of various plastics in our society. In the stated purpose of the Chemistry subject (Swedish National Agency of Education, 2011), it is further strongly emphasised that the students should gain "Knowledge of the importance of chemistry for the individual and society", which provides space for exploring the effects of plastics on the individual dimension, and society in particular focusing on socio-chemistry (see Figure 1) in relation to Roberts's (2007) Vision II. "Issues concerning ethics and sustainable development linked to different ways of working in chemistry and activity areas" is another central requirement (Swedish National Agency of Education, 2011) in chemistry education that can include a critically reflective chemistry education where wicked problems such as the challenges society faces today with plastic waste can be covered in different ways in the chemistry teaching, focusing on critical- reflexive chemistry in relation to Sjöström and Talanquer's (2014) Vision III. In this sense, the choice of plastics may be a way for students to experience metachemistry (Sjöström, 2019) – "to see the forest while not losing sight of the trees" (Mahaffy et al., 2018) and pave the way for humanistic approaches and systems thinking in chemistry education. Hence, students may connect the parts, i.e., plastic's chemical structure and applications in society to local and global sustainability issues as a part of larger systems.

My intention was to design a process drama plan where it would be possible to address all visions in relation to the chemistry content described above in the students' exploration of wicked problems, hereby encouraging systems thinking in chemistry education.

*Design of the initial process drama plan*

First, based on previous research on wicked problems and the use of process drama in science education, with a focus on chemistry education (see Background), I formulated the following design principles to guide the design of the process drama plan:

- *To include opportunities for students to participate in conversations about the plastic issue concerning the social implications of chemistry.* Hence, in line with Yavuzkaya et al. (2022), to put the plastic issue "on the table and make it free" which can enable the students' agency, spontaneity, and creativity, to encourage them to explore and think critically about the issue in focus (cf. Ødegaard, 2003).
- *Enable the students to participate in conversations with issues about the plastic problem that include several actors with different interests, where knowledge of chemistry is in demand, and where they can encounter societal problems and questions regarding plastic waste from a safe position.* Hence, taking a role where they are not held accountable for how they personally tackle the problem (Heathcote & Bolton, 1994; Österlind & Hallgren, 2014).

Second, to design the initial process drama plan based on the design principles, I participated in a university course on process drama during the summer of 2021 (*Drama som verktyg i undervisningen-processdrama – VT21*). During the course, I did a course project to construct a process drama plan in collaboration with Natasha Hägg, a teacher in upper secondary history and social studies. Together we developed a process drama plan focusing on the subject of chemistry. Natasha recommended the fictional dystopian book *Memory of water* (my translation from Swedish, *Minnet av vatten*) written by the author Emmi Intäranta (2020). The book, which inspired us in the creation of the process drama plan, is about a future dystopian society where the water is poisoned and the surviving people walk on huge plastic graves. Drawing on the dystopian book and the subject content of plastics, we designed a process drama plan including time travel and called our plan "The Journey to Dystoplastica". The process drama plan was partly tested with the participants attending the process drama course and based on this we reworked the plan where, among other things, we included an exercise where the students had to text a friend. We also extended the time for the participants' improvisation. To familiarise myself with the current research on the impact of plastics on the environment, I interviewed a professor of environmental science at Stockholm University, Mathew MacLeod, who conducts research on the threat of plastic pollution. In addition, to add authentic data to the process drama plan, I included a publication from MacLeod's research that had recently been published in the journal *Science* (MacLeod et al., 2021).

Based on previous research, the guiding design principles, our experiences as teachers, course literature, newly acquired knowledge from the ongoing process drama course, the fictional dystopian book, and the interview and article from the plastics researcher, we designed a process drama plan. The process drama plan "The Journey to Dystoplastica" forms the basis of the intervention which was implemented in two cycles as part of Project II.

*Rationale for design of drama activities*

In the process drama, students were assigned roles as members of a team of chemists, researchers, politicians, and journalists, and their task was to explore which plastics we should use/produce and which we should avoid. During the drama, the students and teachers travel back and forth in time to explore the uses of plastic, the motives and needs for using plastics, and the consequences of plastics use (i.e., plastics pollution) today and in the future. An overview of the episodes (1–13), the drama conventions we included, and the purpose of using them can be found in the process drama plan in Table 3.

One of our overall choices for the process drama plan was, inspired by Bowell and Heap (2013), to create a context that would engage the students in taking the drama further in a meaningful way. We therefore built up the process drama plan in episodes with the aim of contributing to students' reflections, and encouraging them to come up with ideas about how to deal with the plastic problem, while also enabling students to focus on different visions of chemistry teaching – in this way, offering students a coherent and holistic experience, which, according to Dunn (2016), is one of the key functions of process drama.

The process drama began with a "picture gallery" (Episode 1), which was to create a "hook", and "bring" the students into the drama (Bowell & Heap, 2013). The pictures convey the consequences of plastic waste in a way that we wanted to be emotional and engaging, to create questions based on the students' own everyday experience, and inspire them with the theme. After looking at the pictures, each student had to continue the sentence saying: "I see..." or "I hear..." where the teacher also repeated the utterances to help the participants feel affirmed.

After the first episode, the participants were invited to close their eyes while the teacher used the drama strategy of storytelling to move on and introduce new relevant content (Heggstad, 2014) which was integrated into the context (Bowell & Heap, 2013) of plastics. The point was to arouse curiosity and was a way to start introducing the dilemma (Episode 2). Also, our intention was to enable students to connect the plastic issue to sustainability issues.

At the Public Health Authority (Episode 3), there were chairs on which cards with short role descriptions had been placed in groups of four, enabling participants to choose their roles as researchers, journalists, or politicians. As emphasised by Bowell and Heap (2013), our intention was to give the students roles that served the context from different perspectives. Although the teacher in Cycle 1 invited students to change roles, they kept the first chosen roles throughout the process drama. During the following improvisation, the students had the opportunity to introduce themselves to each other and individualise the roles, for example, according to research interests, where they worked, etc. This created space for them to express different views on the plastic issue, addressing visions II and III. For the students to receive information and facts about the plastic problem as part of the drama, we had the

Table 3: An overview of episodes (1–13), description, drama conventions, and the aim of the activity in the initial process drama plan.

| **Episode** | **Description** | **Drama convention(s)** | **Aim** |
|---|---|---|---|
| 1. | *Picture gallery.*<br><br>Looking at depicted animals affected by plastic pollution. After looking at the pictures, each student has to continue the sentence saying: "I see...or I hear..." | I see… or I hear… exercise. | Create entry into the drama and common focus on plastics. Raise ethical concerns. |
| 2. | *Listen to the plastic problem on the radio*.<br><br>The students sit or lie on the floor, are encouraged to close their eyes and imagine driving their car. The teacher as a radio newscaster reports on polluted seas in the neighbourhood. The students are called to an important meeting with the Public Health Authority. | Narrative by TiR.<br><br>Visualise the plastic problem. | Create context about the plastic problem. |
| 3. | *Role taking and information at the Public Health Authority*.<br><br>Students assume roles by sitting on chairs, with role descriptions on the seats, placed in teams, as chemists, researchers, politicians, and journalists. The teacher as Public Health Authority representative provides information about plastic pollution and the background to why the teams have been called to the meeting. | TiR as Public Health Authority representative.<br><br>Improvisation – students and TiR. | Information about the plastic problem.<br><br>Get role improvisation going and create tension between the participants. |
| 4. | *Task to write reflection in the form of SMS.*<br><br>The students are asked to write a text message to a friend in which they express in one sentence something they have experienced during the meeting. They then get to read the message aloud. | Writing in role, visualising and sharing thoughts. | Reflection on what one has experienced. |
| 5. | *Discussion and reflections out of role.*<br><br>Students and teachers discuss what they have experienced in the drama. | Whole-class reflection out of role. | Allowing students to ask questions and share their thoughts. Highlight issues from different perspectives. |
| 6. | *Information from the Space Agency chief about the assignment*.<br><br>TiR as Space Agency chief informs the teams about the time machine, and the mission to travel in time to find out which plastics we should develop and which we should avoid. | TiR as Space Agency chief.<br><br>Improvisation – students and TiR. | Establish context.<br><br>Raise the tension and clarify the dilemma. |
| 7. | *Travel back in time and meeting with the chemist Hermann Staudinger.* | Visualise ritual of time travel. | Clarify movement in time. |

| | | | |
|---|---|---|---|
| | The teams travel back to the 1920s where they are met by a chemist who talks about the first plastic materials and how they were made. | TiR as the Chemist Hermann Staudinger.<br><br>Improvisation – students and TiR. | Information about and creating an understanding of the history of plastics. |
| 8. | *Task to make an advertising jingle.*<br><br>The students are invited to help the chemist Hermann from the past make an advertising jingle, where the teams are assigned the task of showing with their bodies and verbally why plastic is good. | Partly Tableau.<br><br>Small-group teamwork and enactment in whole class. | How plastic was seen "back then" as a fantastic material for the future. |
| 9. | *Discussion and reflections out-of- role.*<br><br>Students and teachers discuss what they have experienced in the drama. | Whole-class reflection out of role. | Allowing students to ask questions and share their thoughts. Highlight issues from different perspectives. |
| 10. | *Time travel to Dystoplastica and meeting with villager.*<br><br>The teams travel 100 years forwards in time, to the future Dystoplastica. There, they create a collective statue of things they see in the polluted environment, and meet a villager. | Visualise ritual of time travel.<br><br>TiR as a villager.<br><br>Improvisations – students and TiR.<br><br>Creation of collective statue tableau. | Clarify movement in time.<br><br>Reflections on the consequences of plastic use. |
| 11. | *Task to write reflections in the form of diary*.<br><br>Back in the time machine, each team member reflects on their time travel experiences thus far, by writing in their diary. They are asked to underline the most important sentence which the teacher then reads aloud. | Writing in role. | Reflections on what one has experienced. |
| 12. | *Time travel back home and task to work with the assignment*.<br><br>The teams travel back to the Public Health Authority. The teams are tasked to present three important proposals to reduce the negative impact of plastic on the environment. They must also state which plastic materials we should develop and which plastics we should avoid. | Visualise ritual of time travel.<br><br>Small-group teamwork in- role with reporting in whole class. | Clarify movement in time.<br><br>The students work collectively to come up with proposals for different solutions to the plastic problem. |
| 13. | *Discussion and reflections out of role.*<br><br>Student and teachers discuss what they have experienced in the drama. Finally, students' reflections on how it felt to do the process drama, learning in chemistry teaching, and development of the process drama are discussed. | Whole-class reflection out of role. | Allowing students to ask questions and share their thoughts about their experiences in the process drama. |

teacher assume the role of Public Health Authority representative. The TiR provided information about plastic pollution and the background to why the teams had been called to the meeting. The idea of letting the TiR be the representative of the Public Health Authority positioned in an intermediary role – the role as the next decision-maker – was to enable student questions while the TiR was given the opportunity to be flexible – both to relinquish his authority and to take control depending on what unfolded in the course of the drama (Heggstad, 2014).

With the TiR as the Swedish Space Agency's chief of staff (Episode 6), our intention was twofold: to create a contrast in both the role category – the TiR now had a leader/authority role with full control over the decisions that were made (Heggstad, 2014); to increase the pace of events which raised the tension and clarified the mission to take the drama further. The team was ordered to immediately take a seat in the time machine (Episode 7), where we performed a ritual at the exit to create a collective situation that reinforced the story, helped participants to focus, and emphasised the seriousness of the situation (Heggstad, 2014).

In the process drama plan, we also acknowledged that the dramatic context could be located in the past (episodes 7 and 8), the present, or the future (episodes 10 and 11; Bowell & Heap, 2013), which enabled a perspective that, related to time, made visible aspects that would not otherwise have been present had the process drama only taken place in "the present" (Hallgren, 2018). An overall choice was therefore to insert time travel into our drama, which resulted in students forming research teams and travelling in a time machine. The choice to let them travel back in time was to get a perspective on how plastics were once seen as a huge future possibility for humans, although at the time we didn't foresee the consequences for the environment. Through the meeting with the TiR as the positive chemist Hermann Staudinger (Episode 7), our idea was to reinforce, from a historical perspective, the image of that period's view of the possibilities for plastics and to introduce chemistry content that the students could connect to their own experiences with organic chemistry from a Vision I perspective. By having the students make an advertising jingle (Episode 8), our intention was to let them bodily express their view of the positive properties of plastic, partly through the drama convention "tableau" – to make a bodily formation of their thoughts.

Our intention with travelling into the future Dystoplastica (Episode 10) was that the participants would have the opportunity to imagine what it could look like in the future and reflect on the consequences of plastic use, as well as give space for reflections on the problem from different perspectives (addressing visions I, II, and III). To build up the context, i.e., landscape and surroundings in Dystoplastica, we used storytelling to tell the participants that we were now at a former lake, where they had to stand in a ring, form a "collective statue" (Heggstad, 2014), say: "I am...", and then each of the students had to embody their utterance. This they then had to repeat, but now in silence. We wanted,

through the collective statue, to give the participants the opportunity to interpret and reflect on what they felt and imagined (Heggstad, 2014) while giving them a collective experience. Through the meeting with the TiR as a villager, our intention was to create space for improvisation and reflection on the consequences of plastic use, where chemical content could also be included.

Another important choice was to give the students sufficient time for reflection, both in role and out of role, which can increase the opportunities for learning (Wagner, 1976/1992). The goal was to create opportunities for aesthetic doubling (see Chapter 2) and aesthetic engagement such as *connection* and *heightened awareness* for the students to see the connection between the drama and their own life (Hallgren, 2018), which is often made visible during reflection (episodes 5, 9, and 13).

During reflection, one can, collectively or individually, go through what has happened to examine the consequences of alternative decisions and courses of action. In this sense, see events from the point of view of other roles (Bowell & Heap, 2013), which was connected to our goal of letting students experience multiple perspectives regarding the plastic problem. To give the students the opportunity for individual reflection, we also included episodes where the students had to write in role about their experiences in the drama (episodes 4 and 11).

To tie the drama activities together in a meaningful way, the student teams were invited back to the Public Health Authority after their time travel, where they were given the task of discussing in small groups and presenting to the whole class three important proposals to reduce the negative impact of plastic on the environment. They were also tasked with stating which plastic materials we should develop and which we should avoid (Episode 12). In this sense, our idea was to create opportunities for students to focus on socio-chemistry by using a critical–reflexive perspective integrated with disciplinary chemistry.

Finally, we wanted the students and teachers to reflect on what they had experienced in the drama so we included an episode (13) with out-of-role reflections. Then, after the process drama, we invited them to express their opinions and reflections on how it felt to do the process drama, and their thoughts about using process drama in chemistry education (Episode 13). This information helped us to develop the plan for the next cycle.

**Implementing the intervention in two cycles**

The process drama intervention was conducted in two cycles. In this section, I describe how each cycle was implemented. Next, I describe how we reflected on and evaluated the students' activities after the first cycle to form the foundation for redesign in the second cycle. Thus, the design principles were gradually refined to grasp important features of the design of process drama with the objective of enhancing students' understanding of wicked sustainability problems regarding plastic use/waste. The empirical data produced in Project II are presented in Paper III and Paper IV.

*Cycle 1*

The first cycle of intervention was planned and conducted in School A, in collaboration with science teachers and one mother-tongue teacher. Fourteen students aged 18–19, me, and one of the teachers participated in role, in the process drama, which was enacted in the school's drama room. After I presented the process drama plan to the teachers, they decided that we should implement the intervention during the school's yearly thematic week, which that year dealt with human rights. Further, we decided to use the process drama plan that I presented, but to also include a perspective on human rights. This perspective was included when the students meet the villager in Dystoplastica (see Episode 10 in Table 3). The plastic issue related to topics in the teaching of the ongoing course Natural Science Specialisation, and the subject of Swedish (mother-tongue education). The students' mother-tongue teacher, who was also their mentor, expressed interest in participating in the process drama, and we met later to plan the drama in more detail. The students had recently entered the third and final year of their science education and had completed the secondary school Chemistry courses when the process drama was conducted. The students were not given any tasks to prepare ahead of the event, instead they had to work on the plastic problem during the afternoon after experiencing the process drama. They had to present the plastic problem to other classes in the science programme at the end of the week. I participated as a teacher and a teacher-in-role and had previously taught chemistry to the students in the first year of their education. In addition, the students' mother-tongue teacher participated as a teacher-in-role, and as a team member in one of the groups. One of my supervisors assisted in observing and managing the recordings during the lesson. The research lesson lasted for approximately two hours and was video- and audio taped with two roving cameras and two audio recorders.

*Reflections, evaluation, and foundations for redesign*

During the research lesson, my supervisor and I observed that the students, during the first improvisation, had difficulty getting started with the discussions. In the last episode (13) of the process drama, I highlighted this in a discussion with the students when it emerged that they had made the same observation. One student said: "during the discussions, when we all had a role to play, we didn't know what we were supposed to discuss". They emphasised that there should have been more information on the role cards or questions they could have discussed. They also said that the discussions would have been better had they had more time. One student said that, in the role of a researcher, they would have needed more time to convince the politician "that you are not right" and, they suggested "before we had a break and went out and wrote [text messages], I mean that we [would have needed to have had] some time to discuss before we went away [to travel back in time]". As a

consequence, we decided to redesign the drama to give the students more elaborate role cards. The new cards were developed in collaboration with Jenny Olander at the Chemistry Teachers' Resource Centre (*Kemilärarnas resurscentrum*; KRC), based on enquiries to plastics scientists and chemical engineers. In the redesign of the process drama plan, I also decided to add another improvisation moment in Episode 3 and generally give the students more time for improvisation.

Although the preliminary analyses of Cycle 1 revealed that the students were encouraged to use disciplinary chemistry resources during process drama, I wanted to explore the possibility of further supporting student agency in the uses of disciplinary chemistry resources in the drama. Therefore, in the redesign of the research lesson, we decided to include plastic artefacts and molecular models of organic compounds related to plastics. In addition, we decided to strengthen the disciplinary context of the drama and conduct it as part of ongoing teaching of organic chemistry.

I contacted a chemistry teacher who had previously expressed an interest in using process drama in chemistry teaching. When we meet to plan the research lesson, we decided to redesign the plan by introducing plastic artefacts and molecular models of organic compounds related to plastics in the first episode, and to add an extra moment of improvisation after the information from the authority. On the chemistry teacher's advice, we changed the Public Health Agency to the Environmental Protection Agency. Also, the teacher thought that the name of the process drama "The journey to Dystoplastica" could be associated with too gloomy a vision of the future, so we decided to rename it "The journey to and from Dystoplastica" for Cycle 2. The students' Biology teacher had also expressed interest in participating in the process drama. Because the Chemistry and Biology lessons were adjacent to each other, we were then able to increase the time available for our research lesson.

*Cycle 2*

Cycle two was conducted in School C during one prolonged lesson that lasted three hours. Seventeen students aged 16–17, a Chemistry teacher and a Biology teacher participated in the drama, which was enacted in the school's music/drama room. The Chemistry teacher participated as a teacher and a teacher-in-role and the Biology teacher participated as a teacher-in-role. I participated as a teacher and drama facilitator. The process drama was conducted in the ongoing teaching of organic chemistry in the second year of the students' science education. In the first episode, the students were encouraged to choose a plastic artefact from a bag (e.g., diaper, plastic straw, medical plastic visor, etc.) and molecular models of organic compounds (e.g., ethylene and propylene) related to plastics, reflect on what it had to do with the drama, and then tell the whole class what they thought, instead of looking at pictures of animals. During the implementation of Cycle 2, we had not had time to design detailed role cards from authentic stakeholders for all participating students. Some of the students were therefore provided with the same role cards as the

students in Cycle 1. However, all students were provided with name tags and were asked to decide on a name for their role and write it on the tag. During Episode 3, an extra improvisational moment was added before the students texted a message (Episode 4). Also, unlike Cycle 1, the students had to present their proposals (Episode 12) on a "stage" and were encouraged to explain ways we should avoid or develop the plastics they had chosen. They were not given any task to prepare ahead of the process drama, but during the week after the drama they had to submit to the Chemistry teacher the task they had presented on their computers during the drama.

*Reflections, evaluation, and foundations for design principles*

Our observations in the classroom and the transcribed video recordings revealed that the students in this cycle had much more time to improvise and assumed roles earlier than the students in the previous cycle did. For example, in improvisation episodes, in small groups, when the students were asked to interact with each other, such as at the Environmental Protection Agency, all groups stepped into their roles and directed the narrative forward, whereas the students at the Public Health Agency in Cycle 1 took much longer to do this.

Following the same procedure as in Cycle 1, at the end of the research lesson the students and I reflected on our experiences in the process drama. One student expressed that the presentation at the Environmental Protection Agency was interesting because "that's basically what we're doing otherwise, hydrocarbons and the like, and it was a great connection to reality, to the present and, like, above all the future [...] sustainable development and that whole bit". The findings were then used as foundations for refining the design principles.

## Data production

In the two projects, video recording was an invaluable tool for collecting data because I wanted to capture the participants' bodily mode, gestures, and movement in the classroom, which would not have been possible, for example, with audio recording alone (cf. Heath et al., 2010; Flewitt, 2006). By analysing video recordings, the researcher has the opportunity to see how bodily modes are synchronised with the verbal modes, which may facilitate the interpretation of the results (Heath et al., 2010). According to Flewitt (2006) and Moschovich (2019), video recordings should be complemented with other data collection methods, to provide more reliable data. Thus, video data in these two empirical projects do not stand alone, but have been complemented by audio recordings, used together with video recordings as the primary means of producing data. In addition to the video and audio recordings, I made field notes that I used for my ongoing documentation and reflection on the research process.

Another important methodological issue to consider is how the participants, in this case the students in the classroom, may have been influenced by the presence of the cameras. In line with Jordan and Henderson (1995), I noticed in direct observation in the classroom and later in the analysis that at the beginning of the research lesson the students commented and demonstratively "spoke to" the cameras and the audio recorders. However, this "camera effect" diminished surprisingly quickly, and eventually became "part of the furniture" that no one mentioned explicitly.

The choices made before the actual video recording have a significant impact on the ontological position and the analysis that is then made possible (Chan et al., 2019; Heath et al., 2010). Thus, to capture data on the activity during the research lessons of the two projects, it was important for me to plan how many cameras and audio recorders would be used, how they would be placed, and whether the cameras would be mobile or stationary.

## Project 1

In Project 1, in the first cycle, two stationary cameras on tripods were placed at the back and front of the classroom, to capture the classroom activities from several directions. To obtain richer data that also captured the students' discussions in the whole-class activities, two of the four groups were recorded with audio recorders randomly placed on the tables. Because I, as a teacher–researcher, participated in the activity myself, I was not able to operate the cameras, move them, and point them in the desired direction. Later, during the analysis, it was sometimes difficult to observe the activities that took place in the groups because the range of the cameras was limited. Cycle 1 was intended as a pilot that was part of probing/mapping, but it became important to describe the study despite the lack of video. Cycle 2 was recorded with five video cameras. One camera roved around the classroom to capture the whole-class activities, and four were stationary, placed at the four student groups where discussions were also being audio recorded. My supervisors observed the activities and were in charge of the video recordings. In this way, I obtained richer empirical material. I also audio- and video recorded in Cycle 3, with one roving camera, three stationary cameras, three audio recorders in the first class, and four audio recorders in the second. In Cycle 2 and Cycle 3, semi-structured interviews were conducted in connection with the drama activities – video- and/or audio recorded in small groups in separate rooms to ensure video and audio quality. The audio- and video recorded interviews and written material from the students' tasks from Project 1 have been used as background information and do not constitute a basis for detailed analysis.

## Project 2

Unlike in Project 1, the groups in Project 2 had no special place, like tables, where group discussions and activities were carried out; instead, the students

moved around the room and constantly switched in relation to the episode that was unfolding in the drama. Thus, in Project 2, in addition to using multiple roving cameras to capture the classroom activities from several directions, the audio recorders were moved around by my supervisor, following the students' activity in the room. In Cycle 1, two cameras and two audio recorders were used, and in Cycle 2 three cameras and four audio recorders. Sometimes the recorders were placed so close to each other that it became difficult to distinguish who said what. But by repeating the audio recordings while watching the video recordings, it was possible to interpret what was said and who was speaking in most cases.

## Data processing and choice of transcript representation

The video and audio recordings from projects 1 and 2 have been transcribed verbatim. Engaging in transcription not only enhances one's familiarity with the data, but also cultivates the indispensable methodological and theoretical thinking necessary for interpretation (Lapadat, 2000). Translating the students' interactions in the drama activity from audiovisual recordings of oral speech to written text offers limited possibilities for reproducing all nuances and dynamics in students' interaction. The term "verbatim" thus refers to my intention to translate the recordings into a written language, ensuring that no spoken words are omitted, and to present them in a way that includes instances of, for example, bodily movements, gaze, moments of silence, and instances of laughter. There are various methods for making transcriptions of audio- and video recordings, and each will have an impact on how participants and activities are portrayed and perceived (Poland, 2002). Hence, choices must be made about what to include and what to exclude in the transcriptions.

In the multimodal social semiotic analysis in Project 1, I analysed how students used different semiotic resources together with speech when visualising abstract chemical concepts and processes with their bodies. It was crucial to show in the transcripts that speech should not appear as the primary semiotic resource, but that other semiotic resources such as bodily movements and gestures should also be perceived as equal to speech. In addition, I wanted the transcripts to clearly show *when* the students were performing a specific gesture or event. Therefore, I chose to present the reproduced transcripts (papers I and II) in a linear format where I showed when an event occurred in relation to the speech. I have used the symbol * (asterisk) in the transcripts of speeches, which are accompanied by a transcription of another event marked with the asterisk at the end and beginning of the event description, as shown in Table 4. To clarify the multimodal analysis, I have used images in connection with the transcripts where I show the participants' different bodily positions. Multiple images connected to each other have been used to clarify the motion sequence when students, for example, were showing how electronegativity may arise. A question that arose was how I could anonymise the students without losing the purpose of what the images were supposed to show. I chose to blur

parts of the faces in the pictures (papers I and II), which allowed the students' positions and movements to still be visible, while their facial expressions were partly obscured.

In Project 2, instead of visualising different chemical objects and processes, the students had to be different subjects where they assumed different roles to explore the plastic problem in the process drama. In the analysis, my intention was to capture what dimensions of the wicked plastic issue the students had explored, how they had explored the issue and how time travel had affected their understanding of the wicked problem. To be able to answer these questions, it became important to analyse their interactions in the classroom with a focus on speech. Consequently, I chose not to describe bodily gestures with the same level of detail as I did in the reproduced transcripts of Project 1 (papers I and II), and I also decided to exclude images. Transcripts of Project 2 (papers III and IV) do not show when a movement/event occurs in relation to the speech, but when a movement or event occurs that can enhance the interpretation of the results, it has been marked within parentheses after the speech (see the example in Table 4).

The available video technology provides researchers with powerful "microscopes" that increase the ability to analyse and re-analyse the data several times (Derry et al, 2010), which has been helpful in my data processing and analysis. The iterative data process began with me listening thorough the audio recordings and watching the videos to get an overview of the material, while noting when and where different episodes/events unfolded in the drama activity. After that, I transcribed the audiovisual data in their entirety, and by synchronising the video recordings with the audio recordings, I was able to obtain a more comprehensive set of data (Rosenstein, 2002). Hence, what I couldn't hear in the video, I could often find in the audio recordings, and I could supplement the audio recordings by watching the video (see also Project 2 on page 73). Additionally, by repeatedly replaying the recordings, I gradually enhanced my transcriptions of the audiovisual data. After that I was ready to delve deeper into the transcripts depending on my research questions, which are described in more detail under the section Analytical procedure.

Table 4: Transcription of key notations used in the transcripts.

| Paper | Notation | Meaning |
|---|---|---|
| I, II, III, and IV | [valence electron] | Referring to, e.g., how a student refers to a valence electron. |
| | (...) | Omitted Speech/Sequence of Events. |
| | , (comma) | Continuing intonation (more to follow) |
| | . (full stop) | Closing intonation |
| | *Italics* | Speech emphasising specific word/s |
| | ! | Speech with exclamation |
| | ? | Speech with a rising intonation (question). |
| I and II | *(asterisk) | Something that happens in the room in relation to the speech. |
| | I * want to be an oxygen atom. | Speech showing when the activity occurs (at *). |
| | **points hand to chest** | Shows the activity that occurs in relation to the speech, written in italics between asterisks (*). |
| III and IV | Interesting, do you agree? (The teacher looks across the room at all teams). | Text in parentheses shows the activity that occurs in relation to the speech. |

## Summary of settings, participants, and empirical material

In all, 58.5 hours of audiovisual data were collected and transcribed in Project 1 and Project 2. The collected data consist of 28 hours of video recordings and 25 hours of audio recordings from whole-class and group interactions in the classroom. Five and a half hours of audiovisual recordings consist of interviews in separate rooms adjacent to the classroom. In total, 136 students and four teachers in three schools, me as teacher–researcher, and two of my supervisors participated in the projects. In Table 5, a summary of settings, participants, and empirical material in Project 1 and Project 2 are provided.

Table 5: Summary of settings, participants, and empirical material in Project 1 and Project 2.

| | **Project 1** Papers I and II | | | **Project 2** Papers III and IV | |
|---|---|---|---|---|---|
| | **Cycle 1** | **Cycle 2** | **Cycle 3** (two sub-cycles) | **Cycle 1** | **Cycle 2** |
| **Conducted** | January 2015 | November 2015 | February 2017 | September 2021 | December 2021 |
| **Schools** | School A | School A | School B | School A | School C |
| **Participants** | 25 students aged 16–17, me. | 26 students aged 16–17, my supervisors (Andrée and Enghag), and me. | 26 + 28 students aged 16–17, Chemistry teacher, and me. | 14 students aged 17–18, a Swedish (mother-tongue) teacher, my supervisor (Andrée), and me. | 17 students aged 16–17, a Chemistry teacher, a Biology teacher, my supervisor (Andrée), and me. |
| **My role** | Teacher/ researcher | Teacher/ researcher | Researcher | Researcher, teacher-in -role, and drama facilitator. | Researcher and drama facilitator. |
| **School subject and ongoing teaching content** | Chemistry, chemical bonding | Chemistry, chemical bonding | Chemistry, chemical bonding | Thematic week (human rights), natural science | Chemistry, organic chemistry. |
| **Length of research lesson** | 30 minutes | 1 hour | 1 hour + 1 hour | 2 hours | 3 hours |
| **Forms of data collection and activities studied** | Video- and audio recordings from classroom interactions. (including group discussions before, during, and after drama activity in each task). | Video- and audio recordings from classroom interactions and interviews. (including group discussions before, during, and after drama activity in each task). | Video- and audio recordings from classroom interactions and interviews. (including group discussions before, during, and after drama activity in each task). | Video- and audio recordings from drama room interactions. | Video- and audio recordings from drama/music-room interactions. |

| | **Project 1**<br>Papers I and II | | | **Project 2**<br>Papers III and IV | |
|---|---|---|---|---|---|
| | **Cycle 1** | **Cycle 2** | **Cycle 3** (two sub-cycles) | **Cycle 1** | **Cycle 2** |
| **Empirical material** | About 1 hour of video recordings in the classroom. | About 5 hours of video recordings in the classroom and 2 hours from interviews. | About 9 hours (4 + 5) of video recordings in the classroom. | About 4 hours of video recording. | About 9 hours of video-recordings. |
| | About 2 hours audio recordings of 2 groups of total 5 (4–5 students/ group) | About 4 hours audio recordings of 4 groups of total 5 (4–6 students/ group) and 2 hours from interviews (5 groups). | About 7 (3 + 4) hours audio recordings of 3 groups (in the first class) of total 6 (4–5 students/group) and 4 groups (in the second class) of total 6 (4–6 students/ group). About 1.5 hours (0.5 +1) audio recordings of interviews (2 groups). | About 2.5 hours of audio recordings of 2 groups of total 4 (3–5 students/group). | About 9.5 hours audio recordings of 4 groups of total 4 (4–5 students/group). |
| | Written material from group tasks. | Written material from individual submission tasks. | | Written material from writing in role. | Written material from writing in role. |

# Analytical procedure

The audiovisual and transcribed empirical material from Project 1 forms the basis for the analyses conducted in Paper I and Paper II, and the audiovisual and transcribed material from Project 2 forms the basis for the analyses in Paper III and Paper IV. Driven by my research questions and my broader theoretical assumptions, I conducted thematic analyses of the data (Braun & Clarce, 2006; Erlingsson & Brysewich, 2017; Graneheim & Lundman, 2004). This approach involves different forms of analysis depending on the role the theory plays – often it is a gradual shift towards a theory-driven analysis or an explorative empirically driven analysis (Braun & Clarke, 2006). Theory-

driven analyses "tend to be driven by the researcher's theoretical or analytic interest in the area" (Braun & Clarke, 2006, p. 84), whereas empirically driven analysis is a "process of coding the data without trying to fit them into a pre-existing coding frame, or the researcher's analytic preconceptions" (Braun & Clarke, 2006, p. 83). In Paper I, I approached the data with a theory-driven analysis. In Papers II, III, and IV I adopted an empirically driven analysis and searched for themes in a more flexible and exploratory way to uncover new insights directly from the data.

## Multimodal social semiotic analysis.

In Paper 1, I used a multimodal social semiotic analysis. I studied the semiotic resources and the kind of semiotic work students were involved in when they explored abstract non-spontaneous concepts related to electronegativity and chemical bonding in creative drama. The empirical material in Paper 1 was analysed based on Cycle 2, partly because I realised that the rich data from Cycle 2 were sufficient for answering my research question in Paper I, and that the range of the cameras in Cycle 1 was limited. After the preliminary overview of the transcripts, I chose the unit of analysis to be the parts of the audiovisual material where the students worked with the water molecule (see tasks 3 and 4, page 54). I chose this part of the drama activity because I found it interesting to analyse the students' exploration of the more complex molecule, where the students created a need to represent the angle of the water molecule in several ways. I analysed the recorded material based on multimodal micro-analyses (cf. Heath et al., 2010) and noted the semiotic modalities that the students used when exploring the non-spontaneous concepts. To distinguish the processes where meaning was transformed, I used the operational concepts of transduction and transformation (see Kress, 2010). As described earlier in Chapter 4, transduction refers to inter-modal changes; when the entities switch from one semiotic modality to another. For example, when students in creative drama make a written structural formula for a molecule and then visualise the molecule with bodily mode. Transformation refers to intra-modal changes, which means that units/elements are reshaped within a certain semiotic mode. For example, when the students in one group were inspired by another group's representation of a molecule and transformed the molecule into the representation with their own bodies. In a thematic analysis of the material, I noted the inter- and intra-modal changes that became visible when the students explored the non-spontaneous concepts in the drama activity (tasks 3 and 4), which I then categorised into different types of transductions and transformations.

## Qualitative content analysis

Qualitative content analysis, which was used in papers II, III and IV, is a thematic analysis method used to explore and interpret textual and visual data in

a systematic and rigorous manner. It involves the process of categorising, coding, and analysing data to identify patterns, themes, and relationships, and aims to capture the subjective and nuanced aspects of human communication (Erlingsson & Brysewich, 2017). In the analysis of papers II, III and IV, I adopted qualitative content analysis as described by Erlingsson and Brysewich (2017) and Graneheim and Lundman (2004) also embraced by Wiblom (2020) in educational research. When I applied the qualitative content analysis framework, I first identified meaning units (1), sentences, or paragraphs that contained aspects related to each other through content or context. In the next step, these meaning units were condensed into codes (2), that most accurately described what the meaning units were about. Then the codes that were related to each other through the content or context were grouped into categories (3) and finally, as an expression of latent content in the data, categories were grouped into themes (4). Below, I describe how I applied the framework in relation to papers II, III and IV.

**Paper II**

In Paper II, the empirical material from Project 1 was analysed based on cycles 1, 2, and 3, to investigate how students establish relationships between concepts related to chemical bonding and the ways in which the drama activity may afford collective student agency. Before the actual analysis began, I decided that the unit of analysis would include the students' multimodal interaction (bodily, verbal, and textual) when they explored electronegativity and chemical bonding. My analysis includes the students' work in groups before, during, and after a completed drama activity, as well as the interactions in whole-class activities.

Table 6 illustrates how the steps of the analysis are related to each other. The left column exemplifies meaning units that were discerned from the transcripts when the students worked on creative drama. To frame what the students explored about electronegativity and chemical bonding in creative drama, the meaning units were condensed into codes that served as labels for which chemical content the students explored. The second column (from left) illustrates how the three meaning units were condensed into codes: *Fighting for the electrons*, *The most electronegative atom pulls on the shared electrons more*, and *Covalent bonding, with linked arms and a willingness to share electrons*. Once all meaning units had been coded, they were grouped into categories with similar content that answered the question of the ways in which students explored electronegativity and chemical bonding in creative drama. Each category served as an umbrella for the content that was related to that the students explored in their semiotic work. As can be seen in the third column (from the left), the codes *Fighting for the electrons* and *The most electronegative atom pulls the shared electrons more* are both associated with students' work on electronegativity and the bodily embodiment of electronegativity using of anthropomorphic expressions. This is sorted under the category

*Display electronegativity within the bodily mode together with anthropomorphic expressions*. Similarly, the code *Covalent bonding, with linked arms and a willingness to share electrons* was sorted under the category *Display covalent bonding within the bodily mode together with anthropomorphic expressions*.

Table 6. Examples of how the qualitative thematic content analysis was applied in Paper II.

| Meaning unit | Code | Category | Theme |
|---|---|---|---|
| *Lisa: You must fight with your electrons – so you have to stand and pull and tear into the oxygen atom.*<br>*Lars: Mmmmm.*<br>*Lisa: Because she has everything – is most electronegative!* | Fighting for the electrons | Display electronegativity within bodily mode together with anthropomorphic expressions | Displaying electronegativity and chemical bonding with anthropomorphic expressions |
| *Elliot: Eeeee! who has, who pulls the most?*<br>*Arne: Anna pulls the most.*<br>*Elliot: Am I the most electronegative?*<br>*Per: Yes.* | The most electronegative atom pulls on the shared electrons more | | |
| *Isak: And so they share two electrons, which is why they hold each other in their arms there, because both atoms want an electron * points to their friends who visualise covalent bond by holding each other's arms**. | Covalent bonding, with linked arms and a willingness to share electrons | Display covalent bonding with the bodily mode together with anthropomorphic expression | |

Finally, to discern themes in the students' semiotic work, the transcripts and the audiovisual data as a whole were re-read in search of patterns. A theme can be seen as an expression of latent content in the text and answers the question "How?" (Graneheim & Lundman, 2004). The fourth column (from left) is the theme *Displaying electronegativity and chemical bonding with anthropomorphic expressions*, which describes the ways in which students explored the chemistry content through creative drama.

**Paper III**

In Paper III, the data from cycles 1 and 2 in Project 2 were analysed to investigate what dimensions of plastic pollution and plastic use the students explored when participating in a chemistry education process drama. The unit of

analysis includes the students' individual explorations as well as group and whole-class interactions, when they worked with the wicked plastic issue in all episodes in process drama (see Table 3). The analysis in Paper III primarily relies on students' interactions in the classroom with a focus on speech. I followed the same qualitative content analysis procedure as described in Paper II, above. Table 7 illustrates an example of how the thematic content analysis was applied in Paper III. For example, the meaning units sorted under the codes *Disseminate knowledge* and *Recycling and reuse* were associated with the category *Societal-oriented solutions to problems of plastics*. Together with another category (*Framing the plastic issue as a societal problem*), this category formed a theme which I labelled *Exploring the plastic problem from a societal perspective*.

Table 7. Examples of how the qualitative thematic content analysis was applied in Paper III.

| Meaning unit | Code | Category | Theme |
|---|---|---|---|
| *Student: Journalists have an important role to play as an intermediary in the transfer of knowledge.*<br><br>*Student: Scientists must get better at disseminating facts to citizens.* | Disseminate knowledge | Societal-oriented solutions to problems of plastics | Exploring the plastic problem from a societal perspective |
| *Student: We need to improve infrastructure and general advice so that it becomes possible for everyone to handle plastics – the infrastructure plays a large part in plastic recycling.* | Recycling and reuse | | |

When analysing the ways in which the students achieved agency when dealing with complex sustainability issues (experienced by participating in chemistry education process drama), I re-read the transcripts and the audiovisual data as a whole. I searched for patterns and used the dialectics of margin|centre and agency|structure to analyse and describe how the students were enabled to participate in the drama.

**Paper IV**

In Paper IV, based on the empirical material from Cycle 2, I investigated how imaginary transitions through time in process drama could support students' exploration of wicked problems. The students in Cycle 2 had more time for improvisations and reflections out of role in the process drama which provided me with a rich data. In the transcribed data from all episodes in the process drama (cf. Table 3) and in students' texts produced when they were writing in

role, I searched for instances when the students were engaged in temporal transitions. I followed the same qualitative content analysis procedure as described in Paper II, and III above. Table 8 illustrates an example of how the thematic content analysis was applied in Paper IV. Following the example, meaning units sorted under the codes *Give general advice and act now otherwise worst-case scenario* and *Not to have the problems today in the future to live in a climat-smart way* was categorized in relation to how the students connected the temporalities in the process drama – *Connecting present solutions to future scenarious.* This category, together with other categories formed a theme *Connecting social and environmental perspectives into the bigger picture,* that captured what dimensions of the plastic problem were made visible in the temporal movements in the process drama.

Table 8. Examples of how the qualitative thematic content analysis was applied in Paper IV.

| Meaning unit | Code | Category | Theme |
|---|---|---|---|
| *Stina: We must give general advice and "act now!" Otherwise worst-case scenario (shows picture of hugh plastic pile on her computer) - otherwise remain in Dystoplastica!* | Give general advice and act **now** otherwise **worst-case scenario** | Connecting present solutions to future scenarious | Connecting social and environmental perspectives into the bigger picture. |
| *Lisa: In order to not have the problems we have today in the future, we must create opportunities to live in a climate-smart way - more recycling stations - there must be opportunities for everyone regardless of where you live.* | Not to have the problems **today** in the **future** to live in a climat-smart way | | |

## Forms and conditions for participation in the projects

In the projects, I took on different positions in my role as a researcher, which affected the form and conditions of the participating teachers, students, and researchers. I had the role of teacher–researcher – participating in the research lesson as a teacher conducting research in my own practice with my own students; I was an observer in the classroom when another teacher I have collaborated with performed the research lesson with his students; in between, I actively participated to varying degrees in the research lesson as teacher-in-role (TiR) and drama facilitator; I also collaborated with other teachers. Below, I describe the research roles I have had and forms and condition for participating in the research project's various cycles.

## Conducting interventions in my own practice

In the first two cycles in Project 1, I was both teacher and researcher and conducted the research together with my own students in the ongoing teaching in the classroom. In the other cycles in both projects, I collaborated with teachers in various ways. When the first project was conducted, I taught chemistry in secondary school part time, and participated in a graduate school in science education at a university. The aim was to strengthen the link between research and school development, but also to expand science teachers' (didactic) knowledge base and professional development. The dual role of teacher and researcher allowed me to anchor my challenges in teaching in relation to theoretical perspectives and relevant research literature from the graduate school. In addition, in Cycle 2, my supervisors participated in the research lesson, assisting me in the data collection. Further, my knowledge of the school's context, extensive teaching experience (20 years), the chemistry curriculum, and my own lesson plans facilitated the planning of the research lessons. Thus, the research lesson was aligned with the ongoing teaching about chemical bonding, which enabled both me as the teacher and the students to experience the research lesson as meaningful. The students thus participated in both research and teaching conducted by their own teacher, which has consequences for the projects' validity and ethical stances (cf. Andrée et al., 2020), further discussed under the validity and ethics sections.

## Conducting interventions as an observer

I have also assumed the role of researcher observing the intervention in the classroom. This was most evident in Project 1, when the teacher in Cycle 3 performed the drama activity with his students. The teacher participated in the research by teaching the students during the intervention, but also through our joint planning and discussions in connection with the two research lessons. During the planning sessions, I strove to present and discuss the design of the creative drama so that the teacher could adapt the research lesson according to his wishes and conditions in the current school context – for example, conducting the research lessons in both of his classes. As a researcher, I was given the opportunity to walk around in the classroom and observe the activities from an outside perspective while operating cameras and recorders. When the research lesson started, I tried to stay in the background and not disturb the activity in the classroom. However, as the research lesson progressed, I experienced (in line with previous close-to-practice research; cf. Wiblom, 2020) how the students started treating me as a teacher – asking me for advice and assistance. According to Sensevy et al. (2013) this blurring of roles between teacher and researcher is a sign of "local indistinguishability" between the two. I accepted this role even though it wasn't what I had in mind. A conse-

quence of this was that I sometimes guided the students and answered questions, while gaining an increased insight into how the students reasoned about chemical bonding.

### Conducting interventions as teacher-in-role and/or drama facilitator

In Project 2, I had the role of an observing researcher in parts of the research lessons in cycles 1 and 2. Unlike the last cycle in Project 1, described above, I had already decided, in the planning of the implementation of the research lessons, that there was a need for me as a researcher to participate in the process drama. One reason for this was that in Project 1 I was able to design and implement the research lesson in creative drama based on previous research on drama in science education, my subject knowledge of chemical bonding, and experience from many years of teaching. In Project 2, I learned that this was not enough, but to design and implement the research lessons, I also needed to acquire knowledge of how process drama, with all its drama conventions, could be put into practice. This also meant that the participating teachers in Project 2 who were not familiar with process drama, needed guidance from me during the research lessons, unlike the teacher who participated in Project 1. In Project 2, I therefore participated in both cycles as a researcher and teacher in the form of a drama facilitator. In Cycle 1, in Project 2, in addition to participating as a drama facilitator, I also participated as TiR and narrator and guided the drama conventions which consisted of reflections out of role. In addition to TiR, the participating teacher acted as a team member together with the students throughout the drama activity, as well as participating in the reflections out of role. In Cycle 2, in Project 2, I had a less active role and participated solely as a drama facilitator and researcher, while the teachers participated as TiR. In addition, the teachers also narrated and guided the reflections out of role. As an observer, this gave me insights into how transferable the process drama design was to another teacher.

## Methodological considerations

Throughout the study, I used various strategies to ensure validity and credibility. Validity is contingent upon the mode of research (Newton & Burgess, 2008). My dissertation reports on a design-based educational study that seeks to advance knowledge on how different forms of drama in upper secondary chemistry education can support students' learning in chemistry teaching, and how the drama can be designed to achieve this purpose. Thus, the mode of this research can be characterised as knowledge generating and practical (improvement of practice). The primary forms of validity for knowledge-

generating research are outcome- and process validity (Newton & Burgess, 2008). Outcome validity measures how the research purpose is aligned with the research outcomes, and process validity the extent to which the data one has hold up as evidence for the claims one wants to make. In accordance with Anderson and Herr (1999), the credibility of close-to-practice research also depends on dialogic, democratic, and catalytic validity. Dialogic validity is about how the research has been exposed to scrutiny in a critical and reflective dialogue with other researchers, democratic validity to how the research is done in collaboration with all participants, and catalytic validity is about the extent to which the research process has contributed to a transformation of the people who have participated. In the text below, I reflect on the methodological considerations regarding different forms of validity and conclude by discussing various aspects of generalisability that underpin my dissertation.

## Validity

Outcome- and process validity in qualitative research focus on the process of interpretation, how the interpretation has been made, and on the researcher's awareness of the features that may influence the interpretation (cf. Coe, 2013). In the processes of analysing data, I have striven to be transparent in the interpretation process by thoroughly describing how I transcribed the data and performed the various analyses that form the basis of the interpretation of the results. The iterative nature of the design-based study has helped to develop and refine my interpretation of the results. In this way, theory has been built on data and both theory and interpretation of data have been updated for each cycle to ensure an overall consistency in the study. In addition, the multimodal and thematic qualitative analysis is based on rich empirical material and I sought to provide "thick descriptions" of the research lessons (Geertz, 1973). Another methodological concern is whether the results could have been influenced by my own opinions, background, and values. Anderson and Shattuck (2012) argue, in line with Coe (2013), that it is a well-known challenge in many forms of qualitative research for the researcher to avoid researcher bias in the research process. However, they also point out that many proponents of qualitative research claim that the researchers themselves with all their bias, insight, and deep understanding of the context are still the best research tools. Hence, having in-depth knowledge of the context where the interventions were conducted could be regarded as an advantage. For example, background knowledge about the participating students in Project 1 (cycles 1 and 2) gave me the opportunity to compare the students' activity in traditional chemistry teaching to their activity during the interventions. During my active participation in the research lessons, I observed how the students positioning themselves in the classroom. Several of the students who previously had not participated in the teaching participated through bodily formations of molecules and through chemical reasoning. This was an asset when interpreting the results. Throughout the research process, I tried to maintain a balance between

my background as a teacher and later researcher, but I cannot ignore that my teaching background may have influenced the interpretation of the results. Thus, another researcher may have interpreted my data in another way.

Dialogic validity is key for ensuring both outcome- and process validity and involves critical and reflective dialogue between researchers in the analysis of the results (cf. Coe, 2013). Throughout projects 1 and 2, I collaborated closely with my supervisors in a critical and reflective dialogue during the process of analysis. The analysis has further been verified by other researchers in seminars with research colleagues at the university, and at National and International research conferences.

The catalytic validity is key for the knowledge-generating as well as the practice-developing purposes, and concerns the extent to which the entire research process has contributed to a transformation of the participants in the projects (Newton & Burgess, 2008). Wagner (1997) describes how research projects are in themselves social interventions in the lives of researchers and practitioners, and a transformation became very tangible in this research process. Because this close-to -practice research has high ecological validity, the transformation becomes part of the students' teaching. In Project 1, students may transform their understanding of chemical concepts, and in Project 2, they may transform their understanding of the wicked plastic problem. Methodological consideration was given to the students who were in the classroom but who for various reasons did not want to participate in the study. In the design of the research lessons, we took these students into account, so they were guaranteed equivalent teaching (see also the section on ethical considerations). All students' "voices must be heard" in the results, which is a prerequisite for achieving democratic validity (Newton & Burgess, 2008). Transformations also became tanglible from my own perspective as teacher and researcher in the same person, and for the teachers who participated in the projects. My research project has become an intervention that has influenced my teaching as well as my view of my own teaching. The participating teachers and I have been able to directly apply the acquired knowledge about drama in science education that the research generated. For example, at the end of the process drama in Project 2, the Chemistry teacher told the students that "[the Biology teacher] and I, we are actually very keen to do this [process drama] again in other groups and then take this with us." The teacher asked: "This way of doing it a little differently, do you think we should do that?" to which several students responded "Yes!" In addition, the participating teachers and I have been able (and still can) share our experiences with the closest colleagues who, although they did not participate in the research, may have been indirectly transformed and developed their teaching accordingly.

## Generalisability

Critics argue that qualitative research results are difficult to generalise beyond the situation in which they are produced and that it is impossible to generalise

the results to other settings (Bryman, 2007). Instead of marginalising the generalisation issue, Larsson (2009) emphasises the importance of a pluralistic perspective on the generalisation discourse because different types of research face different types of generalisation problems. My investigations were produced with close-to-practice research consisting of relatively few cases and based on the assumption that learning is situated in practice, which implies certain limitations for the generalisability of the results. The first two cycles in Project 1 were conducted in my own classroom with me as the teacher well-grounded in the context, which mainly resulted in an understanding of learning within a specific context. One question I asked myself after Cycle 2 was how the intervention would work with another teacher who had no prior experience of creative drama, teaching students in another classroom. To answer the question, the third cycle of the study was carried out in a different context, where the teacher was able to work productively with his students on the tasks included in the research lesson. The first cycle in Project 2 also generated knowledge in a local context in the sense that I was familiar with the school, the students, and the teachers. Hence, I had taught the students chemistry one year before the intervention was carried out. To expand the context, the intervention in the second cycle was carried out with teachers and students who had no previous experience of using process drama in chemistry education. Although I participated as a drama facilitator, I observed that the teachers were able to work productively with their students on the tasks included in the research lesson, just like the teacher in Project 1.

Interventions in projects 1 and 2 made it possible to generate knowledge in an expanded context, at the so-called *middle-range theory* level (McKenney & Reeves, 2012), which can be considered to increase the generalisability of the study. Further, in line with Larsson (2009), the results from the two projects have the potential to be generalised through *context similarity* and *recognition of patterns.* For a reader to be able to assess the context similarity, I have striven to provide a "thick description" of the interventions. For example, giving a teacher–researcher/teacher help in assessing how transferable the results are to their actual context. Even if the context is different from the context in which the drama was performed, generalisation can be based on recognition of patterns. For example, how students transform the bodily mode between each other when exploring abstract non-spontaneous concepts. In my analysis, I describe and interpret processes that have emerged from situations of human activity. In my interventions, it is a process not a person or context that is the focus of research. In this sense, it is very difficult to predict when and where something similar will occur, but we can be attentive when we observe similar situations. For example, how the students in particular situations use the semiotic resources in the drama activity regardless of the classroom and even the subject. The research in this dissertation is aimed at understanding special situations, what Carlgren (2011) in educational research calls *particularistic research.* While research conducted from a *universalistic perspective* aims to develop knowledge about general relationships, particularistic-

oriented research aims to develop knowledge that can contribute to the qualification of a teacher's professional judgement (Carlgren, 2011). Knowledge generated in close-to-practice research, where teachers have had an active role, can be understood as a tool for the planning, analysis, and follow-up of teaching – "tools to think with" (Anderhag et al., 2023).

# Ethical considerations

Throughout the research process, I made decisions in accordance with the ethical regulations and guidelines provided by the Swedish Research Council (2017). The data collected in this dissertation do not contain sensitive personal data (GDPR EU 2016/679), and were thus, in accordance with how sensitive data are defined in the Ethics Review Act (SFS 2003:460, 2003[2]), not subjected to ethical review.

However, close-to-practice research still entails ethical challenges (Barab & Squire, 2004) that go beyond these regulations. The close-to-practice research is embedded in a social context with teachers, students, researchers, and other stakeholders both inside and outside the classroom. Various issues are at stake in terms of loyalty, dependence, assessment, power relations, and relationships for participants in different positions, which require insightful attention to ethical considerations (cf. Andrée et al., 2020). My dissertation projects thus entail ethical challenges in addition to the issues of informed consent and confidentiality, which are important to stress and reflect on throughout the research process (cf. Adams & Siry, 2020; Andrée et al., 2020; Otrel-Cass, 2020). In the text that follows, I highlight some examples from situations in the research process where the importance of ethical considerations and reflections became essential. In the text, I also emphasise how I paid attention to ethics in planning, implementation, analysis, and documentation. Finally, my ethical considerations concern the dissemination of the results from my research projects.

## Reflexivity in the research process

In collaboration with teachers, I have been guided by Sensevy et al. (2013) principle of symmetry. The collaboration between the participants in this design-based research ensured that the researchers and teachers shared responsibility for the classroom intervention, thus ensuring that knowledge and

[2] Sensitive personal data is data concerning; racial or ethnic origin, political opinions, religious or philosophical beliefs, membership of a trade union, health, a person's sex life or sexual orientation, genetic data and biometric data that is being used to uniquely identify a person.
See also:
https://www.imy.se/verksamhet/dataskydd/det-har-galler-enligt-gdpr/introduktion-till-gdpr/personuppgifter/kansliga-personuppgifter/

power in the research was distributed equally. In addition, my ethical reflections include ontological, epistemological, and methodological considerations that go beyond this principle of symmetry (Andrée et al., 2020). Reflexivity has also been a guiding light throughout the research process. As Otrel-Cass (2020) indicates, "[e]thical considerations and negotiations should not only take place before but also during the process of data collection, and later on the analysis" (p. 197). Hence, it is important to be able to change the planning so that the participating teachers' knowledge and knowledge interests are utilised, which promote the consideration of symmetry and epistemological values. In all cycles where I collaborated with teachers, I entered as a researcher with a more or less complete intervention that I presented to the teachers, which I found challenging for the symmetry. To reduce the gap between researchers and teachers, we planned the research lessons together and I was very sensitive to the teachers' views regarding both the planning and implementation. For example, in Project 2, the teachers, during the planning in Cycle 1, wanted the drama to focus on human rights regarding the plastic problem, because it was this theme that was being dealt with in the teaching, so we incorporated this into the drama plan (in Episode 10, see Table 3). In line with the principle of symmetry (Sensevy at al., 2013), the teachers and I (as researcher) shared the responsibility for the implementation in the classroom/drama room, even though it was the teacher who made the on-the-spot decisions in the teaching situation, and everything was subsequently discussed in the "team". As Otrel-Cass (2020) points out, it is important that research conducted in the classroom – on a micro level with both teachers and students – allows for constant negotiation. In Project 2, where the students became involved in creating the process drama in an ongoing activity (for example, regarding how far we should travel into the future) and in out-of-role reflections, this negotiation became most tangible. Also, the students were enabled to orally share their experiences of participating in the process drama and come up with suggestions for how the design could be improved. In Project 2, the students thus became involved in the design of the next cycle and may partly be considered co-researchers (cf. Otrel-Cass, 2020). For example, the students in Cycle 1 requested more developed role descriptions, which we created for the next cycle. Hence, throughout the research project, the students' voices in particular have been essential.

## Dependency and assessment

In all cycles in projects 1 and 2, formal written consent was given by the participating students in accordance with the ethical guidelines provided by the Swedish Research Council (2017). According to the consent requirements, research participants have the right to decide for themselves about their participation and in research where they participate actively, consent must always be obtained (Swedish Research Council, 2017). As both researcher and teacher, this was an important ethical consideration to take into account, clarify, and

discuss, and the question of student assessment must be considered. In Project 1, this became obvious when the students on several occasions during cycles 1 and 2 asked how they would be assessed on this part of the teaching. Because the study was part of the ongoing teaching, the students' enactment in the classroom was also taken into account, which was a consequence of the study being situated in a natural context with me in the dual role as teacher and researcher. However, in projects 1 and 2, the students were informed that video and audio recordings would only be used for research purposes but that the written assignment in Project 1 would be assessed and was mandatory for all students, i.e., not only the ones who participated in the research. In this way the students' participation in the drama activity was not assessed during the research lesson (see Österlind & Hallgren, in press), thus there would be no risk of harm in relation to assessment for the students who chose not to participate in the research. Also, all students were provided an opportunity to display their learning about electronegativity and chemical bonding and have it taken into account in the final assessment.

Another ethical consideration concerns how to deal with students who do not consent to participate in the study. To create an equal teaching situation that gave all students the opportunity to develop and learn chemistry, it was important that the students who did not give their consent were offered participation on the same terms as the participating students. During all three cycles of Project 1, these students were placed at a table without any audio recorder and out of camera range. They were offered participation in all activities and were also interviewed in Cycle 2 after the actual drama activity. Because these students did not dramatise their tasks and did not participate in the bodily visualisation in the classroom, I made sure to pay attention to them so that they were not "forgotten". During the group discussions, I spent just as much time with this group as I did with the others, listening to the discussions and giving them the opportunity to ask questions. I also paid attention to letting them into the classroom conversations.

In Project 2, students and teachers performed and created the process drama together, and I found it more difficult to place a group out of the camera's reach. All participants moved around in the room and the improvisation episodes were more unpredictable. Several weeks before the intervention was conducted, I discussed this with the teachers and they developed various teaching alternatives for the students who chose not to participate. In Cycle 1, there were several students in the class who emphasised that they did not want to be video recorded, but in Cycle 2, all the students gave their consent to participate. During the students' follow-up work connected with the process drama in the first cycle of Project 2, I moved around the classroom and discussed the plastic issues with them. I drew attention to and reflected on what consequences it had for the students who chose not to participate. I paid attention to how the students who had participated asked questions that were probably sparked by the drama. For example, they were curious about Hermann

Staudinger and his work with plastics and also asked questions about the plastic material that we used in the drama (e.g., polyethene). The students who did not participate in the drama, but instead had worked with self-studies about plastics, did not come up with those questions. In hindsight, from an ethical point of view, to increase the possibility of giving all students an equal education, I could have conducted the process drama twice – once with video and audio recorders and once without.

## Documentation of the research

Other challenges in participatory educational research concern the documentation of the research (Adams & Siry, 2020; Andrée et al., 2020; Zeni, 1998). An important ethical consideration for the researcher, regardless of whether they are a teacher or not, is to have insight into what can be documented in the research without exposing students and teachers to negative consequences. In both projects, I was given a unique insight into the micro-dynamics of students' discussion, both during observations in the classroom/drama room and in the subsequent analyses. In line with the Swedish Research Council (2017) guidelines, I took both the research requirement and the individual protection requirement into account and weighed these two requirements against each other, so that a knowledge contribution could benefit the students and lead to increased learning in both the short and long term without jeopardising their anonymity. All students who participated in the research project have therefore been anonymised and there is no information in the documentation that can reveal their identities.

The teachers involved in the project did not participate in the documentation process, but I would like to emphasise that they were a very important part of the project where their opinions, knowledge, and actions in the drama itself, not least in the form of teacher-in-role, affected the entire research process. In the cycles where I have had various forms of collaboration with teachers, I have not named the teachers in the documentation, in accordance with the provisions on anonymity in the consent form. Of course, this challenges the symmetry with respect to giving them recognition and credit.

## Transformation and dissemination

Finally, I would like to say something about the utility-oriented aspect of the project which is an important quality criterion both for design-based research (van den Akker et al., 2006), and close-to-practice research. Adler & Lerman (2003) ask for what and for whom the research is for. This is related to the catalytic validity previous discussed and linked to ethics – it would not be ethically correct to study the teaching and not give anything back to either teachers or students, both locally and more generally. As previously mentioned, because the research took place as a part of ongoing teaching, the trans-

formation itself became part of the teaching, which involves students, teachers, and me as a researcher. Ethical consideration was given to the students who were in the classroom but for various reasons did not want to participate in the study, so that these students were guaranteed an equal education which enabled transformation.

As Adams and Siry (2020) emphasise, it is important, not least from an ethical point of view, that research results are made available more widely than just to those who are directly involved in the research, and that we must find other ways to disseminate research than merely publishing in research-oriented journals. Hence, a rationale of this dissertation is that chemistry teachers find the research results useful and are able to try the proposed design principles from Project 1 and Project 2 as a framework for using drama in their classroom. Not solely for those who took part in the research, but also so that the knowledge produced can be stored and shared, for example in a "teacher's guide", enabling other teachers to benefit from the results – a prerequisite for strengthening the knowledge base of the teacher profession.

# 6. Summary of papers I-IV

This chapter is a summary of the four papers included in this dissertation. For each paper, a short background, the theoretical approach, the aims and particular research questions posed, the methodology, the main results, and conclusions are provided.

## Paper I: Creative drama in chemistry education: a social semiotic approach

The first paper focuses on the kind of semiotic work students are engaged in when exploring chemical bonding and electronegativity through creative drama in upper secondary chemistry education. Chemistry in upper secondary school predominantly involves concepts that may be classified as non-spontaneous scientific concepts (Vygotsky 1934/1999). Non-spontaneous concepts are those that do not arise from personal experiences and are not developed naturally through everyday life. Initially, these concepts are completely abstract, but they can be acquired through teaching. Previous research has identified several key non-spontaneous concepts, particularly regarding the various organisational levels of chemistry – *macro, sub-micro*, and *symbolic* (De Jong et al., 2013; Gilbert & Treagust, 2009; Johnstone, 1982). Students have difficulty moving between the different levels of organisation (Gilbert & Treaugust, 2009; Harrison & Treagust, 2002), and for students to understand chemical observations at the macro level, they must use sub-micro scale models (Oversby, 2000). Such models need to "make the invisible visible" – that is, the models need to describe, or explain, macro-level observations with the sub-micro model (De Jong et al., 2013; Harrison & Treagust, 2002; Wu, 2003). The particulate nature of matter is another key non-spontaneous concept of chemistry (Harrison & Treagust, 2002; Taber & Coll, 2002), strongly linked to chemical bonding (Harrison & Treagust, 2002; Taber & Coll, 2002). Students have difficulty distinguishing between intra- and intermolecular forces in chemical bonding (De Jong et al., 2013; Peterson & Treagust, 1989; Taber & Watts, 2000), and lack an understanding of the non-spontaneous concept of *electronegativity* – the atom's ability to attract electrons from other atoms (Harrison & Treagust, 1996; Nahum et al., 2008; Taber & Coll, 2002).

Theoretically, the paper draws on Vygotsky (1934/1999) to explore how creative drama in chemistry education can enable chemical concepts – particularly those dealing with different organisational levels of chemistry – to grow into the concrete personal experience of students. In the paper, the sociocultural theory of learning (Vygotsky, 1934/1999) is combined with multimodal social semiotic analysis (Kress & Bezemer, 2015). In social semiotics, meaning is created by many semiotic modes in addition to speech and writing, always in specific combinations, where speech and writing are not necessarily central (Björkvall, 2009; Kress et al., 2001; Kress & Bezemer, 2015). The aim of the paper is to investigate how creative drama can afford students' meaning-making of abstract, non-spontaneous chemical concepts related to chemical bonding by exploring the kind of semiotic work students are engaged in when given the opportunity to use their own bodies as semiotic resources. In response to this, the following research question was asked: *What kind of semiotic work do students engage in when exploring abstract, non-spontaneous concepts related to chemical bonding in creative drama?*

Paper I reports from Project 1 which was conducted in three cycles between 2015 and 2017 in Sweden. The empirical data presented in Paper I come from the second cycle. The intervention lasted for 60 minutes and was conducted during a lesson in upper secondary school Chemistry with a group of 26 students in their first year in the Natural Science programme. During the research lesson, the students explored chemical bonding through creative drama. The main goal of the research lesson was to support their understanding of forces within and between molecules, and the concept of electronegativity at various organisation levels of chemistry. The students, seated in small groups (4–6 students) were given the task of visualising molecules and electronegativity with their own bodies. After enacting the hydrogen fluoride and water molecules in their small groups, the task was to enact the liquid phase of the matter in whole class, in the space in the middle of the classroom, and then to alternate between the different phases of matter. The whole-class activity was intended to comprise key activities to provide students with opportunities to explore how several molecules interact with each other, and allow the teacher to visualise the students' models and discuss their possibilities and limitations. To allow students to use a range of semiotic resources when creating their molecules, artefacts were placed on the tables (white and coloured paper, clothes pegs in different colours, pens, scissors, and tape). The students were also given digital tablets to document the molecules produced in the small groups. The audiovisual and transcribed data were analysed with respect to the *transductions* (*inter*-modal changes – when the units change from one semiotic mode to another) and *transformations* (*intra*-modal changes – when units/elements change within a particular semiotic mode).

The results showed that most students used the textbook or their own notes as the primary semiotic resource and transduced and transformed meaning from the multimodal semiotic complex to written, verbal, and then bodily mode. When the students in the drama activity used bodily mode to display

molecular structures and electronegativity, they transferred meaning from other modes, which means they had to reinterpret semiotic resources. Hence, transductions between written mode and bodily mode as well as between verbal mode and bodily mode enabled semiotic work where students recreated meaning from one mode to another. Because transduction involves an ontological change, transduction is considered to be more far-reaching than transformation where the units remain the same (Kress, 2010). In all groups, the bodily formations of the water molecule enacted by other groups functioned as prompts for the students' semiotic work to recreate meaning from bodily mode to verbal and written mode. The students' bodily formation of the molecules in the classroom served as a prompt for semiotic work which also involved transformations within the bodily mode. The students inspired each other and incorporated each other's bodily formations and changed them into their own creations.

Paper 1 points to the importance of transduction and transformations of meaning for enhancing students' conceptual understanding of chemical forces. Creative drama in chemistry should therefore enable students to use bodily mode in combination with a variety of other modes and enable students to engage in collective semiotic work. Our results show that the interactions between the student groups were key to enabling them to link the sub-micro and macro levels of chemistry. The semiotic work, in the form of transformations within the students' bodily mode, can be considered to strengthen the link between sub-micro and macro level. Hence, the students were given the opportunity to link groupwise bodily formations, representing separate molecules at the sub-micro level, to a collective whole-class bodily formation of a molecular grid structure, representing how molecules are organised on the macro level (e.g., liquid water). Further, when the students' bodily movements and positions were transformed from one group of students to another, we observed creative imitation, in the form of *mimesis*. This paper illustrates how students' bodily mode prompted semiotic work from one student to another in a non-authoritarian environment. This flow of transductions and transformations may extend the functional potential of meaning-making and increase the potential for learning non-spontaneous chemical concepts in the Chemistry classroom. This paper suggests that when using creative drama in chemistry education about chemical bonding, it is important to allow sufficient time for students to interact with each other, move between different states of matter, and talk about why they position themselves in relation to one another in the ways they do. The paper also highlights that teachers using creative drama should be aware of the limitations of simplified models and act to provide students with opportunities to reflect on such limitations. In this way, the bodily models may serve as an anchor for more scientific descriptions and explanations.

To afford students' meaning-making of abstract non-spontaneous chemical concepts when implementing creative drama in chemistry teaching Paper I suggests the following design-principles: (*1) Creative drama in chemistry*

*should open up for students to use bodily mode in combination with a variety of other modes. (2). Creative drama in chemistry should enable students to engage in collective semiotic work.*

## Paper II: The drama of chemistry – supporting student explorations of electronegativity and chemical bonding through creative drama in upper secondary school

Building on the results from Paper I, the aim of Paper II is to investigate how students establish relationships between concepts related to chemical bonding by using creative drama, and how such conceptual relations are challenged and explored by the students in the drama activity. The paper also investigates the ways in which the drama activity can afford collective student agency. Paper II focuses on foundational concepts that previous research has identified as troublesome for students (e.g., Bergqvist & Chang Rundgren, 2017; Nahum et al., 2010; Nicoll, 2001; Taber & Coll, 2002) and, in our experience, difficult for Swedish first year upper secondary students to master during their introductory chemistry course: particulate nature of matter, distinguishing between intra- and intermolecular bonding, hydrogen bonding, electronegativity, and polarity. Whereas previous research has pointed to the potential of using two- and three-dimensional visualisations to facilitate students' theoretical reasoning concerning chemical bonding (for example, Venkataraman, 2009; Wu et al., 2001; Zhang & Linn, 2011), this paper focuses specifically on the potential of using drama where students use their own bodies as semiotic resources. An assumption is that the bodily experiences afforded in a drama activity have consequences for student learning and support student agency (Andrée, 2012; Goulart & Roth, 2010; King, 2012) when exploring chemical bonding.

This paper draws on a conceptualisation of student agency as the driving force of student engagement (Goulart & Roth, 2010). Inspired by the work of Roth and his colleagues (Goulart & Roth, 2010; Roth, 2007) on dialectics in science education and King's (2012) work on interactions in a context-based Chemistry classroom, a dialectical sociocultural lens where agency is conceptualised in the two dialectical relationships of, agency|structure and agency|passivity is adopted. In relation to creative drama in chemistry education, questions of agency concern how the material and social resources provide opportunity and responsibility for the students to transform their understanding of chemistry. The following research questions were asked: (1) *In what ways may creative drama afford students' conceptual exploration of electronegativity and chemical bonding?* (2) *In what ways may creative drama support collective student agency in exploring electronegativity and chemical bonding?*

Paper II reports on Project 2 which was conducted in the form of design-based research in two municipal upper secondary schools in Sweden. A total of four research lessons over three cycles were conducted in the ongoing chemistry teaching about chemical bonding, with students attending their first year in the Natural Science programme. Cycle 1 (25 students) and Cycle 2 (26 students) were conducted in the same school with the first author also being the regular chemistry teacher. Cycle 3 was conducted in another school, in two lessons (26 + 28 students) with a teacher who had not previously worked with creative drama. The interventions (which lasted for 30–60 minutes) were single-lesson interventions consisting of drama activities and discussions in whole class and student groups. The first task the students were given during the research lesson was, in small groups, to form a hydrogen fluoride molecule with their own bodies and show which of the atoms is most electronegative. They then had to provide an oral account of the formations they had made. The second task was, in a whole-class activity, to form the liquid phase of hydrogen fluoride with a large group of students and alternate between the different phases of matter. In the third task, the students in small groups had to form a water molecule with their own bodies and show which of the atoms is most electronegative, and then provide an oral account of the formations. The final task was, in whole-class activity, to form the liquid phase of water with a large group of students and alternate between the different phases of matter. To support the students' scientific reasoning and semiotic work, they were encouraged to use any semiotic resources available in the classroom (e.g., coloured paper, textbooks, computers, digital tablets, cell phones, scissors, clothes pegs, and tape) in combination with the bodily mode. The primary objectives of the lesson were to enable students to distinguish between stronger intramolecular bonds and weaker intermolecular bonds and to enable students to reason about molecular sub-micro level interaction in relation to macrolevel phenomena such as substances' different phases of matter. Another objective was to support the students' ability to link electronegativity (the ability of an atom to attract electrons from other atoms to itself; cf. Danielsson Thorell & Johansson, 2016) to the appearance of the polarity of the bond. The audiovisual data were transcribed and analysed with qualitative content analysis, including coding, categorisation and thematisation (Graneheim & Lundman, 2004). The exploratory analysis made visible themes that captured the ways in which the students explored electronegativity and chemical bonding and how creative drama enabled collective student agency.

The overall results showed that the students demonstrated electronegativity and chemical bonding in several ways. One way was with anthropomorphic expressions, for example, acting like happy, sad, or strong atoms. They also introduced movements to depict electronegativity (especially to bodily express chemical bonding as a continuum) and amplified bodily configurations with other semiotic resources. For example, students made paper electrons and

paper protons that showed the location of the positive pole in the water molecule. Concerning in what ways creative drama supported collective student agency in exploring and demonstrating electronegativity and chemical bonding we distinguished how the students resolved *epistemic dissonance* sparked by bodily prompting. We observed that when the students were asked to present their molecules in an organised form in front of each other and to document their creations with digital tablets, their bodily visualisation became even more visible in the classroom. This encouraged epistemic work in other groups, which had consequences for the students' collective agency. Especially when the students showed the angle of the water molecule, for example, by placing the student representing oxygen upwards (standing on a chair) or downwards (students representing hydrogen atoms by standing on the chairs), questions arose in the groups. We observed that emergent epistemic dissonances constituted opportunities for collective work concerning the conceptual relations where students acted as learning resources for one another. In addition, the students did not merely show that the water molecule has an angular structure; in almost all the groups there were reflections on why the water molecule has an angular structure.

Paper II illustrates that the artefact creation in combination with bodily mode enabled the students to understand the relationship between electronegativity, polarity of the molecule, the angularity of the water molecule, and the occurrence of hydrogen bonding. Further, the findings indicate that using creative drama as a teaching strategy in chemistry education can create opportunities for students' agentic engagement in chemistry. For example, when the students collaboratively resolved epistemic dissonance. The students' interpretation of discursive models (e.g., Mickey Mouse, representing a water molecule, where the ears of Mickey Mouse represent the two hydrogen atoms and the face the oxygen atom), was made visible in action, which enabled the teacher to give the students tools for developing their conceptual understanding. In line with Manneh et al. (2019), the paper argues that anthropomorphic expressions can help students to better understand electronegativity and chemical bonding, which, with the help of the teacher, can then be developed to align with scientific discourse. However, Paper II also suggests there is a risk that potentially ambiguous or incorrect conceptions will arise from the bodily visualisation, and that Chemistry teachers need to be sensitive and act to provide students with opportunities to react to incorrect or limited models.

Based on the results presented in this Paper and Paper I the following design principles intended to support students' exploration of electronegativity and chemical bonding in chemistry teaching are proposed: *(1) Create opportunities for students to work symbolically at both the sub- micro and macro levels and enable reflections at different organizational levels by offering students different semiotic resources as they materialize scientific concepts and processes with their bodies. (2) Create opportunities for students to interact*

*with each other and the teacher in an environment where students' collective agency is promoted.*

## Paper III: Process drama as a tool for participation in explorations of "wicked problems" in upper secondary chemistry education

Paper III focuses on chemistry teaching in relation to complex sustainability problems in today's society, and how drama may be used as a means to support student participation in conversations about such problems. If chemistry education is to be of relevance in relation to such challenging or wicked problems (cf. Rittel & Webber, 1973) – dealing with complexity, uncertain facts, disputed values, high stakes, and the need for urgent decisions, subject matter knowledge on its own is not enough. Instead, chemistry teaching must be organised so that students will be provided with opportunities to engage in conversations about wicked problems, where knowledge of chemistry comes to matter (cf. Block et al., 2019) not as isolated facts, but as part of larger systems, such as the environment. In other words, chemistry teaching should promote *systems thinking* (Mahaffy et al., 2019b). Integrating complex sustainability problems into chemistry teaching can, as Bursjöö (2014) writes, be challenging for a teacher. The teaching must at the same time deal with chemistry content as well as the students' uncertainty and feelings towards issues involving ethical and moral values. Therefore, there is a need to develop teaching methods to handle these challenging issues in chemistry education (Block et al. 2019). Paper III targets a special form of educational drama, *process drama*, as a potential means for enabling student engagement with wicked problems in upper secondary chemistry education. Process drama in teaching gives students the opportunity to face authentic problems and dilemmas from a safe position (Österlind & Hallgren, 2014). There are studies that describe the potential of using drama in teaching about sustainability issues (e.g., Lethonen et al., 2020; McLauchlan, 2006) but studies in upper secondary chemistry education are limited and the possibility of using process drama needs both further scrutiny and design development.

Theoretically, Paper III draws on a sociocultural framework of agency and participation. The metaphor margin|centre dialectic is adopted as a framework that allows learning as participation to be seen as a fluid process and that makes sense of how transformation, development, and learning unfold within the classroom at individual and collective levels (Roth et al., 2013). The two dialectical relations, agency|structure and agency|passivity (cf. Goulart & Roth, 2010; King, 2012) are used for describing students' participation in chemistry education process drama. The aim of this study is to explore how process drama in upper secondary chemistry education can afford students agency when dealing with wicked sustainability issues where chemical

knowledge may be important. For the process drama intervention, plastic pollution and plastic use were chosen as the wicked sustainability issues to focus on. Although there are numerous initiatives to address this issue, consensus on how to deal with it is lacking and the solutions being proposed raise considerations about values related to, for example, the environment and social and economic justice. The following research questions were addressed: (1) *What dimensions of plastic pollution and plastic use do students explore when participating in a chemistry education process drama?* (2) *How is student agency achieved in a process drama on plastic pollution and plastic use?*

Paper III reports from Project 2 which was conducted in the form of design-based research with interventions in two cycles in two municipal upper secondary schools in Sweden during 2021. The students were enrolled in the Natural Science programme. Cycle 1, which lasted for 120 minutes, was conducted during a thematic day about human rights. Fourteen students and a teacher participated as teacher-in-role (TiR), with the first author acting as a teacher and TiR. Cycle 2, which lasted for 180 minutes, was conducted during the ongoing teaching about organic chemistry, with 17 students and two teachers participating as TiR, with the first author acting as a teacher. A process drama plan ("The Journey to Dystoplastica") was designed, focusing on the problem of plastic pollution. Based on role descriptions, students were assigned roles in teams of chemists, researchers, politicians, and journalists who had been given the task of discovering sustainable ways of dealing with the plastic problem. During the process drama, the students and teachers travelled back and forth in time to explore several aspects of plastic use – the motives and needs, and the current and future consequences of plastic pollution. The interventions were video- and audiotaped and thereafter transcribed. To investigate what dimensions of plastic pollution and plastic use the students explored when participating in a chemistry education process drama, an exploratory qualitative content analysis including coding, categorisation, and thematisation (Graneheim & Lundman, 2004) was conducted. When investigating the ways in which the student's agency was achieved when dealing with wicked problems of plastic pollution and use, the dialectics of margin|centre and agency|structure were used to analyse and describe how the students were enabled to participate in the drama.

The results show that the students explored the plastic issue in several dimensions in the process drama. They approached the issue from a *scientific perspective*, considering climate issues and current research, and used familiar resources and artefacts to explore the chemistry of plastics. The students also engaged from a *societal perspective,* finding societal-oriented solutions to plastic problems, including production and consumption, recycling, and economic considerations. From a *value perspective,* they reflected on the value of plastic and its necessity, leading to a better understanding of the complexity of the issue, which also included a global justice perspective. The students and teachers participated in a constant flow between margin and centre with varying degrees of autonomy, from more space to less space, to enact agency. In

some instances, the teacher directed the conversation and the students responded, for example, when the class travelled back in time to meet the chemist Hermann Staudinger. In other instances, the students had more space to enact agency, such as when they were invited to create an advertising jingle for plastic. In these moments, the students were able to move towards the centre of the activity and participate collectively through dance, song, and rhyme. Overall, the process drama allowed the students to actively engage, and shift the margin|centre, taking on roles and precipitating changes in perspective.

Paper III shows that process drama can provide opportunities for students to bring the context of reality into chemistry teaching that tackles wicked problems, and talk about plastic pollution while drawing on knowledge and perspectives of science as well as values and societal and social science perspectives and knowledge. Thus, the process drama mediated a process of dealing with the plastic problem as a complex issue, while it embraced systems thinking (Mahaffy et al., 2019b). In this sense, process drama in chemistry education promotes a pluralistic perspective where students have the opportunity to participate and critically assess several different ideas and ways of managing sustainability problems Our results indicate how a role becomes a resource for both students and teachers to explore the plastic issue in chemistry teaching. Stepping out of the typical "teacher role" (i.e., assuming a role that would not have been appropriate in a normal classroom situation) became a tool for the TiR to mediate and support the students' agentic participation in exploring the plastic issue. In brief, the process drama prompted a need to know and talk about chemical concepts related to the complex issues connected to chemistry content. However, although the process drama in the second cycle drew the students' attention to using more disciplinary resources of chemistry connected to organic chemistry concepts than in the previous cycle, it was the teacher who often introduced the chemical content. If we acknowledge that it is not enough that the teacher uses certain chemical concepts, a remaining challenge is how to strengthen students' agency in using disciplinary chemistry resources as part of process drama.

## Paper IV: Travelling through time in a process drama on plastic pollution – temporality in teaching about the complexity of wicked problems

Paper IV focuses on students' understanding of wicked problems and their preparedness to take action towards a sustainable future, which involves the ability to navigate between past, present, and future. Wicked problems characterised by complexity and ambiguity are problems not easily solved, or of such a nature that there is no solution in the present society (Glasser, 2018). In previous research in science education, the importance of teaching involv-

ing futuring strategies (i.e., strategies for actively imagining futures, thus facilitating anticipatory competence in teaching) has been emphasised. In particular, the FEDORA project has contributed important insights which have been summarised in a manifesto with ten recommendations on how to stimulate "futures thinking" in science teaching (Bol et al., 2023). In this study, students were invited to participate in a process drama dealing with wicked problems in chemistry education, focusing on the resources of all three temporalities (past, present, and future), to make them aware not only of time but of how perspectives and ways of understanding a wicked problem change over time. This may provide students with a more holistic experience and foster a more nuanced understanding of wicked problems, which may support anticipatory competence.

Theoretically, Paper IV draws on the notions of *historying* – imagining the past – and *futuring* – imagining the future – understood as something done in a shared activity where social and material structures mediate and provide the opportunity and space for students to exercise their agency (Goulart & Roth, 2010). The aim of this paper is to explore the ways in which temporal transitions in the form of historying and futuring may contribute to adding layers of complexity to wicked problems in chemistry education. For the process drama intervention, plastic pollution and plastic use were chosen as the sustainability issues to focus on. The rationale for using process drama is that the use of dramatic contexts in the past, present, and future enables the shifting of perspectives and transitions in time, with the potential to make aspects of the complex issue of plastic use visible to students in ways that would not be possible if the process drama only took place in the present (Hallgren, 2018). The following research questions were addressed: *How do students connect different temporalities in the process drama? What dimensions of the plastic problem were made visible in the temporal transitions in the process drama?*

Paper IV reports on Project 2, which was a design-based study conducted in two cycles during 2021 with Chemistry students in upper secondary school in Sweden. The data presented here stem from the second cycle which was conducted in the ongoing teaching of organic chemistry with 17 students aged 16–17. The process drama was planned and conducted in collaboration with a Chemistry teacher and a Biology teacher who participated as teachers in role in the drama, which was performed in the school's music/drama room. A process drama plan, "The Journey to and from Dystoplastica" was designed, where in the dramatic context shifted between the past, the present, and the future (Bowell & Heap, 2013). During the process drama, the students acted as members of research teams – assigned roles as chemists, researchers, politicians, and journalists. The drama involved travelling in a time machine, and the students were invited to explore different aspects of plastics: their uses, the reasons for using plastics, and the impacts of plastic pollution today and in the future. The interventions were video- and audiotaped and thereafter transcribed. The concepts of historying, and futuring were used to describe

and analyse how an imaginary transition in time can enable explorations of plastic as a sustainability issue and afford a nuanced understanding of sustainability problems.

The results show that the students established connections between various temporal dimensions within the context of the process drama through multiple approaches. The students moved between past and present in their reflections on the plastic problem, especially after travelling to the past when the innovation of plastic held many promises. The students engaged in such historying by raising questions about how it was "back in the days", what the alternatives to plastic were, and what possibilities there are for doing without plastic today. The transitions between the present and the future, and back again, were made visible in several instances in the process drama, especially when the students had to come up with suggestions on how we should reduce the negative effects of plastic on the environment. Above all, the experience of travelling backwards and forwards in time in the process drama sparked students' historying and futuring, and they connected these to each other, which was visible in their reflections both out of role and in role. The temporal transitions in the form of historying and futuring made visible several dimensions of the plastic issue in the process drama and contributed to adding layers of complexity to the issue of plastic use and waste. Dimensions that were made visible in the process drama included the students' *moral responsibility* towards the plastic issue, discussions about *global injustices* framed within a temporal perspective that encompassed both historical contexts and future implications of the plastic issue, as well as the *emergence of new injustices* concerning plastic waste management in different parts of the world. Our *dependence on plastic in everyday life,* and a *connection to social and environmental perspectives on plastics into the bigger picture* (e.g., climate issues), were other dimensions that became visible in the process drama.

Paper IV shows that through historying and futuring, the students encountered the plastic issue from different perspectives and dimensions, enabling them to experience a more nuanced understanding of the plastic issue. For example, when the students travelled to the past and experienced plastic when it was seen as a hopeful thing for humanity, and little was known about the environmental implications, a different perspective on plastics compared to today's plastic issue became visible. In line with Rudnert (2019), the findings indicate that the students' transition through time enabled them to highlight the difference between the past and the present concerning the plastic sustainability issue – an ability to understand the present based on the past which may provide them with a readiness to act for the future. However, a question that remains is whether the students' imaginations about alternative futures could have been further strengthened and challenged if they had had the opportunity to face several future and past scenarios (Rieckmann, 2018; Voros, 2003) in the course of the process drama. The results indicate that travelling through

time in the process drama enabled the students to navigate between past, present, and future – a skill students need to be equipped with to deal with the future both in science education in general (cf. Levrini et al., 2021) and chemistry education in particular (Herranen et al., 2021), which is a prerequisite for strengthening students' anticipatory competence (Rieckmann, 2018;Voros, 2003)

# 7. Discussion and implications

This dissertation has sought to contribute to ways of teaching that tackle issues of learning and relevance in upper secondary chemistry education through the use of drama. Why and how drama may support learning in science, particularly in chemistry, is a relatively unexplored area. In this dissertation, I describe how I designed and actively participated in the research lessons in various ways, which enabled me to study the research process and the learning process as a teacher from the "inside", but also as a researcher from the "outside". Hence, by zooming in and examining the actual drama activity in the classroom, this dissertation contributes to the understanding of why and how drama may support students' learning across a spectrum of upper secondary chemistry education, including visions I, II, and III. Findings in Paper I and II contribute to the understanding of why and how drama may support students conceptual learning, in the context of teaching electronegativity and chemical bonding in upper secondary chemistry education. Findings in papers III and IV contribute to the understanding of how drama may support learning about how to tackle wicked problems involving chemical knowledge in the context of teaching about plastics. Below, I discuss the findings from papers I–IV in relation to the dissertation's overall research questions and contribution to how drama may support relevance and learning of chemistry. I then reflect on the balancing act between freedom and guidance when using drama in education. I go on to present the design principles for introducing drama into chemistry teaching practice, and reflections from a teacher's perspective. Finally, I discuss a research agenda for drama in chemistry education.

## How drama can support relevancing and learning in chemistry

An observation I made in my research was that during the research lessons, when drama was introduced into the subject of Chemistry, *all* students participated in the chemistry teaching. No student objected to participating and no one wanted to leave the classroom. We may take this to imply that the drama activities afforded many possible ways of participation. In the creative drama and process drama, the students could shift between passive and active participation. Even if the margin|centre framework was not used in Project 1, the results show that the students moved across a trajectory of margin|centre in a

similar way to Project 2. Their participation in creative drama and process drama was not static but, in line with Goulart and Roth (2006), each moment of participation constituted both marginal and central participation, creating a flow of participation that constantly changed in the classroom. Based on Vygotsky (1934/1999), I emphasised that learning is an integral and inseparable aspect of participating in a social practice, which I linked to Lave and Wenger (1991), who describe learning in terms of expanded repertoires for participation in communities of practice. The findings of this dissertation show that when drama was introduced into chemistry teaching, new resources became available to the students and teachers which brought new ways of acting and participating in the chemistry teaching. Thus, the repertoires for participation for both students and teachers were expanded. In particular, the *bodily mo*de was highlighted in the drama activity, explicitly as a resource for meaning-making in chemistry. I also highlight the importance of *the role and the fictitious situation*, and the *collaborative work* where resources, intertwined with the drama settings' social and material structures became available to the students and teachers. Although these resources are entangled with each other, the text below focuses on each of these resources in relation to social and material structures in creative drama and process drama, to discuss how and why drama may support learning and relevancing in chemistry.

## The significance of bodily mode as a semiotic resource

When the students were allowed to use bodily mode in creative drama to visualise molecular structures and electronegativity with their bodies together with a range of other semiotic resources, other types of semiotic work involving various kinds of aesthetic expressions were enabled than those typically offered in chemistry education. Findings from Paper I show that transductions between written mode and bodily mode, and between verbal mode and bodily mode promoted semiotic work where students re-created meaning from one mode to another. Also, the bodily visualisations of the chemical concepts promoted transformations within the bodily mode. Taken together, the bodily semiotic work in creative drama enabled the students to move from a model or description in the textbook's two-dimensional structure to reconstruct and develop their own understanding of specific scientific concepts in a three-dimensional living model with their own bodies (Ødegaard, 2015). No matter how the change of mode – transduction or transformation – changes in meaning were produced, and such meaning production constituted learning (Kress & Bezemer, 2015). In this sense, using the bodily mode in creative drama enabled students to analyse and synthesise information and transfer non-spontaneous concepts and processes into a personally meaningful form that may expand the functional potential of meaning-making and increase the potential for learning.

This dissertation also provides insights into the significance of *producing bodily visualisations* in the classroom that are made visible to the students. In

a social semiotic perspective, bodies – in this case, the students' bodies – can be seen as a "text" which, in line with Brandscombe (2019); "is based on the understanding that the body, still or in motion, carries meaning and can therefore be read" (p. 6–7). In this sense, when the bodily visualisations – "texts" – are made visible in the classroom, it has consequences for the students' learning in chemistry, in several ways. When the students' molecular formations were made visible in creative drama, the formations served as inspiration and prompted other student groups in their semiotic work of creating meaning about the shape and structure of the molecules. The students' visible formations were used both when the students worked in groups on the tasks and when the separate molecules were presented, as well as in the collective presentation of the liquid phase of the matter. The students inspired each other and incorporated each other's bodily formations and transformed them into their own creations. Thus, the bodily movements and positions travelled across the classroom and were transformed from one group of students to another. The semiotic work involved in these transformations includes creative imitation, or mimesis (Wulf, 2008). According to Wulf (2008) mimesis is an important form of learning which relates to the body and creates a practical knowledge that can grow into the concrete personal experience (cf. Siry et al., 2024). There are mimetic elements in any learning process, but drama activities have the potential to foreground and enable more of such non-linguistic mimetic processes. In conclusion, in line with previous research (Brandscombe, 2019; Braund, 1999), these findings contribute to the understanding of drama which emphasises that students do not only learn through their own drama activity, but also by watching the enactments of others.

A main result from Paper II is that when the students' bodily visualisations of chemical concepts became visible in the classroom, it not only inspired them to transform the visualisations of other students' through mimesis into their own creations, but also provided opportunities for the students to agentically pay attention to bodily visualisations which did *not* agree with their own perceptions. These contradictions became opportunities for the students to collaborate and learn from each other, which will be further discussed in relation to students' agency in the section on "togetherness".

The results from Paper III also point to the significance of the bodily visualisations for supporting student learning in relation to humanistic approaches in chemistry education. For example, when the students were given tasks to bodily visualise different aspects of the wicked plastic issue in the established drama convention *tableau* (Brandscombe, 2019), they collaboratively created a statue. In this way, the students in the process drama were enabled to collaboratively express their visions of the future in a silent image – which may promote anticipatory competence. The students were enabled to imagine the future in a way that is not usual in traditional chemistry teaching.

The results also give insight into the significance of *bodily movements* in visualising different aspects of wicked problems and chemical concepts and processes. When the students travelled back in time and were instructed to

make an advertising jingle for plastics, the idea in the original drama plan was for them to make a still bodily image in the form of a tableau. However, the results from Paper III revealed that the students further developed the task and added more modalities. They introduced bodily movements and with song, rhyme, and dance, expressed the view of plastics in the historical past. This can be interpreted as meaning that the students did not consider a static bodily representation in the form of a tableau sufficient to express what they wanted in the task, or that the students had difficulty working with this drama convention because it was a novelty.

Bodily movements also became significant in creative drama. By inviting the students to visualise atoms and molecules with their bodies, the creative drama activity enabled students' spontaneous movements to show electronegativity, enabling an exploration of how electronegativity gives rise to polarity in molecules and how electronegativity and chemical forces are related in a continuum. These chemical processes would have been difficult to visualise in a static representation. Also, the findings from Paper II reveal that the movements and interactions between the student groups were crucial when the students were given the task of linking groupwise bodily formations, representing separate molecules at the sub-micro level to a collective whole-class bodily formation of a molecular grid structure representing the macro level (e.g., liquid water). The semiotic work, in the form of transformations within the students' bodily mode, can be considered to strengthen the link between sub-micro and macro level. The students' engagement in the semiotic work in the creative drama enabled them to bodily move between the different organisation levels of chemistry. In moving between the different organisation levels of chemistry, they engaged in multilevel reasoning which previous research has shown can support students' learning of non-spontaneous chemical concepts and their conceptual relationships (Johnstone, 1982).

These findings, that show how drama can support students' movement between the macro and sub-micro levels of chemistry are in line with Otter's (2020) findings, which were based on interviews with students who had worked with physical simulations of chemical reactions in drama. Otter (2020) concluded that performing drama helped students move from concrete macro-level understandings to more abstract sub-micro level understandings of the relevant chemical concepts. The results from Paper II, which is based on an *actual drama activity in the classroom*, provide the insight that drama can support students' abstract sub-micro level understanding because the students were enabled to *bodily move* between the organisational levels of chemistry.

My conclusion is that although static forms of bodily visualisations, such as a tableau, do have a place in chemistry education to support the learning of chemical concepts and the handling of wicked problems, static tableaux are not sufficient. This is because processes – movements and transitions – are fundamental to chemistry, therefore it is pivotal to include movements in addition to using a tableau when using drama in chemistry education.

## The significance of the fictitious situation

Fiction and imagination are fundamental to drama, and my research shows that the creative drama and process drama indeed established a fictional context with a playful format in chemistry teaching. This highlights the pedagogical potential of serious playfulness (Heikkinen, 2016), which enabled students to be in the fiction while simultaneously being aware of reality, which in drama pedagogy is referred to as aesthetic doubling (Heikkinen, 2016; Østern & Heikkinen, 2001). Moreover, the serious playfulness also has the potential to promote students´ emotionally lived experience – perezhivania (Hallgren, 2018), and in the drama activities the students' emotional involvement became visible, especially when they assumed different roles. Stepping in and out of role in a fictious situation became a recourse for students to learn chemistry in both Project 1 and Project 2.

In Project 1, the students focused on physical simulations and visualised atoms, molecules, and chemical processes with their bodies. However, the students in Project 1 went beyond merely using their bodies as visual models. The findings in papers I and II reveal that when the students in creative drama bodily transformed the macro level representing their real-world experience (e.g., liquid and solid water), and moved to the invisible and abstract imaginary sub-micro level of chemical bonding, they assumed different roles. They showed this by using anthropomorphic expressions regarding the "atom's characteristics" (e.g., strong or weak), but also by bodily visualising emotions (e.g., happy or sad). The students' physical simulations thus displayed elements of human attributes, and show that they assumed roles, and moved between fiction and reality. Accordingly, when the students in creative drama explored electronegativity and chemical bonding in a playful format, it was possible for them to reinterpret symbols and their conventional meanings (Heikkinen, 2016). In this sense, the anthropomorphic expressions became a natural part, promoted by the playful activity in the fictional world, providing an expanded opportunity for experience and reflection. Previous research has problematised the use of various anthropomorphic expressions in chemistry education (Bergqvist, 2017; Nahum et al., 2008; Taber & Coll, 2002). Findings from Paper II show that the anthropomorphic expressions used in a playful format functioned as a means to make sense of electronegativity and chemical bonding, and, in line with Varelas et al., (2010), offer students the opportunity to delve deeper into chemical concepts, thus blending conceptual understanding with emotions.

In Project 2, the findings from papers III and IV add to the body of literature that supports the contention that the role and fictitious situation in process drama provides a more holistic, complex learning experience (Österlind, 2020; Österlind & Hallgren, in press), promoting transformative learning and a more nuanced understanding of wicked problems. In line with Bowell and Heap (2001), by assuming different roles in the fiction, the students found a reason to act – a motive to express themselves from the perspective of the role.

The findings showed that assigning the students different roles as journalists, scientists, and politicians who served the context from different perspectives in the process drama enabled the students to participate in conversations about the plastic issue and experience various perspectives – societal, scientific, and value based – in a playful format, moving between fiction and reality, and bringing their real-life experiences into the process drama. In addition to the disciplinary side of chemistry education, the process drama thus enabled students to experience the humanistic, social, and environmental science perspectives that have the potential to support students' systems thinking, and in line with Sjöström (2019), encounter a meta perspective on chemistry teaching, thus blending visions I, II, and III.

On several occasions in the process drama, the students stepped into role and moved into the centre of the activity, participating and changing the content structure that the TiR had initiated in the narrative. Thus, students becoming central participants in the process drama mobilised the attention of others to focus on their contributions to the collective effort. Although it was the teacher who mediated the transition and took the new perspective, it was the students who, by stepping into the role, used the structure the role provided to move to the centre and give rise to the change of perspective. The findings in Paper III thus reveal that process drama enables students to go "outside the box" in chemistry teaching and promote pluralistic teaching practices (Öhman & Östman, 2019). In this sense, the students were able to participate and critically assess several different ideas and ways of tackling wicked problems.

Moreover, in the whole-class reflections out of role, the students were given the opportunity to move between fiction and reality, and the findings in papers III and IV show that the students in these discussions often used their previous interactions in role as a resource. Further, in the process drama, the students also had the opportunity to move between human and non-human roles when, in Dystoplastica, they had to build a collective statue through tableau where most students bodily visualised plastic items from their real-life experiences.

Assuming a role, and experiencing other roles from the perspective of other participants, as well as going into and out of one's own role, partly within the improvisation moments and partly when reflecting out of role, promoted the students' oscillation between fiction and reality and awareness of both at the same time, enabling the embodied experience of aesthetic doubling – which may give rise to the emergence of meaning in the spaces or gaps that are created (Hallgren, 2018). Those gaps may reinforce the opportunity for self-reflection (Hallgren, 2018) – between the perspective of the roles and one's own perspective. This movement between perspectives can expand the opportunity to experience the plastic problem from several perspectives, acknowledging a more nuanced understanding of wicked problems.

Placing the fictional situation in the process drama in a time perspective enabled the students to shift perspectives not only between in role and out of role, but also between past, present, and future, which made aspects of the

plastic issue visible to the students in ways that would not have been possible had the process drama only taken place in the present. The findings in Paper IV show that when the students in the process drama travelled back and forwards in time, it enabled them to experience how the wicked plastic problem developed over time, which gave rise to imagination and reflections among the students. This became visible in the students' individual written reflections (writing in role) as well as in whole-class reflections and discussions out of role, where the students navigated between the different time perspectives. Moving through time in a fictional situation became a resource that unlocked the students' imagination and created engaging narratives that made past and future scenarios come to life in process drama (e.g., Rasa et al., 2022). In this sense, moving through time in process drama facilitated students' anticipatory competence, of which collective work is an important part, and will be further discussed in the following section.

## The significance of "togetherness" and collective agency

Drama is a form of activity largely characterised by acting together, supporting a collaborative learning process (Fries & Österlind, 2020). Participating in a fictional activity with a playful format involves understanding that "we are doing this together" (Hallgren, 2022). Although this agreement is not always explicitly stated, this dissertation provides insight into how this form of "togetherness" was manifested in the form of collective agency when creative drama and process drama were introduced into chemistry teaching. Findings from projects 1 and 2 reveal that the social structure of small-group constellation in combination with whole-class activities enabled students to act as learning resources for one another, promoting collective agency.

The findings from Paper II reveal that in the creative drama opportunities were created for the students to pay attention to bodily visualisations which did not agree with their own perceptions – in this dissertation called *epistemic dissonance* – to account for the emergent epistemic tensions/contradictions that the students came to recognise. The findings reveal that these contradictions created a "need to know" among the students in the drama activity, and became opportunities for the students to collaborate and learn from each other to better understand the conceptual relationships involved in chemical bonding. Also, when the students were asked to collectively visualise the intermolecular bond between the molecules, the students discussed and negotiated, thereby acting as learning resources for one another (findings from Paper II). The students who showed that they had understood how the water molecules bind to each other in the liquid phase acted as learning resources for students who did not know how to position themselves in relation to the other students. These students showed with bodily movements their willingness and openness to learn, which can be a sign of agency (Roth, 2007) and provides insight into

the potential of creative drama to increase the understanding of scientific concepts for both low-, average-, and high-achieving students (Abed, 2016; Aubusson et al., 1997).

The findings from Paper III show how in the process drama students in small groups collaboratively created and shared a narrative where they raised and listened to each other's questions and arguments concerning the plastic issue based on their role positions. For example, when the students positioned themselves as stakeholders and discussed different societally and scientifically oriented solutions to address the plastic issue. Also, as aforementioned, in the whole-group improvisations, students stepped into role and became central participants in the process drama, mobilising the attention of others to focus on their own contributions to the collective effort. In relation to the collaborative nature of the drama, *expectagency* (Hallgren, 2018) becomes an important component for promoting the students' collective work with the wicked issue of plastics. Hallgren (2018; 2022) describes expectagency as a forwards movement, encompassing expectation and hope that the contribution in the drama narrative given is received by other participants in the drama, but that it is also reciprocated. Hallgren (2022) further emphasises "Such a capability, which has a collective dimension, should be of great importance for how we will be able to handle uncertainty and change together. This capability is crucial in the world right now, given the challenges we face" (p. 51).

This reasoning strengthens the importance of letting students in chemistry teaching participate in a process drama about wicked problems, and findings from Paper IV provide insight into how capabilities such as anticipatory competence (cf. Ødegaard, 2023) may come to life when students collectively move through time in a playful format. In the drama, the students not only had to imagine futures and pasts (e.g., Levrini et al., 2023; Rasa et al., 2022 p. 67), they also had to creatively embody their imagination, such as in a tableau that built a collective statue of the future, and to collectively imagine the view of plastics in the past through dance, song, and rhyme. Moreover, I theorise agency from a non-dichotomous, dialectical approach which, in line with Stetsenko (2020), "gives full credit to the social roots of agency and does justice to it being an achievement of togetherness possible only in a communal world shared with others" (p. 5).

In conclusion, when the students in the chemistry teaching were enabled to participate in a process drama about wicked problems, it contributed to the development of their creativity and cooperation skills, which can make chemistry relevant in relation to the critical citizenship required to meet today's and future challenges, focusing on Vision III (Sjöström & Eilks, 2018; or IIB, Sund, 2016). Following these findings, highlighting "togetherness" in learning chemistry both from a disciplinary perspective and a humanistic perspective, this dissertation adds to the body of literature which claims that drama in science education enables students to learn from and with each other (Butler, 1989, Dorion, 2009: Hendrix et al., 2012).

## The balancing act between creative freedom and productive constraint

This dissertation provides insight into the various ways in which the teacher may steer the students in a certain direction where different degrees of structuring of the students' agency become tangible in the drama activity (cf. Ødegaard, 2003). It also throws light on the significance of working as a teacher to establish the fictional context in the classroom.

In creative drama, a flow of transductions and transformations in the classroom stimulated the students to explore electronegativity and chemical bonding, under the guidance of the teacher. However, the findings in Paper II reveal that in some parts the students participated with their bodies in a step-by-step enactment directed by the teacher. In these cases, the teacher did not function as a mediator, but more as a director, using the students as semiotic resources, while verbally explaining why she had positioned the students' bodies as she had. Here, the teacher, not the students, acted with agency in the exploration of intermolecular bonding. During the third research lesson, the students were invited to participate in a collective semiotic work. The teacher enabled a social structure in the classroom that enabled a joint exploration of how electronegativity is linked to intermolecular bonding. The social structure in the first case did not support students' collective agency, while the teacher gave students more room for conceptual exploration in the second case. Also, the students' interpretation of discursive models was made visible in action, which enabled the teacher to give the students tools for developing their conceptual understanding in line with the scientific discourse (Hendrix et al., 2012; Braund, 2015). Previous research has problematised the contention that if students are given a high degree of freedom without any guidance from the teacher in the drama activity, they might through their spontaneity use bodily models that are not in line with the scientific discourse (see Turkka & Aksela, 2022). However, Project 1 also shows that making the bodily visualisations visible in the classroom (thereby promoting epistemic dissonance) and providing sufficient time and space, helped the students to collaboratively explore each other's bodily visualisations in line with the scientific discourse, *without* guidance from the teacher. Hence, it is important for the teacher to be responsive and, if necessary, interact with and guide the students in a direction that is in line with the scientific discourse, while giving the students the freedom to explore the scientific concepts in a variety of ways.

The findings from Paper III show how in process drama the teacher was given opportunity to support the students' participation and agency from inside the drama, through the drama convention TiR. Assuming an authoritarian high-position role as the Swedish Space Agency's chief of staff provided little room for student agency, but when the teacher assumed a middle-position role as representative of the authority and villager in Dystoplastica, space was given for the students' agency – they stepped into role and changed the structure of the drama. Also, when the teacher in the first cycle assumed a role as

a team member in the small groups, she functioned as a mediator and kept the narrative going, supporting serious playfulness and students' agency. However, the results also show that the drama sometimes turned into a regular lesson when the teacher acted as a teacher-in-disguise (Berggraf Sæbø, 2009), or did not clearly position herself as being in role. On those occasions, the students reverted to a more passive student role with limited agency. In this way, the drama's ability to extend learning in the form of movement between different perspectives, as discussed above, was diminished. The consequence of this was that in certain episodes, such as at the meeting with the TiR as Hermann Staudinger from the past, it was the TiR that provided information and thus introduced the chemistry content – a structure that limited the students' agency. There is a tension here between the teacher's ambition to focus the drama on the subject content while giving the students freedom to explore the plastic issue on their own in a playful format.

The findings reported here support the results of previous research which emphasises that drama activities involve a balancing act between creative freedom and productive constraint (Edmiston, 2003; Ødegaard, 2023), adding to the body of research that suggests that the teacher's planning and guidance is crucial for learning in chemistry to take place when drama is used in teaching. According to Berggraf Sæbø (2009), if the teacher provides gentle professional guidance, along with certain limitations on students' autonomy, this could potentially facilitate greater levels of creativity and disciplinary reflections. Permitting student-structured drama activities without any teacher intervention runs the risk of limiting students' imagination, reflection, and knowledge about the subject, rendering the activities more incidental than purposeful (Ødegaard, 2023). In light of this dissertation's findings, I suggest that the balance between guidance and freedom depends on the purpose of the drama activity. In the improvisation parts, where the purpose was to give the students background information on the plastics issue, there were thus more elements of guidance from the teacher, where the results show that despite the guidance, it was important that the teacher was in role and did not become a teacher-in-disguise. On the other hand, in the improvisation parts where the students worked in small groups, giving time for interaction and greater freedom was pivotal, which in line with (Hallgren, 2022) shows how the students were given more space to move between fiction and reality and bring their real-life experiences into the drama.

## Putting drama into Chemistry teaching practice

Although my design-based research has generated knowledge about how the different types of drama can support students' learning in chemistry, the research has also provided insights into how the different drama activities can be put into chemistry teaching practice to support student learning. The different types of drama are intended to be used as a supplement to the regular

teaching of chemistry, as a way to engage, broaden, give perspective to, and increase understanding of the subject content. I have also shown that it is possible to perform the drama activities productively within the time and place constraints of regular chemistry teaching. However, although the process drama required more time, the teachers participating in Project 2 found time by performing the drama on a thematic day, or by collaborating with another teacher to combine two regular lessons. Based on the results from the projects, I have developed design principles which are intended to be used by Chemistry teachers as guiding resources for designing and adapting drama activities to their own teaching.

## Design principles for using creative drama in the teaching of disciplinary concepts in chemistry education.

Based on the findings presented in papers I and II, the following principles for designing creative drama intended to support students' learning of disciplinary concepts are proposed:

- Design Principle 1: *Create opportunities for students to work symbolically at both the sub- micro and macro levels and enable reflections at different organisational levels by offering students different semiotic resources as they materialise scientific concepts and processes with their bodies*. The findings indicate that for students to be given opportunity to conceptually link the chemistry's sub-micro level to the macro level, the teaching should enable reflections at the two organisational levels and provide opportunities for collective semiotic work. It seems beneficial for the students' conceptual learning to provide opportunities for students to explore conceptual relationships by bodily visualising concepts and processes together with a range of semiotic modes. Hence, students are provided an experiential basis for engaging with chemical concepts and processes, and differences in the visualisations may afford the emergence of productive epistemic dissonance.
- Design Principle 2: *Create opportunities for students to interact with each other and the teacher in an environment where students' collective agency is promoted.* The results show that visualisations of the students' bodily formations created opportunities for students to pay attention to differences in representations, and afforded collective agency. The emergent epistemic tensions/contradictions that the students recognised in the creative drama constituted opportunities for collective work concerning the conceptual relations where students acted as learning resources for one another. Thus, drama activity may create opportunities for students to work at a collective level with the conceptual relations. A prerequisite is that teachers provide sufficient

space and time for students to interact with each other and to discuss how chemical concepts could be performed differently in the drama activity.

In addition to the above design principles, it may be important to formulate additional design principles, for example, regarding the sequencing of using creative drama in teaching disciplinary concepts. Based on the experiences from Project 1, it may be an advantage to work with creative drama after the concepts have been introduced in the regular chemistry teaching. However, further research is needed to conclude whether, and under what circumstances this might be the case.

## Design principles for using process drama in the teaching of wicked problems in chemistry education

Based on the findings presented in papers III and IV, the following design principles for process drama intended to support students' exploration of wicked problems in chemistry education are proposed:

- Design principle 1: *Formulate a wicked problem for process drama that involves both pressing societal challenges and appropriate chemistry content in such a way that different levels of complexity of the problem can be made explicit in the classroom*. Our findings show that it is important to formulate and define a problem that gives students the opportunity to work with the problem at different levels of complexity (Sjöström & Talanquers, 2014) by focusing on various parts of chemistry knowledge for teaching, addressing visions I, II, and III in chemistry education. The findings show that it is advantageous to identify and include actors, research problems, societal problems, and value dimensions in the process drama where the disciplinary chemistry gains relevance and is connected to humanistic approaches in chemistry teaching. It also seems advantageous to integrate authentic material, for example, current research dealing with the problem that can be linked to many levels of complexity.
- Design principle 2: *Create roles for students and teachers to play that enable the students to discern different dimensions of the wicked problem, and that invoke opportunities for students to work collaboratively with ideas about how to deal with the wicked problem.* The findings show that assigning students different roles as journalists, scientists, and politicians who serve the context from different perspectives provides opportunities for the students to collectively explore the problem and move between societal, scientific, and value-based perspectives, hereby promoting a more nuanced understanding of wicked problems. It seems beneficial for students' role taking to provide quite

detailed role descriptions, preferably from authentic stakeholders, and it is important to provide time and space for the students to enact and interact in role.

- Design principle 3: *Create opportunities for the students to investigate temporal dimensions of the wicked problem.* The findings indicate that moving between past, present, and future in the process drama enabled the students to experience how the wicked problem had emerged over time, which gave rise to students' reflections on and imaginings of the future. This provides an expanded opportunity for experience and reflection, which may support imagination of many possible futures and past scenarios, promoting a more nuanced understanding of the wicked problem as well as actions to deal with the problem.

In addition to the above design principles, it may be important to formulate additional design principles, for example, for how process drama intended to support students' learning of wicked problems in chemistry teaching may give space and time for their emotional involvement. This emerged as important during the research process, but did not form the basis of analysis, and needs to be studied further. Based on the experiences from Project 2, it may be an advantage to work with process drama in the ongoing teaching because the students have up-to-date knowledge of the disciplinary part of chemistry that can be integrated with the social implications of chemistry. Also, to take into account experiences, knowledge, and the interest that the process drama has aroused, it could be beneficial to connect the process drama to the regular chemistry teaching after the drama has been performed, or later. However, more research is needed to develop and validate design principles in line with these observations.

## Transferability of results

The results that form the basis of the design principles are grounded on specific subject areas (chemical bonding and plastic use/waste) that have been developed into more general principles, which actualises the transferability of the results in both projects.

In Project 1, to understand how creative drama could support conceptual understanding in chemistry, chemical bonding and electronegativity were used as the central concepts. The results show how creative drama enables the students to work and move between the different organisational levels of chemistry, which can be considered fundamental to the conceptual understanding in chemistry, and therefore becomes the basis for the design principles proposed. In this way, for a teacher, the design principles are also transferable to other areas of chemistry teaching, for example, solubility and precipitation reactions. The proposed design principles could also be transferred

and adapted to other science subjects, where the movement between the submicro and the macro perspective plays a role in conceptual understanding, such as in disciplinary areas within Biology and Physics teaching.

In Project 2, I used plastics as a wicked problem because the basic organic chemistry could then come into play together with the complexity of the wicked problem, which was the basis for the design principles proposed. However, other wicked problems that can be connected to the chemistry topic in a similar way can also be used in a process drama in chemistry teaching (see Design principle 1). In addition, I suggest that the design principles could be transferred and adapted to Biology and Physics, or science in general. This is because, in science subjects like Chemistry there are disciplinary as well as humanistic visions for the students' learning which can constitute appropriate science content and pressing societal challenges for formulating a wicked problem to deal with in the process drama.

Given the above discussion, the results could be useful not only for chemistry teachers, but also for teachers in other science subjects, as guiding resources for designing and adapting drama activities to their own teaching. However, although the participating teachers in my research conducted the drama activities productively during the research lessons, I was also involved in various ways, informing and planning the drama activity. This raises questions about whether a teacher with no previous experience of drama needs support, and if so what support, to be able to use drama and put the design principles into practice in their own teaching.

## What might be required of a Chemistry teacher to engage in using different types of drama in the teaching?

In my research, I studied two different types of drama while acting as a Chemistry teacher, researcher, and drama facilitator. Although my focus was on students' learning, I also gained experiences during the research process that have provided insights into what might be required of a Chemistry teacher to engage in using different types of drama in the teaching. In this section, I reflect on these experiences from a teacher's perspective.

In Project 1, I designed, planned, and guided the research lessons in creative drama based on my knowledge of chemistry, teaching experiences, and relevant literature in chemistry education. Apart from preparations related to the data collection, I found that planning and conducting the creative drama with my own students did not take more time and resources than usual lesson work. Implementing the drama plan in a new classroom with another teacher of course required more preparation both in terms of collaboration with the teacher and data collection. After the teacher and I had planned the drama activities based on my framework, the teacher was able to conduct the drama activities in the classroom and support the students' learning of chemical bonding. In addition to setting aside time for planning the drama activities with me, it was a requirement that the teacher feel comfortable performing the

drama with their students. However, a "playful format" implies that the teacher functions as a mediator or facilitator, and that it is more about creating the learning object than that it is already defined.

On the other hand, during the research process in Project 2, I experienced that when the process drama was to be designed with the purpose that the students participate in conversations about wicked problems in chemistry teaching, it was not possible to start solely from my own teaching experience and chemistry knowledge. As described in the methodology section, both theoretical and pedagogical knowledge and practical experience with process drama were needed for me to be able to implement process drama in chemistry teaching for both research and learning purposes. The help of drama educators was thus indispensable.

For the teachers, in addition to setting aside time for their information about, and planning the process drama based on my framework, they were also required to find time in their schedule (the time for the implementation was outside normal lesson time in chemistry) and a space for the implementation (bigger than the Chemistry classroom). Knowledge about and preparation for acting as a teacher-in-role was required. My experience during both implementations was that the teachers were able to act as teachers-in-role and guide the discussions out of role so that these became meaningful for the students, while also focusing on chemical content. A very rewarding and pleasurable experience for me (and also, I noticed, for the participating teachers), was acting as a teacher-in-the role, and how my different positions (authoritarian or intermediate position), in relation to the students, gave me space to interact and steer the activity in a certain direction from within the drama (although sometimes I did this too much). This would not have been possible in my ordinary chemistry lessons.

My experiences of working with process drama during the research process provide insight into the fact that the Chemistry teacher who performs process drama needs knowledge of both chemistry and drama to be able to plan and guide the students between the educational and fictional activity and to perform the various drama conventions supporting the students' learning. My experience is reflected in Hallgren and Österlind (2019) study of process drama in civic education that suggested that process drama should be guided by "either individuals with both civic and artistic drama skills or co-teaching between civics teachers and drama pedagogues" (p. 20). Regardless of whether the teacher has pedagogic drama skills, or whether the drama is facilitated by a drama pedagogue in the classroom, it is an advantage if the drama activities in theoretical subjects are led by the subject teacher because the teacher can then guide the students in such a direction that the drama makes sense in terms of the subject content (cf. Fries & Österlind, 2020; Hallgren & Österlind, 2019).

In conclusion, based on my experience, I think that chemistry teachers, in addition to knowledge of chemistry, need more knowledge of drama pedagogy to perform process drama in their teaching than is required to perform creative

drama. It is especially important to know how to manage the transition between the educational and fictional part of the drama activity (cf. Braund, 2015), and the powerful drama convention of acting as TiR. In addition, in relation to both creative drama and process drama, a risk may be that an enthusiastic teacher without drama experience does not give students time to slow down, but instead guides students too quickly through the drama activity, reducing students' opportunity to reach deeper engagement.

## A research agenda

Given the above question, to gain insight into what is required of chemistry teachers without previous experience of drama to perform drama in their own teaching, a set-up could be, based on the proposed design principles and the drama plans from my dissertation work, to develop a teacher's guide for creative drama and process drama, respectively. Through design-based research, these teacher guidelines could then be tested and further developed together with teachers and drama educators. The guidelines could be implemented and adapted to the teachers' own practice, and based on data from audio-visual recordings of the research lessons and reflections with teachers in focus groups, make visible what the teachers need to better be able to perform drama in chemistry education in their own teaching. For example, in process drama, do the teachers need more knowledge about dealing with the complexity of wicked problems, or perhaps about using drama conventions? Concerning creative drama, do the teachers need more insight into different ways of guiding the students, or more resources for making the students' visualisations visible in the classroom? Based on the findings, the material for both creative drama and process drama can then be developed into robust teachers' guides that are comprehensible to chemistry teachers, that are adaptable and manageable in a regular classroom/drama room, and that focus on the central aims and content of chemistry education. In addition, the participating teachers would "own" the drama plans that are developed while simultaneously gaining knowledge about drama based on the project in which they have participated.

Moreover, the findings from such a research project could be used to implement drama for learning in chemistry in teacher education, for both educational purposes and research. Integrating the developed drama plans into preservice teacher training would increase the opportunity for the chemistry teachers to become independent in developing and adapting drama plans to their own teaching, which can also be adjusted to a changing curriculum. As described in my previous overview of research, Turkka and Aksela (2022) studied the use of drama related to chemistry in teacher education in Finland, but research in the Swedish context would be needed to gain knowledge about what teacher students need to be able to use drama in their future teaching or as part of their pre-service teaching.

A question about further research to be raised in direct relation to this dissertation's findings is how to strengthen students' agency in using disciplinary chemistry resources as part of process drama. To answer this question, further research, based on the generated design principles, could make creative drama for conceptual understanding integral to the process drama. The students would, with their bodies, visualise organic molecules at a sub-micro level, then together visualise the polymerisation process, thus enabling an understanding of plastics on the macro level. Another set-up could be to investigate the integration of a more disciplinary part of NOS, where the students in a Mantle of the Expert approach (Heathcote & Bolton, 1994) practically conduct a chemical investigation as part of the process drama. In both set-ups, the students' agency would be studied in relation to the material and social structure of the drama, which would provide increased knowledge about how process drama can contribute to students' learning in chemistry. From a teaching perspective, the results would be useful in providing chemistry teachers with insights into how disciplinary chemistry content can be integrated into process drama dealing with wicked problems.

## Bringing Chemistry to Life

This dissertation shows that drama can be a powerful resource for complementing the regular teaching of chemistry. By introducing drama into chemistry education, teachers and students can transform classrooms into vibrant places where chemistry is brought to life. Students are no longer passive recipients of information but active participants, collaborating with each other in the exploration and learning of chemistry. Allowing students to immerse themselves in the world of atoms, molecules, and chemical processes by using their bodies as semiotic resources enables new ways of learning chemistry. The use of drama in chemistry education involves integrating chemistry concepts with real-world implications of chemistry and its impact on society, which gives students the opportunity to both embrace the complexity of, and deal with wicked problems. This contextualisation not only makes the subject more meaningful but also cultivates a sense of responsibility towards the ethical application of scientific knowledge and nurtures a critical citizenship to meet the societal challenges of today and the future. By bringing chemistry to life through drama, teachers can spark a passion for chemistry and unleash the full potential of students' creativity and imagination in exploring "the forest while not losing sight of the trees" in this fundamental scientific discipline.

# 8. Svensk sammanfattning

## Introduktion och bakgrund

I en omvärld med komplexa och samhälleliga hållbarhetsutmaningar såsom klimatförändringar, katastrofrisk, förlust av biologisk mångfald, fattigdom, konsumtion och global orättvisa skulle kemikunskaper kunna bli av betydelse för att eleverna skall kunna förstå, hantera och ta ställning till sådana problem. Kemiundervisningen bör därför sträva efter att bidra till elevernas naturvetenskapliga allmänbildning, *scientific literacy,* där olika visioner för utbildningen får samspela med varandra: Vision I, som syftar till att introducera eleverna till kemins disciplinära värld och förbereda dem för framtida studier i kemi, Vision II, som syftar till att göra kemi relevant för elevers förmåga att leva ett gott liv och att delta i vardagen som informerade medborgare (se Roberts, 2007) och Vision III, som syftar till att förbereda eleverna för deltagande i en växande komplex värld som gör det möjligt för dem att som informerade medborgare kritiskt reflektera över vetenskapens/kemins roll i samhället, som krävs för att möta dagens och framtidens utmaningar (se Sjöström & Eilks, 2018; Sund, 2016). Kemiundervisningen lyckas dock inte alltid att göra kemikunskaper relevanta och engagera eleverna i relation till dessa visioner. Många elever tenderar att se kemiutbildningen som orelaterad till deras egna liv och världen omkring dem och att ämnet ofta saknar kreativitet, känslor och moraliska aspekter (t.ex. Stuckey et al., 2013). Dessutom visar tidigare forskning att elever upplever ämnet kemi som abstrakt och svårt att förstå (Gräber, 2011). Forskning om utmaningar i kemiundervisningen visar att eleverna behöver stöd både för att utveckla sin konceptuella förståelse, och för att förstå hur kemiresurser kan vara användbara ur ett bredare holistiskt humanistiskt perspektiv – som inkluderar etiska, moraliska och emotionella aspekter.

En av de specifika utmaningarna för att förstå kemi ur ett disciplinärt perspektiv beror på att kemi handlar om molekylnivån och partiklar i en skala som inte kan röras eller ses med blotta ögat (jfr Airey et al., 2023). Konsekvensen av detta är att eleverna förväntas tolka en mängd olika symboliska representationer för att utveckla sin förståelse för kemiska begrepp. Dessutom visar studier att eleverna har svårt att hantera och röra sig mellan kemins olika representationsnivåer – makronivå (det observerbara som beskriver vad vi kan se, höra eller mäta), submikronivå (beskriver arrangemang av partikelenheter som atomer, molekyler, joner och elektroner), och den symboliska nivån (kemiska formler och symboler som beskriver ämnen och partiklar; De Jong et

al., 2013; Seifeddine Ehdwall & Wickman, 2018), särskilt inom området kemisk bindning och elektronegativitet som fungerar som en grund för att lära sig andra ämnen inom kemi.

Eleverna skall också kunna hantera den disciplinära kemin i relation till vardagslivet och samhällsutmaningar i ett humanistiskt perspektiv, där en speciell utmaning gäller att hantera komplexa hållbarhetsfrågor – problem och utmaningar som till sin natur är komplexa och öppna för diskussion (Simonneaux, 2008), vilket också kan kallas *wicked problems*. Dessa wicked problems kräver alltså både naturvetenskaplig kunskap och handlingar baserade på värderingar (Bazzul, 2015), vilket gör undervisning om wicked problems till ett utmanande ämne för naturvetenskaplig utbildning jämfört med mer traditionella kunskapsområden.

I denna mening finns det ett behov av att utveckla kemiundervisningen både utifrån ett disciplinärt förhållningssätt i linje med ett Vision I-perspektiv, men också ur ett humanistiskt perspektiv – ett slags metaperspektiv (Sjöström, 2019) som involverar både vision II och III, så att eleverna ”kan se skogen utan att tappa träden ur sikte” (Mahaffy et al., 2018). I denna avhandling undersöker jag möjligheter att utveckla undervisningen i kemi i gymnasieskolan med hjälp av drama som kan stödja elevernas lärande i relation till ”träden (konceptuellt förhållningssätt) och skogen (humanistiskt förhållningssätt)”.

I avhandlingen har jag valt att fokusera på två särskilda former av pedagogiskt drama som används i naturvetenskaplig undervisning – *kreativt drama* (Arieli, 2007) och *processdrama* (Hallgren, 2018). I avhandlingen relaterar kreativt drama till kategorin fysiska simuleringar där eleverna får möjlighet att visualisera olika abstrakta objekt som atomer och molekyler, och processdrama relaterar till sociala simuleringar, där eleverna har möjlighet att "vara" olika subjekt. Gemensamt för båda formerna är att dramaaktiviteten prioriterar lärande genom engagemang i processen snarare än genom att visa upp ett slutresultat för en publik (Clark-Fookes & Henderson, 2021).

Kreativt drama innebär att en lärare guidar eleverna i dramatiseringen av en berättelse eller ett koncept som lärs ut. Det är en form av improviserad lek avsedd att ge eleverna möjligheter att utforska kemiska begrepp och modeller genom att använda sina egna kroppar. Skälet för att fokusera på kreativt drama i denna studie är dess potential att underlätta processer som gör kemiska begrepp personligt meningsfulla för eleverna (Arieli, 2007).

Processdrama är en form av pedagogiskt drama där elever och lärare deltar som både observatörer/publik och aktörer, och antar olika roller under dramat (Bowell & Heap, 2013; Warner & Anderson, 2004). Processdrama används ofta för att stödja elevernas förståelse av ett ämne och skapa kopplingar mellan olika kunskapsområden såväl som mellan etik och känslor. Det som främst skiljer processdrama från andra former av drama och rollspel är att lärarna deltar i dramat och tar roller i ett narrativ som skapas med eleverna på plats (Hallgren & Österlind, 2019). Detta gör det möjligt för läraren i roll att agera flexibelt – att skifta sätt att positionera auktoritet och kontroll över processen

beroende på hur dramat utspelar sig (Heggstad, 2014). Läraren använder en plan, en så kallad pre-text för var man ska börja dramat, grundat utifrån ett förutbestämt tema och uppsättningar av dramapedagogiska konventioner (Hallgren, 2018). Exempel på dramakonventioner är improvisationer, stillbilder, skriva i roll och reflektion ur roll, som möjliggör olika sätt att utforska och fördjupa förståelsen av processdramats innehåll. Eleverna får möjlighet att delta i samtal som omfattar flera aktörer genom att ta roller som till exempel forskare, politiker, och aktivister, där motstridiga frågor kan utforskas utan att eleverna behöver avslöja personliga åsikter eller ställningstaganden. I linje med Warner och Andersen (2004) kräver rollen inte att eleven antar en djup skildring av rollkaraktären, utan snarare ger rollen en möjlighet att uppleva problemet från ett annat perspektiv.

Det finns forskning som visar att elever lär sig genom att använda drama, men hur och varför de lär sig i dramaaktiviteten är inte utforskat i lika stor utsträckning. Få studier som undersöker begreppsförståelse har samlat in data, till exempel genom video, och analyserat vad som händer under själva dramaaktiviteten. Även om forskning om drama som syftar till att utveckla de humanistiska dimensionerna av naturvetenskaplig utbildning i större utsträckning har analyserat den aktuella dramaaktiviteten, dominerar för- och eftertestmetodik samt intervjuer. För att fylla denna lucka i forskningen zoomar jag in på själva dramaaktiviteten i klassrummet för att analysera på vilka sätt drama kan stödja elevernas lärande i kemi.

## Teori, syfte och övergripande forskningsfrågor

I avhandlingen förstås undervisning och lärande som komplexa processer av social interaktion med utgångspunkt i sociokulturella (Vygotsky, 1934/1999) och socialsemiotiska perspektiv (Kress & Bezemer, 2015). Utifrån dessa perspektiv ses lärande som aktivt engagemang med andra och de kulturella artefakter och verktyg som finns tillgängliga inom särskilda praktiker. Ur ett sociokulturellt perspektiv är den kroppsliga modaliteten och fysiska artefakter viktiga för kommunikation och lärande, även om språket anses ha en framträdande plats (Vygotsky, 1978). Ur ett multimodalt socialsemiotiskt perspektiv anses alla modaliteter vara lika betydelsefulla (Kress, 2010). De resurser som finns och hur de används i klassrummet spelar en stor roll för elevernas meningsskapande och är därför intressanta att studera för att förstå inlärningsprocessen. I drama blir den kroppsliga modaliteten, med gester, ansiktsuttryck och rörelser särskilt betydelsefullt. Samspelet mellan social semiotik och sociokulturella perspektiv ger således en lins för att undersöka komplexiteten i lärande och meningsskapande i kemiklassrummet.

I denna avhandling har jag valt att undersöka hur elevernas agens och deltagande påverkas då drama introduceras i kemiundervisningen. Mer specifikt förstår jag agens utifrån perspektivet att det är något elever uppnår (gör) i en

situation snarare än något de äger eller har (Biesta & Tedder, 2007). I kemiundervisningen deltar elever och lärare i en social kunskapsuppbyggnad där strukturer och resurser ger olika förutsättningar för agens i lärandet. Enligt Vygotsky (1934/1999) lär sig eleverna när de deltar i aktiviteter genom interaktion med människor och kulturella resurser. Lärande ses alltså som en integrerad och oskiljaktig aspekt av att delta i en social praktik. Lave och Wenger (1991) beskriver lärande i termer av utökade repertoarer för deltagande i praktikgemenskaper (jfr Wenger, 1998). Här innebär begreppet delaktighet sätt att vara i och få tillgång till praktikgemenskaper. Under det växande engagemanget expanderar sätten att komma in i och sätten att befinna sig i sådana gemenskaper. Denna avhandling fokuserar på hur sätt att delta i en gemenskap av undervisning i kemi kan utökas genom att introducera drama. Frågor om agens handlar i avhandlingen om hur de materiella och sociala strukturerna ger möjlighet och utrymme för eleverna att transformera sin förståelse av kemiska begrepp och processer relaterade till kemisk bindning och komplexa hållbarhetsfrågor i kemiundervisningen.

Syftet med avhandlingen är att bidra till kunskap om hur olika former av drama kan stödja elevers lärande i kemi på gymnasiet, och hur drama kan utformas för att uppnå detta syfte. För att omfatta kemiutbildningens visioner (I, II och III) är syftet mera specifikt att bidra till en förståelse för hur kreativt drama kan stödja elevers lärande av icke-spontana kemiska begrepp relaterade till elektronegativitet och kemisk bindning, och hur processdrama kan stödja eleverna lärande av ”wicked problems”. Avhandling omfattar två övergripande forskningsfrågor:

> (1) På vilka sätt kan kreativt drama stödja elevers begreppsliga lärande av elektronegativitet och kemisk bindning i kemiundervisningen på gymnasiet?
> (2) På vilka sätt kan processdrama stödja elevers lärande att hantera wicked problems i kemiundervisningen på gymnasiet?

De övergripande forskningsfrågorna behandlas i artiklarna I-IV och undersöks i två designbaserade forskningsprojekt: Projekt 1 och Projekt 2.

# Metodologi

De båda projekten utgår metodologiskt från ett praktiknära angreppssätt och har utförts i form av designbaserad forskning i kemiundervisningen på gymnasieskolan i samarbete med lärare och elever. Den design-baserade forskningen bygger på antagandet att forskning om undervisning och lärande skall utföras i de praktiker där undervisning och lärande faktiskt äger rum (Cobb et al., 2003), för att hantera relevanta utmaningar i praktiken. På så sätt kan både forskningens relevans synliggöras i en skolkontext samtidigt som forskningen

kan leda till att utveckla både teori och praktik för lärande, som verkligen spelar roll och kan komma både lärare och elever till godo. De båda forskningsprojekten har utförts i cykliska processer av design, implementering och analys/utvärdering av undervisningen med syfte att bidra till kunskap om hur olika former av drama kan stödja elevers lärande i kemi på gymnasiet, och hur drama kan utformas för att uppnå detta syfte. Eleverna som deltog i projekten gick på det Naturvetenskapliga programmet och hade ingen tidigare erfarenhet av drama i kemiundervisningen.

**Projekt 1**

I det första projektet genomfördes interventioner i form av drama i två kommunala gymnasieskolor i tre omgångar under åren 2015 till 2107. Totalt deltog 105 elever i studien. Första och andra cykeln genomfördes under min egen pågående kemiundervisning. Som ett sätt att testa överförbarhet genomfördes cykel 3 på en annan skola med en annan kemilärare. Totalt genomfördes fyra forskningslektioner när ämnesområdet kemisk bindning täcktes i kemikurserna och ingick i den pågående kemiundervisningen.

I projekt 1 fokuserade jag på disciplinärt lärande och undersökte hur kreativt drama kan stödja elevers lärande av icke-spontana kemiska begrepp relaterade till elektronegativitet och kemisk bindning. Interventionerna (som varade i 30–60 minuter) bestod av dramaaktiviteter och diskussioner i såväl helklass som smågrupper. Eleverna fick i små grupper i uppgift att visualisera molekyler och elektronegativitet med sina egna kroppar. För att stödja elevernas vetenskapliga resonemang och semiotiska arbete erbjöds de en rad semiotiska resurser (t.ex. färgat papper, läroböcker, datorer, digitala surfplattor, saxar, klädnypor och tejp). Efter en inledande diskussion i gruppen fick eleverna kroppsligt gestalta sina molekyler och ge en muntlig redogörelse för hur de hade resonerat. I helklassaktiviteten använde eleverna sedan sina gestaltningar och visade utifrån molekylernas elektronegativitet kroppsligt hur molekylerna interagerade med varandra, vilket gav dem möjlighet att röra sig mellan kemins submikro- och makronivåer. Den empiriska data som har producerats i Projekt 1 presenteras i artikel I och artikel II.

**Projekt 2**

I det andra projektet genomfördes interventioner i form av processdrama i kemiundervisningen i två omgångar under år 2021, i två kommunala gymnasieskolor. Totalt deltog 31 elever, samt tre lärare i genomförandet av forskningslektionerna, som varade i 2 respektive 3 timmar.

I Projekt 2 fokuserade jag på humanistiska förhållningssätt i kemiundervisningen, och utformade en intervention i form av en processdramaplan som stämde överens med mitt övergripande syfte – att utforska hur processdrama kan användas i kemiundervisningen för att utveckla elevernas förståelse för komplexa hållbarhetsfrågor ”wicked problems”. För processdramainterv ent-

ionen valdes plastföroreningar och plastanvändning som de komplexa hållbarhetsfrågorna att fokusera på. I processdramat tilldelades eleverna roller som medlemmar i ett team av kemister, forskare, politiker och journalister, som tillsammans med lärare reste fram och tillbaka i tiden för att utforska användningen av plast, motiven och behoven för att använda plast och konsekvenserna av plastanvändning (dvs. plastföroreningar) idag och i framtiden. Den empiriska data som har producerats i Projekt II ligger till grund för i artikel III och artikel IV.

I båda projekten, efter varje cykel, reflekterade och utvärderade jag resultaten som fick ligga till grund för omformningen av forskningslektionen i den efterföljande cykeln. Genom denna process förfinades designprinciperna gradvis för att förstå viktiga drag i dramats design med målet att förbättra elevernas förståelse för kemisk bindning (Projekt 1) och wicked problems (Projekt 2). Utifrån resultaten föreslås design principer för att utforma kreativt drama och processdrama i kemiundervisningen på gymnasiet.

### Empiriskt material och databearbetning

I båda projekten har data insamlats i form av video och ljudinspelningar som har transkriberats ordagrant. I Projekt 2 har även skriftligt material legat till grund för analysen. För att besvara mina forskningsfrågor analyserades det empiriska materialet utifrån tematiska angreppssätt (Braun & Clarce, 2006; Erlingsson & Brysewich, 2017; Graneheim & Lundman, 2004). I Artikel 1 utfördes en multimodal social semiotisk analys (Kress & Bezemer, 2015) där elevernas semiotiska arbete analyserades utifrån transformationer och transduktioner som sedan tematiserades. I Artikel II, III, och IV tematiserades resultaten utifrån kvalitativ innehållsanalys. I Artikel III användes även dialektiken margin|center och agency|struktur för att analysera och beskriva hur eleverna deltog i dramat.

## Sammanfattning av artiklarna

De fyra artiklar som ingår i avhandlingen sammanfattas nedan med fokus på de frågor som ställts och de huvudsakliga resultaten.

### Artikel 1

Artikel 1 fokuserar på de utmaningar som eleverna i kemiundervisningen på gymnasiet möter när de skall lära sig abstrakta icke-spontana kemiska begrepp, som involverar kemisk bindning och elektronegativitet. Eleverna har svårt att förflytta sig mellan kemins olika organisationsnivåer (makro, submikro och symbolisk nivå) och för att eleverna ska förstå kemiska observationer på makronivå måste de använda modeller i sub-mikroskala för att ”göra det osynliga synligt” – det vill säga sub-mikromodellerna behöver beskriva, eller förklara, observationer på makronivå. Syftet med studien är att undersöka

hur kreativt drama kan möjliggöra elevers meningsskapande av abstrakta, icke-spontana kemiska begrepp relaterade till kemisk bindning genom att utforska vilken typ av semiotiskt arbete eleverna ägnar sig åt när de ges möjlighet att använda sina egna kroppar som semiotiska resurser. Följande forskningsfråga undersöks: Vilken typ av semiotiskt arbete ägnar sig eleverna åt när de utforskar abstrakta, icke-spontana begrepp relaterade till kemisk bindning i kreativt drama?

Huvudresultaten pekar på vikten av transduktion och transformation av mening för att förbättra elevernas konceptuella förståelse av kemisk bindning och elektronegativitet. Resultaten visar på vikten av att göra det möjligt för eleverna att använda kroppslig modalitet i kombination med en mängd andra modaliteter samt möjliggöra för eleverna att engagera sig i kollektivt semiotiskt arbete. Dessutom när elevgrupper arbetar med uppgifter som till exempel gör molekyler synliga i klassrummet i form av kroppslig modalitet, tillåter det dem att observera varandras kreationer, vilket får konsekvenser för det semiotiska arbetet. Resultaten visar att interaktionen mellan elevgrupperna var avgörande för att de skulle kunna koppla ihop kemins submikro och makro nivåer med varandra. Det semiotiska arbetet, i form av transformationer inom elevernas kroppsliga modalitet, kan betraktas stärka länken mellan submikro och makronivå. Därigenom fick eleverna möjlighet att länka de gruppvis formade gestaltningarna vilka representerade separata molekyler på submikronivå, till en kollektiv kroppslig formation av en molekylärstruktur, som representerade hur molekyler organiserades på makronivå (t.ex. flytande vatten). Vidare, när elevernas kroppsliga rörelser och positioner transformerades från en grupp elever till en annan, observerades kreativ imitation, i form av *mimesis,* som anses vara en kraftfull form av lärande (Wulf, 2018).

Sammanfattningsvis visar artikeln hur elevernas kroppsliga modalitet i kreativt drama gynnar semiotiskt arbete från en elev till en annan i en icke-auktoritär miljö. Detta flöde av transduktioner och transformationer kan utöka den funktionella potentialen för meningsskapande och öka möjligheten för att lära sig icke-spontana kemiska begrepp i kemiklassrummet. Artikeln betonar också att lärare som använder kreativt drama bör vara medvetna om begränsningarna hos förenklade modeller och agera för att ge eleverna möjligheter att reflektera över sådana begränsningar. På så sätt kan de kroppsliga modellerna fungera som ett ankare för mer vetenskapliga beskrivningar och förklaringar.

**Artikel II**

Artikel II fokuserar på grundläggande begrepp som tidigare forskning både internationellt och i Sverige har identifierat som svåra för elever att hantera under sina inledande kemistudier på gymnasiet: materiens partikelform, att skilja mellan intra- och intermolekylär bindning, vätebindning, elektronegativitet och polaritet. Med utgångspunkt i resultaten från artikel I är syftet med artikel II att undersöka hur elever etablerar relationer mellan ovan nämnda

begrepp relaterade till kemisk bindning, och hur sådana begreppsliga relationer utmanas och utforskas av eleverna i kreativt drama. I artikeln undersöks också hur dramaaktiviteten kan främja elevernas kollektiva agens. Följande forskningsfrågor formulerades: (1) På vilka sätt kan kreativt drama möjliggöra elevernas utforskande av elektronegativitet och kemisk bindning? (2) På vilka sätt kan kreativt drama stödja elevernas kollektiva agens i utforskandet av elektronegativitet och kemisk bindning?

De övergripande resultaten visar att eleverna gestaltade elektronegativitet och kemisk bindning på flera sätt. Ett sätt var med antropomorfa uttryck, till exempel att agera som glada, ledsna eller starka atomer. De introducerade också rörelser för att gestalta elektronegativitet (särskilt för att kroppsligt uttrycka kemisk bindning som ett kontinuum) och förstärkte den kroppsliga modaliteten med andra semiotiska resurser. I elevernas semiotiska arbete möjliggjordes att skapa relationer mellan elektronegativitet och molekylers polaritet samt att i den kollektiva helklassinteraktion länka molekylernas polaritet till intermolekylär bindning, vilket i sin tur är en förutsättning för att förstå fasändringar på makronivå. Vidare visar resultaten att gruppernas kroppsliga formationer av molekyler i vissa grupper drev på semiotiskt arbete i andra grupper, vilket fick betydelse för den kollektiva agensen.

Ett huvudresultat är att när elevernas kroppsliga visualiseringar av kemiska begrepp blev synliga i klassrummet inspirerade det dem inte bara att omvandla andra elevers gestaltningar till sina egna skapelser, utan det skapades möjligheter för eleverna att agentiskt uppmärksamma kroppsgestaltningar som inte stämde överens med deras egna uppfattningar- som i artikeln benämns *epistemisk dissonans*. Dessa motsättningar skapade ett ”behov att veta” bland eleverna i dramaaktiviteten och blev möjligheter för eleverna att samarbeta och lära av varandra för att bättre förstå de begreppsmässiga sambanden involverade i kemisk bindning. I linje med Manneh et al. (2019) visar resultaten att antropomorfa uttryck kan hjälpa eleverna att bättre förstå elektronegativitet och kemisk bindning, som med hjälp av läraren sedan kan utvecklas för att överensstämma med en vetenskaplig diskurs. Men artikel II visar också att det finns en risk för att potentiellt tvetydiga eller felaktiga föreställningar uppstår från den kroppsliga visualiseringen, och att kemilärare måste vara lyhörda och agera för att ge eleverna möjligheter att reagera på felaktiga eller begränsade modeller. Avhandlingens resultat pekar på vikten av att designa kreativt drama så att både den materiella och sociala strukturen kan gynna elevernas kollektiva agens.

**Artikel III**

Artikel III fokuserar på kemiundervisning i relation till komplexa hållbarhetsproblem, s.k. ”wicked problems” (jfr Rittel & Webber, 1973) – som karakteriseras av komplexitet, osäkra fakta, omtvistade värderingar och behov av brådskande beslut - och hur drama kan användas som ett sätt att stödja elevernas deltagande i samtal om sådana problem. Om kemiundervisningen ska vara

relevant i förhållande till sådana utmanande problem bör kemiundervisningen organiseras så att eleverna ges möjlighet att delta i samtal om wicked problems, där kemikunskaper inte enbart framställs (jfr Block et al., 2019) som isolerade fakta, utan som en del av större system, såsom miljön, vilket kan främja ett systemtänkande i kemiundervisningen (Mahaffy et al., 2019b). Syftet med studien är att undersöka hur processdrama i gymnasieskolans kemiundervisning kan möjliggöra eleverna agens när de hanterar komplexa hållbarhetsfrågor där kemikunskaper kan vara av vikt. För processdramainterventionen valdes plastanvändning och plastavfall som det ”wicked problem” att fokusera på. Även om det finns många initiativ för att ta itu med denna fråga saknas konsensus om hur man ska hantera den och de lösningar som föreslås väcker funderingar kring värderingar relaterade till exempelvis miljö, där sociala och ekonomiska rättvisefrågor aktualiseras. Följande forskningsfrågor undersöks: (1) Vilka dimensioner av plastanvändning och plastavfall utforskar eleverna när de deltar i ett process drama i kemiundervisningen på gymnasiet? (2) Hur möjliggörs elevernas agens i ett processdrama om plastföroreningar och plastanvändning i kemiutbildningen på gymnasiet?

De övergripande resultaten visar att processdrama kan ge eleverna möjlighet att föra in verklighetens kontext i kemiundervisningen som handlar om wicked problems, och prata om plastproblematiken samtidigt som eleverna får använda kunskap och perspektiv utifrån vetenskap, värderingar och samhälleliga och samhällsvetenskapliga perspektiv. Processdramat förmedlade således en process för att hantera plastproblemet som en komplex fråga, samtidigt som det omfattade systemtänkande. På detta sätt främjar processdrama inom kemiundervisningen ett pluralistiskt perspektiv där eleverna får möjlighet att delta och kritiskt bedöma flera olika idéer och sätt att hantera hållbarhetsproblem. Våra resultat indikerar att rollen blir en resurs för både elever och lärare att utforska plastfrågan i kemiundervisningen. Att kliva ur den typiska ”lärarrollen” (d.v.s. anta en roll som inte skulle ha varit lämplig i en normal klassrumssituation) blev ett verktyg för läraren - till att förmedla och stödja elevernas agens när de utforskade plastfrågan. I korthet väckte processdramat ett behov hos eleverna av att känna till och prata om kemiska begrepp relaterade till de komplexa frågorna kopplade till kemiinnehåll. Men även om processdramat i den andra cykeln uppmärksammade eleverna på att använda fler disciplinära resurser kopplade till organiska kemibegrepp än i föregående cykel, var det läraren som ofta introducerade kemiinnehållet. En återstående utmaning är hur elevernas agens kan stärkas i att använda disciplinära kemiska resurser som en del av processdrama.

**Artikel IV**

Artikel IV fokuserar på elevers förståelse av komplexa hållbarhetsfrågor, s.k. wicked problems, och elevernas beredskap att agera för en hållbar framtid, som involverar förmågan att navigera mellan dåtid, nutid och framtid. Tidigare forskning har bidragit med viktiga insikter som har sammanfattats i ett

manifest med tio rekommendationer om hur man kan stimulera ”framtidstänkande” i naturvetenskaplig undervisning (Bol et al., 2023). Den här artikeln undersöker hur elevers deltagande i ett processdrama med imaginära övergångar genom tid kan göra eleverna medvetna inte bara om tid utan hur perspektiv och sätt att förstå ett wicked problem förändras över tiden. Detta kan ge eleverna en mer holistisk upplevelse och främja en mer nyanserad förståelse för problemet, vilket kan stödja elevernas ”framtidstänkande”. Syftet med studien är att utforska på vilka sätt tidsmässiga övergångar i form av ”historying” – föreställa sig det förflutna och ”futuring” – föreställa sig framtiden kan bidra till att lägga till skikt av komplexitet till wicked problems i kemiutbildningen. Studien baseras på en processdrama intervention med fokus på plastanvändning och plastavfall. Skälet för att använda processdrama är att användningen av temporaliteten i en drama kontext (dåtid, nutid och framtid) kan möjliggöra skiftande perspektiv med potential att lägga till aspekter av den komplexa frågan om plastanvändning på sätt som inte skulle ha varit möjligt i ett processdrama som äger rum i ”nuet” (Hallgren, 2018). Följande forskningsfrågor undersöks: (1) Hur kopplar elever samman olika temporaliteter i processdramat? (2) Vilka dimensioner av plastproblemet synliggjörs i de tidsmässiga övergångarna i processdramat?

De övergripande resultaten visar framförallt att upplevelsen av att resa bakåt och framåt i tiden i processdramat, utlöste elevernas ”historying” och ”futuring”, och att koppla dessa till varandra, synligt både i elevernas reflektioner ur roll och i roll. De tidsmässiga övergångarna synliggjorde flera dimensioner av plastfrågan i processdramat och bidrog till att lägga till komplexitetsskikt till frågan om plastanvändning och avfall. Exempelvis synliggjordes dimensioner som visade elevernas *moraliska ansvar* gentemot plastfrågan och *globala orättvisor* inramade i ett tidsperspektiv som omfattade både historiska sammanhang och framtida implikationer av plastfrågan. Sammanfattningsvis visar artikel IV att elevernas tidsresor i processdramat gav dem en referensram i tid för att hantera plastfrågan i kemiundervisningen. Resultat pekar på att resor genom tiden i processdramat gjorde det möjligt för eleverna att navigera mellan dåtid, nutid och framtid – en färdighet som eleverna måste vara utrustade med för att hantera framtiden både inom naturvetenskaplig utbildning (jfr Levrini et al., 2021) och kemiutbildningen (Herranen et al., 2021), vilket är en förutsättning för att stärka elevernas förutseende kompetens (Rieckmann, 2018; Voros, 2003).

# Diskussion

Genom att zooma in och undersöka dramaaktiviteten i klassrummet, bidrar denna avhandling till förståelsen av varför och hur drama kan stödja elevers lärande i kemiundervisningen, som spänner över visionerna I, II och III. Resultaten i artikel I och II bidrar till förståelsen av varför och hur drama kan

stödja elevers konceptuella lärande, med fokus på elektronegativitet och kemisk bindning i gymnasieskolans kemiundervisning. Resultaten i artikel III och IV bidrar till förståelsen av varför och hur drama kan stödja lärande utifrån humanistiska perspektiv i gymnasieskolans kemiundervisning, med fokus på komplexa hållbarhetsfrågor.

Avhandlingens resultat visar att när drama introducerades i kemiundervisningen, blev nya resurser tillgängliga för elever och lärare, vilket gav nya sätt att agera och delta i undervisningen. Särskilt *kroppens* betydelse för meningsskapande i kemi, *rollen och den fiktiva situationen* samt dramats *kollaborativa karaktär* var resurser som tillsammans med dramaaktivitetens sociala och materiella struktur blev tillgängliga och betydelsefulla för elevernas lärande i kemi.

Avhandlingen ger insikter om betydelsen av att låta elevernas kroppsliga visualiseringar av kemiska begrepp och processer bli synliga i klassrummet. Detta ger eleverna möjlighet att observera varandras gestaltningar vilket kan ge upphov till mimesis och produktiv epistemisk dissonans. Avhandlingens resultat pekar också på vikten av den kroppsliga modaliteten som en semiotisk resurs för att röra sig mellan kemins olika organisationsnivåer. Sammantaget möjliggör den kroppsliga modaliteten i kreativt drama för eleverna att röra sig från en modell eller beskrivning av lärobokens tvådimensionella struktur till att rekonstruera och utveckla sin egen förståelse för specifika vetenskapliga begrepp i en tredimensionell levande modell med sina egna kroppar (Ødegaard, 2015). Oavsett förändring av modalitet – transduktion eller transformation – skapas en förändring i mening, och sådan meningsproduktion utgör lärande (Kress & Bezemer, 2015).

Avhandlingen visar på betydelsen för elevernas lärande av att de får möjlighet att anta en roll, och att röra sig in i och ut ur en roll i en fiktiv situation är en resurs för eleverna att lära sig kemi. Resultaten från artikel III visar att genom att tilldela elever olika roller såsom journalister, vetenskapsmän och politiker möjliggörs för eleverna att delta i samtal om plastfrågan och uppleva olika perspektiv – samhälleliga, vetenskapliga och värdebaserade – i ett lekfullt format, samt att röra sig mellan fiktion och verklighet där eleverna kan ta med sina vardagliga upplevelser in i processdramat. Utöver den disciplinära sidan av kemiundervisningen gör processdramat det möjligt för eleverna att uppleva de humanistiska, sociala och miljövetenskapliga perspektiven, och i linje med Sjöström (2019), förstå kemiundervisningen utifrån ett metaperspektiv, och på så sätt inkludera visionerna I, II och III i undervisningen. Dessutom, visar avhandlingen att när den fiktiva situationen i processdramat placeras i ett tidsperspektiv möjliggörs för eleverna att skifta perspektiv inte bara genom att röra sig mellan i roll och ur roll, utan också mellan dåtid, nutid och framtid. Detta gör aspekter av det komplexa hållbarhetsproblemet (plastfrågan) synligt för eleverna i kemiundervisningen på sätt som inte hade varit möjliga om processdramat bara hade utspelat sig i nuet.

Avhandlingen lyfter fram betydelsen av det kollaborativa arbetet i att lära sig kemi både ur ett disciplinärt perspektiv och ett humanistiskt perspektiv, och understödjer slutsatser från tidigare forskning om att drama i naturvetenskaplig utbildning främjar elevers lärande av och med varandra (Butler, 1989, Dorion, 2009: Hendrix et al., 2012).

Vidare stödjer avhandlingen resultaten av tidigare forskning som betonar att dramaaktiviteter i undervisningen involverar en balansgång mellan kreativ frihet och produktiv begränsning (Edmiston, 2003; Ødegaard, 2023), vilket tyder på att lärarens planering och vägledning är avgörande för att lärande i kemi ska ske när drama används i kemiundervisningen.

Sammantaget har avhandlingen bidragit med kunskap om hur de olika typerna av drama kan stödja elevernas lärande i kemi utifrån ett kemididaktiskt perspektiv. Forskningen ger också stöd för hur de olika dramaaktiviteterna kan omsättas i praktiken för att stödja elevernas lärande i kemiundervisningen i form av designprinciper. De olika typerna av drama är tänkta att användas som ett komplement till den ordinarie undervisningen i kemi, som ett sätt att engagera, bredda, ge perspektiv till och öka förståelsen för ämnesinnehållet.

Baserat på resultaten som presenteras i artiklarna I och II, föreslås följande principer för att utforma kreativt drama avsett att stödja elevers lärande av disciplinära begrepp:

- Designprincip 1: *Skapa möjligheter för eleverna att arbeta symboliskt på både submikro- och makronivå och möjliggöra reflektioner på olika organisationsnivåer genom att erbjuda eleverna olika semiotiska resurser när de materialiserar vetenskapliga begrepp och processer med sina kroppar.*
- Designprincip 2: *Skapa möjligheter för eleverna att interagera med varandra och läraren i en miljö där elevernas kollektiva agens främjas*.

Baserat på resultaten som presenteras i artiklarna III och IV, föreslås följande design principer för processdrama avsedda att stödja elevers utforskning av omtvistade hållbarhetsfrågor i kemiundervisningen:

- Designprincip 1: *Formulera ett komplext hållbarhetsproblem för processdrama som involverar både pressande samhällsutmaningar och lämpligt kemiinnehåll på ett sådant sätt att olika nivåer av komplexitet hos problemet kan synliggöras i klassrummet.*
- Designprincip 2: *Skapa roller för elever och lärare att spela, som gör det möjligt för eleverna att urskilja olika dimensioner av det komplexa hållbarhetsproblemet, och att samarbeta med idéer om hur problemet kan hanteras.*
- Designprincip 3: *Skapa möjligheter för eleverna att utforska tidsmässiga dimensioner av det komplexa hållbarhetsproblemet.*

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