Science Education International
33(2), 181-191
https://doi.org/10.33828/sei.v33.i2.6

International Council of Association for Science Education

ORIGINAL ARTICLE

Modeling as a Tool to Improve Second Language Learners' Descriptions of Non-Spontaneous Chemistry Concepts

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ABSTRACT

This study investigated how modeling in chemistry affect second language learners' descriptions of polymeric concepts. The aim was to investigate how chemistry discussions mediated by representations, contribute to second language students' development in the language of chemistry. The study took place in three multilingual upper secondary classes. Participating students were (n = 16) second language learners and (n = 14) first language learners. There were in total eight different first languages represented. Data comprised polymeric concept descriptions, audio recordings, and photos taken during modeling. The concept descriptions were analyzed by an inductive content analysis which was then used for a deductive analysis of the modeling-activity. The results show that 65% of second language learners' concept descriptions showed an increased clarity, and 45% showed increased use of chemical concepts after the modeling-activity. This study highlights how students in a multilingual context develop their language of chemistry by discussing chemistry scaffolded by representations. The results show that second language learners in a multilingual context benefited from the modeling-activity. As such, the study acknowledges that modeling contexts can be used in teacher education, both in-service and pre-service, to highlight the importance of the role of representations when teaching in the multilingual context.

KEY WORDS: Chemistry; modeling-based teaching; language of chemistry; multilingual; second language learners

INTRODUCTION

According to the European Commission, five and a half million refugee asylum applications were submitted in European Union countries during the years 2014–2019 (Eurostat, n.d.). The development has contributed to an increased cultural and linguistic diversity in society and consequently in schools. In Sweden, the teaching of chemistry and subject-specific concepts often occurs in multilingual groups (Swedish Institute for Educational Research, 2019). At the same time, several students have only been practicing Swedish for a limited time. This means that these students must learn new abstract concepts in their second language when the teaching takes place in Swedish. This study focused on how second language learners' descriptions of polymeric concepts developed through modeling-activities in chemistry in a multilingual context.

The importance of linguistic skills to learn chemistry has been noticed, discussed, and highlighted for some time (e.g., Taber, 2015). The role of language when teaching and learning chemistry becomes even more important as the student group to a greater extent develops toward heterogeneity in language, culture, and ability (Childs et al., 2015; Markic and Childs, 2016). If students do not have the necessary skills in the language of teaching, they often have problems understanding the science content, showing lower success in learning than students taught in their first language (Pyburn et al., 2013; Turkan and Liu, 2012; Wellington and Osborne, 2001). Lee (2005) showed that a lack of linguistic knowledge, the usage and understanding of scientific language might constitute a hindrance when asking questions and discussing chemistry. This, in turn, can demotivate students during science lessons. Therefore, an important area of research is how teachers can offer learning opportunities for all students while working in schools with linguistically diverse student populations (Markic and Childs, 2016).

Learning the scientific language does not only include the learning of individual concepts but also the context in which the concepts are used (Lemke, 1990). As such, students' active and purposeful use of language is fundamental when learning the scientific language. A learning situation, which enables students to interact and to use language in language-developing contexts, is desirable (Gibbons et al., 2018). When expressing themselves within the scientific discourse, students might develop ownership of concepts and conceptual use (Gilbert and Justi, 2016). Despite the importance of letting students discuss science to provide learning, studies have shown that student discussion and argumentation rarely occur in science classes (Berland and Reiser, 2009; Duschl and Osborne, 2002).

Many concepts used when speaking the language of chemistry are considered non-spontaneous and do not originate from personal experience but can be acquired through the medium of language and other mediating tools, that is, models and representations (Vygotsky and Kozulin, 1986). Models in chemistry education are considered to be simplified

Science Education International
33(2), 181-191
https://doi.org/10.33828/sei.v33.i2.6

representations of an object, process, or phenomena, explaining an entity (Maia and Justi, 2009). A model can be used as a tool for thinking with and/or to make sense of an experience (Passmore et al., 2017). The use of models in science education is fundamental since models are considered to be the basis of scientific reasoning (Clement, 1998). Moreover, other researchers (Clement and Rea-Ramirez, 2008; Passmore and Svoboda, 2012) have highlighted the need to introduce modeling-activities in the science classroom to investigate the discussions and argumentation during the modeling.

Aim and Research Question

This study intended to meet the need for modeling approaches in teaching which might enable students in a multilingual context to interact and communicate chemistry in an upper secondary chemistry classroom. The purpose of the study was to investigate how modeling about polymers and the discussions scaffolded by created representations, affected second language learners' descriptions of polymeric concepts. The study intends to fill a gap in the literature describing how modeling in chemistry, in multilingual classrooms, affects second language students' ability to express themselves in the language of chemistry. In addition, this study contributes to describing a possible teaching strategy for working in multilingual chemistry contexts. The research question that this article intended to answer was:

- How are descriptions of non-spontaneous concepts in polymer chemistry of second language learners affected by modeling?

LITERATURE REVIEW

The need for student-active approaches and communicative situations in science has been met by other researchers, that is, Yuriev et al. (2016) used crossword puzzles for chemistry education as a specific method for mastering the definitions of chemical terms and concepts. Furthermore, Repice et al. (2016) indicated that the collaboration between the students working in small groups helped them to talk their way through problems, taking turns in explaining and questioning thus regulating, and improving their own and their group's learning through collaboration. A study conducted by Duran et al. (1998) investigated how second language Mexican American high school students constructed understandings of biology concepts with the use of mediating artifacts (diagrams). Their results showed a progression in students' responsibility for constructing meanings and the importance of providing second language learners to acquire the language of science through different mediating artifacts.

Despite the centrality of argumentation to learning science, researchers (for instance, Berland and Reiser, 2009; Duschl and Osborne, 2002; Jiménez-Aleixandre and Erduran, 2007; Newton et al., 1999) have demonstrated that it rarely occurs in science classes. Moreover, other researchers (Clement and Rea-Ramirez, 2008; Passmore and Svoboda, 2012) have highlighted the need for introducing modeling-based teaching (MBT) activities in science classrooms and conducting additional studies that explore the relationship between modeling and argumentation in specific teaching contexts.

This study draws on the work of Vygotsky and Kozulin (1986) and the development of non-spontaneous concepts, that is, concepts acquired in a social context mediated by others through mediating tools, such as language, models, and representations. According to Vygotsky and Kozulin the basis of learning non-spontaneous concepts, rely on earlier learning of spontaneous (everyday) concepts. Spontaneous concepts are used to create representations and understanding of abstract concepts in language development. Furthermore, according to Vygotsky and Kozulin (1986), students' conceptual understanding relies on a learning environment within their personal experience thus within their zone of proximal development (ZPD).

All students, regardless of their first language, share the language of chemistry in the classroom. In the field of chemical education research, the language of chemistry is often referred to as Chemish (Markic and Childs, 2016). According to Wellington and Osborne (2001), the language of chemistry is in several ways unique, which contributes to the difficulties in learning Chemish. According to Childs et al. (2015) and Osborne (2002), the greatest issue is that Chemish in several ways differs from everyday language. Here, we highlight three differences. First, there is a non-spontaneous vocabulary of science rarely met in everyday life, which is like learning a foreign language. Chemistry involves many abstract concepts, that is, polymer, monomer, and polymerization reaction, that cannot be communicated simply by giving students the concept conceptualized by chemists hoping that the students understand the concept (Taber, 2015). Second, the scientific language is polysemous; there are double-meaning words. An example of a polysemous word is solution, solution of sodium chloride in water, or solution to a problem. If you misunderstand a concept in a chemistry discussion or a chemistry text, it may lead to misunderstanding the whole context. Research suggests that spontaneous, everyday concepts in chemistry may be a bigger challenge for second language learners compared to first language learners (Childs and O'Farrell, 2003; Johnstone and Selepeng, 2001). Finally, the scientific language is multi-semiotic. In addition to learning the verbal language, students must understand the connection between language and other modalities used (Lemke, 1998). Furthermore, Lemke highlighted that understanding a concept is concerned with linguistic complexity and only occurs when different aspects of the multi-semiotic language overlap and integrate.

Studies that have analyzed students' discussions in science education have shown that the involvement of students in argumentative situations can contribute to students' conceptual development and clearer understanding of relevant concepts (Allchin, 2011; Chin and Osborne, 2010). Since talking science is crucial for learning science and the development of conceptual use, this might be even more important for second language learners. For students who participate in teaching where the teaching is conducted in the student's second language, the task of understanding the formalized language of science might become problematic. The students need to develop knowledge in their second language at the same time, as they will learn to use the language in a new and specialized context. According to Thomas and Collier (1997), it takes 5–10 years before second-language learners can take part in the education on the same terms as students taught in their first language. The previous studies have shown that conducting a more student-active teaching approach in chemistry leads to the development of students' use of scientific language (Abir and Dori, 2013; Ehdwall and Wickman, 2018).

Modeling in Science Teaching

In the field, a distinction is made between model-based teaching and MBT. Model-based teaching concerns how students use already existing models, while MBT is an educational process where students create and reflect on their representations (Gilbert and Justi, 2016). In this study, the Model of Modeling v.2 (Gilbert and Justi, 2016) is used as a framework for planning and conducting the modeling-activities. In the framework of MBT, models are understood as epistemic artifacts, related to many of the scientific practices in which chemistry reasoning is an essential part (Gobert and Buckley, 2000). According to Gilbert and Justi (2016), modeling can be described as a cyclical process of knowledge building consisting of four parts: The creation of the mental model, expression of model, test, and evaluation of the model. MBT aims to contribute to students' active involvement in their learning process and enable students to *discuss chemistry* in the process of creating, questioning, and evaluating representations. Modeling can provide a teaching activity that goes beyond memorizing facts and offers a tool for students to reason and use facts and concepts to account for phenomena. From such a perspective it is considered that students' active participation in their learning process helps them to construct understanding (Passmore et al., 2017).

According to Taber (2013), discussions are about visualizing our thoughts, our inner images. By creating representations shared and discussed with others in the "public space," our thoughts become visible. In this context, other communicative tools, for example, gestures, facial expressions, and representations (Jewitt et al., 2001) can supplement language. Modeling enables a student-communicative approach to chemistry as the students' representations can be expressed in many ways. When students fail to express their thoughts about a scientific phenomenon verbally, they can use non-verbal representations such as drawings, concrete models, or gestures to support their argumentation (Gilbert and Justi, 2016). Studies show that the use of representations in communication is common when students attempt to express their ideas more clearly for explaining specific scientific vocabulary (Mendonça and Justi, 2013). Furthermore, Oliveira et al. (2015) found that the main reason for using non-verbal communication tools during chemistry discussions was to substitute vocabulary, but also to explain, to check, to understand, to reinforce speech, to refer to and to represent a model. We suggest that these aspects justify the use of modeling-activities in a multilingual teaching situation to investigate development in concept descriptions due to modeling, as well as to fill a gap in literature addressing teaching chemistry in a multilingual context. Concerning students who are not taught in their first language and who have not yet developed their scientific language corresponding to the level of teaching, non-verbal communication tools as mediating artifacts can be of great help to understand processes, contexts, and concepts.

METHODOLOGY

This study took place in three multilingual upper secondary classes at the Natural Science Program. All participating students had studied chemistry corresponding to one and a half years at the upper secondary level. Participating students, aged 17–20, were heterogeneous in their first language. There were in total eight different first languages represented, that is, Swedish, Arabic, Persian, Turkish, Dari, Bosnian, Urdu, and Kurdish. There were 16 second language learners and 14 first language learners. All second language learners had lived in Sweden for 3–6 years and had attended Swedish school with the equivalent amount of time.

Data Collection

To investigate a possible progression in students' descriptions of polymeric non-spontaneous concepts, students completed a concept questionnaire before and after the modeling-activities, Appendix 1 for one example from the concept questionnaire. The questionnaires were used to investigate changes in students' descriptions of 14 different non-spontaneous polymeric concepts (Appendix 2), for example, monomer, polymer, polymerization, amorphous, and crystalline before and after the modeling-activities.

During the modeling-activities, (square 2 in Figure 1), additional data were collected, such as audio recordings and photos. A summary of the methodology is visualized in Figure 1.

The modeling-activities were distributed on 3–4 occasions of around 50 min each, over a week. The activities were audio-recorded with a recorder placed in the middle of the student group. The purpose of the audio recordings was to document the discussions within students' ZPD and further explore how the students explored non-spontaneous concepts. A photo camera was used to document students' representations during modeling.

The modeling-activities began when their teachers (different teachers in each class) instructed students that they should

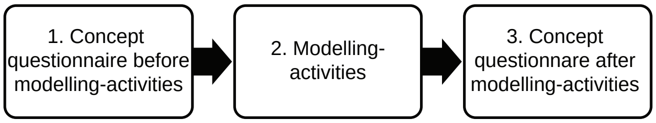

Figure 1: Research methodology summary scheme

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33(2), 181-191
https://doi.org/10.33828/sei.v33.i2.6

develop one, or several, representation(s) to visualize polymers. The students were asked to discuss: (1) What is a polymer? (2) How are polymers formed? and (3) What is the chemistry behind the properties of polymers? In addition to the third question, the students were asked: Using your representation(s), how can you describe polymers that have different properties such as elastic, inelastic, soft, or hard? First, all students for 15–20 min individually considered possible representation(s) to visualize polymers according to the questions, that is, creation of mental models. Then the students were grouped into groups of 3–4 students who were not homogeneous in their first language. During the modeling activity, all students spoke Swedish. In total, eight different multilingual groups participated in the study. In each group, the students compared and discussed their different ideas, which led to some initial representations being rejected since they were not considered to visualize what was intended. Not rejected representations followed the four parts: Creation, expression, test, and evaluation by the framework of MBT (Gilbert and Justi, 2016). Materials used by students when expressing their representations were rope, string, tape, paper, paper clips, beads, stickball models, macaroni, cooked and uncooked spaghetti, and students' bodies. Figure 2 illustrates how one group visualized polymer chains with the help of paper clips, strings, and beads.

Data Processing and Analysis

This article seeks knowledge on how modeling affects second language learners' concept descriptions of non-spontaneous polymeric concepts. The primary forms of validity for knowledge-based research are according to Newton and Burgess (2008) outcome and process validity. The main action to ensure outcome and process validity has been the critical and reflective dialogue between three researchers, that is, the authors. Through the study, the implementation of the method, analysis of data, and documentation of results have been discussed and reflected on by all three researchers. The involvement of three chemistry teachers in the categorization of students' concept descriptions also adds to strengthen the outcome validity. To ensure external validity our purpose is to provide content-rich material in our results (Robson, 2011) that can be used and applied by other researchers and in another setting with similar conditions. Reliability is addressed since the same methods and activities are performed in three different classes involving different students and teachers. Analyzed data consists of second language learners' written concepts descriptions, multilingual group discussions, and expressed representations. Thus, we are only able to analyze what these particular students present to us. We are not able to go beyond what is out in the "public space" (Taber, 2015), which might be a limiting factor in this study.

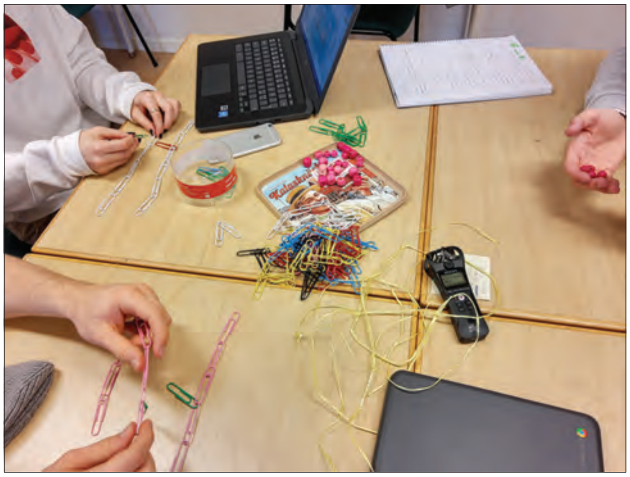

Figure 2: Vizalusation of polymer chains using paper clips, string, and beads

The first stage in the process of inductive analysis of data was to compile the concept descriptions from the questionnaires and to categorize second language learners' concept descriptions into two categories "correct" or "incorrect." The descriptions were first categorized by the researchers and then discussed with the chemistry teachers until consensus was reached. A concept description that was classified as correct was considered an approved description by both researchers and teachers. The number of approved descriptions of concepts was compiled and comparison for all 14 concepts between before and after the modelling-activities was made. The compilation is presented in Appendix 2. Based on the compilation, five non-spontaneous concepts with large progression in correct explanations of concepts were selected for further analysis in the modeling-activities, that is, monomer, polymer, polymerization, amorphous, and crystalline. The process of this analysis is further described as the third stage.

In the second stage, an inductive content analysis was performed on second language learners' correct written concept descriptions, given before and after the modeling-activities. The content analysis followed the guidelines of Erlingsson and Brysiewicz (2017). All correct concept descriptions were read several times and relevant parts, changes in descriptions, were condensed into meaning units, that is, unit of analysis, and then coding units. Coding units are here considered as a label, a word that describes what the meaning unit is about. The coding units were finally categorized. The process of coding and categorizing was discussed by the three researchers and remade by returning to concept questionnaires and repeated until final codes were determined, and consensus was reached. The process is exemplified by two examples in Table 1.

Finally, three categories were determined: Relational progression between concepts, progression of the representation level a concept is assigned to, and increased use of non-spontaneous chemical concepts. Four subcategories were determined: molecular multiparticle, macromolecular, and macro level. The subcategories were used to clarify both relation and organization levels between concepts. The molecule level refers to concepts that are related to small molecules like monomers, the macromolecule level refers to concepts that are related to a large molecule as a polymer chain,

Table 1: Application of content analysis on a concept description

Meaning unit before modelling-activities	Meaning unit after modelling-activities	Coding unit	Categories	Subcategories
"A part of a polymer" *"The chains have bonds between each other"*	*"Monomer is a molecule make up a polymer, for example an ethylene molecule"* *"Covalent bonds between the chains. They give the polymer a much stronger structure"*	Increased clarity	Progression of the representation level a concept is assigned to.	
			(Monomer is a molecule…)	Molecular level
			(bonds between chains)	Multiparticle level
			Relational progression between concepts.	
			(monomers make up a polymer…)	Molecular level and macromolecule level
			(They give the polymer a stronger structure)	Multiparticle level and macro level
			Increase use of nonspontaneous chemical concepts	
		Increased use of non-spontaneous concepts	*(molecule, ethylene)*	
			(covalent, polymer)	

and the multi-particle level refers to concepts that are related to the structure and interaction between several macromolecules. The macro level concerns concepts that describe the properties of the material as soft, hard, elastic, or inelastic. A possible progression in descriptions of concepts between questionnaires before and after the modeling-activities was analyzed in relation to determined categories. A summary of the frequency of the categories; relational progression between concepts, progression of the representation level a concept is assigned to, and increased use of chemical concepts, was made.

The third stage in the analysis was to listen to the audio recordings from the eight groups modeling-activities. Audio recordings were listened to several times to provide an overview of different events during modeling. Deductive analysis was conducted where relevant parts, discussions about non-spontaneous chemistry concepts, reflecting the categories in Table 1 in combination with the five selected concepts (i.e., monomer, polymer, polymerization, amorphous, and crystalline), were selected and transcribed verbatim. Selected transcripts that were relevant for illustrating students' discussions and modeling about polymeric concepts and how this affected concept development, were discussed by the three researchers until consensus was reached. To increase clarity in presented dialogues minor linguistic clarifications have been made, but without changing the content.

Ethical Considerations

This research project follows the ethical guidelines stated by the Swedish Research Council (2017). Before data collection teachers and students were informed about the purpose of the study and chosen methods. Participating teachers and students (aged 17–20) gave their written consent to be part of the study, to be audio recorded and photographed. No individual personal data are stored nor are privacy-invasive issues addressed. Ethical guidelines explicitly state that all participants must have the opportunity to approve or decline to take part in research at any time during data collection, which everyone was informed. All data have been anonymized without distorting the scholarly meaning.

RESULTS

The research question that this article intends to answer is: *How are descriptions of non-spontaneous concepts in polymer chemistry of second language learners affected by modeling?* The results present and discuss six examples illustrating students' concepts descriptions, given before and after the modlling-activities based on the identified categories, excerpts from dialogues between individuals in the group, and examples of representation(s) created by the group during modeling. These examples have been selected to illustrate a possible connection between a progression in concept description and the modeling-activity and are representative for all eight groups of students. The result is presented in three sections according to the categories: Progression of the representation level a concept is assigned to, relational progression between concepts, and increased use of chemical scientific concepts.

Before presenting the result, we characterize the examples given to facilitate the understanding of the context in which it occurred. To clarify students' concept descriptions and excerpts we have inserted a clarification by using square brackets [ ]. In the excerpts, the students are identified by the code (SY), where Y is a random number identifying the student, and **second language learners are marked with ***.

Progression of the Representation Level a Concept is Assigned to

A progression of the representation level the concept monomer is assigned to be found in several examples where students' descriptions before the modeling-activities are unclear about the fact that a monomer is a molecule. In example 1, before modeling, (S1*) wrote: "*a monomer is atoms that bind together.*" This illustrates the unclarity to which representation level the concept monomer is assigned. The student's description before the modeling-activities can be interpreted as either that a monomer is a molecular compound or a metal compound, or both. Excerpt 1 illustrates the student discussion discussing the concept monomer during modeling.

Excerpt 1:

(S1*): *But polymers, so then monomers are just what the polymers are made of?*
(S3): *Yes like ethylene or alcohol?*
(S2*): *So it must be a group?*
(S3): *It must be a molecule*
(S1*): *So it is not a carbon atom or a hydrogen atom but it is a molecule that binds to another molecule?*
(S2*): *And it's not just two I think it must be many to make it a polymer*

After the modeling-activities, (S1*) described monomers as "*small molecules that bind together and form polymers.*" (S1*) clarifies that a monomer is a molecule, attributes clarity to the concept within the molecular level by stating, "*molecules bind together.*" In addition, the fact that monomers are molecules was also visualized by the students during modeling. The mediating artifact developed by this group was stickball models that identified a molecule, Figure 3, not an atom, and was used as building blocks to illustrate that monomers form a polymer, Figure 4. The produced models scaffolded the students in the clarification of concepts, that is, monomer and polymer.

In example 2 stick-ball models were also used by another group during modeling to clarify the concept monomer. Before modeling, (S5*) wrote: a monomer is "*the part in polymerization,*" the student is non-specific of the meaning of "*part.*" After the modeling-activities (S5*) wrote: "*Little molecules that together form polymers,*" specifies that a "*part*" is a molecule. Excerpt 2 illustrates the student discussion during modeling.

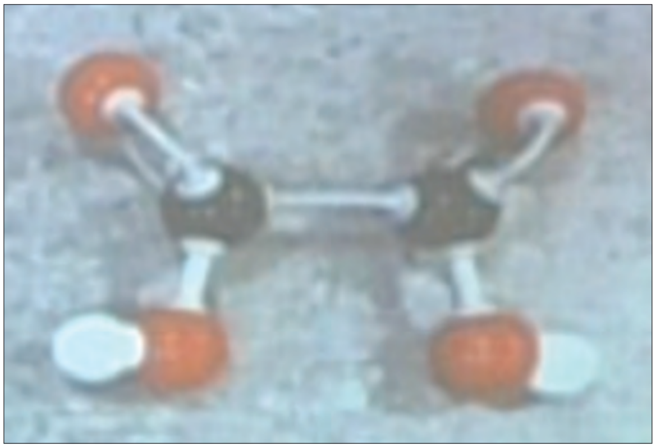

Figure 3: A monomer

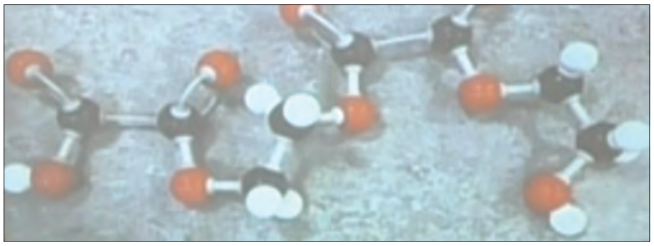

Figure 4: A polymer

Excerpt 2:

(S4): *You can say that polymers are, polymers that consist of several small molecules, several smaller molecules that are put together in a chain.*
(S5*): *Linked molecules, monomers?*
(S4): *Yes*
(S6*): *Like a protein?*
(S4): *Yes*
(S6*): *And then the monomers are the amino acids?*

Furthermore, in the second example, (S6*) could not give a description of the concept monomer before the modeling-activities but after modeling the student wrote: "*Monomer is a molecule in a polymer that together with other molecules form a polymer.*" Example of a monomer is an amino acid in a protein. The student included that "*example of a monomer is an amino acid in a protein.*" Here (S6*) refers to amino acids to clarify the concept of monomer as amino acid was a known concept to the student. These two examples illustrate that students' concept descriptions show increased clarity in representational level the concept monomer is assigned which illustrates a molecular level scaffolded by produced models.

Example 3 illustrates a progression in clarity in assignment to representational level for the concept polymer. Before the modeling-activities, (S7*) described the amorphous structure as a "*molecule that has an unstructured form.*" Here, the student is unclear about what level of representation the molecule is assigned, namely, molecule level or macromolecule level. The concept description given after modeling shows a progression as (S7*) writes "*an unstructured form in which polymers are placed.*" The student uses the concept of polymers instead of molecules and further develops the description by writing "*There is little bonding between the polymers, weak plastic.*" In addition, before the modeling-activity (S7*) described the crystalline structure as "*molecule that has an unstructured form*" and after the activity "*A structured form in which polymers are placed. There will be many bonds between polymers, strong plastic.*" In the descriptions after modeling, (S7*) clarifies the concept of polymer's assignment to three different organizational levels, namely, macromolecule level (polymer) multiparticle level (bond between the polymers), and macro level (the material plastic). Furthermore, during the discussion, illustrated in Excerpt 3, the students placed their polymer chains according to Figures 5 and 6. The use of the produced models scaffolded the students in the discussion exploring and clarifying the concepts of amorphous and crystalline structure. Students placed macaroni chains, that is, polymer chains in an irregular pattern according to Figure 5 to visualize amorphous structure and in a regular pattern to visualize the crystalline structure, Figure 6. In the dialogs, (S7*) and (S9) stated that the structure of the polymer chains in relation to each other contributes to different numbers of bonding occasions. As (S7*) in the concept description stated, unstructured means "*little bonding*" and structured "much bonding."

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Excerpt 3:
(S8): *Amorphous leads to less dense structure, how should they be placed?*
(S9): *We do this* (puts the polymer chains according to Figure 5).
(S7*): *Then it is less dense and less bonding.*
(S7*): *Crystalline what does it mean?*
(S8): *When they are tightly packed* (Figure 6).
(S9): *Yes, it will be strong, there will be more bonds.*

In addition, another student (S14*) first described a polymer as "*several monomers that are attached and form a kind of chain,*" "*a kind of chain*" do we consider a non-specific conceptual use. After the modeling activities, the student wrote a "*polymer chain*" instead of an only chain. This example illustrates clarification of the representation level the concept polymer is assigned, the macromolecule level.

Several examples highlight the fact that the concept polymer is a polymorphic concept, which means that the concept can be assigned to several levels: Macromolecule level, multiparticle level, or macro level. In example 4, (S7*) gives an unclear description, before the modeling-activities, according to the representational level of the concept polymer. (S7*) wrote, "*A polymer is a long chain assembled by small parts.*" It is not clear if the student refers to a polymer as a macromolecule or a material i.e., macro level. After modeling, (S7*) clarifies that the concept polymer can be described as one chain referring to macromolecule level, but also that a polymer can be described as plastic material, macro level, consisting of many polymer chains referring to multiparticle level. After the modeling activity the (S7*) wrote: "*Polymers are chains long chains of monomers that bind together. There are polymers with only one chain as well, ex DNA. Many chains can be plastic.*" Excerpt 4 illustrates the student discussion concerning polymer as a polymorphic concept during the modeling-activity.

Excerpt 4:
(S8): *You can use polymers in materials, like in plastics. Then there are chains…*
(S7*): *Yes, DNA is also a polymer, right? One chain?*
(S8): *Yes*

Produced models, illustrated in Figures 7 and 8, scaffolded the students in exploring the concept of polymer. The models visualize and clarify the concept of the polymer as one chain

Figure 5: Amorphous structure

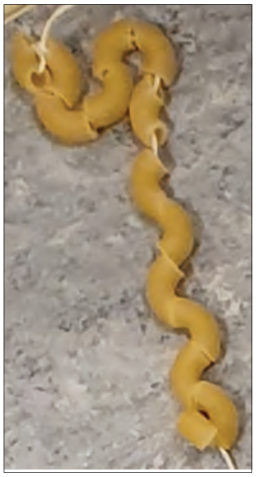

Figure 7: A polymer chain

Figure 6: Crystalline structure

Figure 8: Polymer chains

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https://doi.org/10.33828/sei.v33.i2.6

(macromolecule level) or several chains like in plastic (macro and multiparticle level).

In example 5, before the modeling-activities, (S10*) described the concept of polymerization as "*several monomers sitting together,*" here the student's perception about the concept of polymerization is unclear using the expression "*sitting together.*" After modeling (S10*) described polymerization as "*A long chain consisting of monomers, that is molecules that have reacted with each other through a polymerization reaction.*" In the second description, the student both clarifies the concept of monomer "*that is molecules*" and the concept of polymerization by stating that is a reaction between monomers. Excerpt 5 illustrates the student discussion concerning the concept of polymerization during the modeling-activity.

Excerpt 5:
(S10*): **What is polymerization?*
(S11*): *It's when they are joined together…*
(S12): *Polymerization is when monomers join together to form a polymer…*
(S10*): *How are polymers formed?*
(S11*): *There are two ends* (in a molecule) *that can react and then it can be built on these free ends*
(S10*): *Yes because we still have the other side, so that it can bond to something… if you stand two* (persons standing side by side)*… if you will hold my second hand, then it will, just it's still free*
(S11*): *Yes his hand is still free, he can bond to another., come here and take my hand, yes it is good because then you can show that it continues*

In example 5, students illustrated monomers by humans and a polymer chain by humans holding hands according to Figure 9. The dialog clarifies that a polymer is formed when molecules bond to free ends in the polymer chain and that the reaction is repeated. (S11*) said, "*There are two ends that can react… then it can be built on these free ends.*" The representation is then used to illustrate polymerization. (S10*) continued "*If you hold my second hand…then it's still free*" and (S11*) said, "*his hand is still free, he can bond to another, come here and take my hand… then you can show it continues.*"

Relational Progression between Concepts

Examples 1 and 2 indicate a relational progression between monomer and polymer, that is, that monomers (molecular level) are the building blocks of a polymer chain (macromolecule level). In example 1 (S1*) first wrote a monomer is "*atoms that bind together*" but do not clarify the relation in representational level between monomers and a polymer chain. After the modeling-activity (S1*) wrote that monomers are "*molecules that bind together and form polymers.*" From the student description, it appears that the student considers it important to highlight the relationship between the concepts monomer and polymer. (S1*) assign the concept monomer to molecule level and polymer to macromolecule level and clarify the relationship in representational levels between the concepts. The same progression is shown in example 2 where (S5*), before the modeling-activities, wrote "*the part in polymerization*" but after the modeling-activities wrote, "*little molecules that together form polymers.*"

Figure 9: A polymer produced by polymerisation

Another aspect of how students clarify the relationship between the concepts of monomer and polymer is by clarifying the relationship between number and size. In example 6, before the modeling-activities (S14*) described a polymer by "*several monomers attached.*" The descriptions are unclear since the student state several monomers. Polymers are macromolecules that consist of many monomers. After modeling (S14*) wrote: "*a polymer chain consists of many polymers up to 1000 monomers.*" Excerpt 6 illustrates the student discussion about that many monomers make a polymer during the modeling-activity and Figure 10 illustrates the model produced by the students.

Excerpt 6:
(S13): *There are not so few that can form a polymer but there are several.*
(S 14*): *What was the shortest polymer? What is not this with amino acids, that 50 are needed?*
(S13): *It's 50 in the shortest protein. It does not have to be so few monomers that bind together, but it can often be up to several thousand monomers.*
(S14*): *But we have problems, how do we make a polymer? We cannot use people because we are only four.* (refers to the number of participants in the group)
(S13): *We could use other things to show monomers, such as paper clips instead of persons.*
(S14*): *Look this is a monomer* (holding up a paper clip), *if you pick up a monomer* (asking another student to pick up a paper clip) *we can put them together.*
(S13): *If we put many together.*
(S14*): *It will be a polymer.*

During modeling, the mediating artifacts were paper clips used to scaffold clarity between concepts and to visualize the relation between the concepts monomer and polymer. (S14*) says "*look this is a monomer*" holding up a paper clip, (S13*) continues, "*if we put many together*" and finally (S14*) "*It will be a polymer,*" according to Figure 10.

Clarity about the number and size between monomers and polymers are found in most students' descriptions after the

Figure 10: Polymer chain made by paper clips as monomers

Science Education International
33(2), 181-191
https://doi.org/10.33828/sei.v33.i2.6

modeling-activity. Several students included "*little or small*" in their descriptions when describing monomers in comparison to polymers. Clarification between the concepts was made by a polymer is described according to macromolecular level (long-chain) and monomers by molecular level (many, small, and little).

Increased Use of Chemical Scientific Concepts

The examples show an increased use of chemical scientific concepts thus a progression in chemish. Examples 1 and 3 illustrate that (S1*) and (S7*) before the modeling-activities use the incorrect concepts "*atoms*" and "*the molecule,*" when describing the concepts monomer, amorphous and crystalline. After modeling (S1*) replaced the concept atom with a molecule and in addition, include the concept polymer in the description. The same pattern of increased use of chemical concepts can be observed in examples 2 and 4 where (S5*) and (S7*) replace "*the part/part*" with a "*molecule/monomer.*" In example 3 is "*chain*" replaced by "*polymer chain,*" and (S7*) uses the incorrect concept "*the molecule*" before the modeling-activities but after the modeling-activities (S7*) describes amorphous and crystalline structure by replacing "*the molecule*" with "*polymers.*" Using polymers instead of the molecule (S7*) clarifies that the terms amorphous and crystalline often refer to the interaction between several polymer chains. By replacing incorrect or non-specific concepts with correct and specific chemistry concepts, the description increases in chemical clarity, thus a progression in chemish.

Furthermore, example 4 (S7*) first describes a polymer by "*a long chain assembled by small parts*" but after the modeling activities (S7*) replace "*assembled*" by "*bind together,*" referring to chemical bonding. Another example of a progression in chemish is example 5 where (S10*) before the modeling-activities describes polymerization by "*several monomers sitting together.*" "*Sitting together*" is not an expression used to express in scientific language. After the modeling-activities (S10*) wrote: "*molecules that have reacted with each other*" in this description the student has increased use of scientific concepts thus stating "*reacted*" instead of "*sitting together.*"

In summary, the result from the analysis of concept descriptions (n = 154) concerning all concepts (n = 14, presented in Appendix 2) given by 16 second language students, show that in total 101 concept descriptions (65%) showed an increase clarity. Based on this, 86 descriptions indicate an increased clarity to the representation level the concept was assigned, and 46 descriptions showed a relational progression between concepts. Furthermore, 70 concept descriptions (45%) showed increased use of chemical concepts. This result indicates an increased clarity of students' explanations as well as more frequent use of chemical concepts after the modeling-activities. The dialogs between students scaffolded by representations offered students an opportunity to explore, discuss, and visualize non-spontaneous polymeric concepts. We claim that, after modeling, the second language learners' dialog mediated by representations contributed to a progression in conceptual use and an increased ability for students to express themselves in the written language of chemistry.

DISCUSSION AND CONCLUSION

Teaching and learning chemistry are in many ways considered complex since learning chemistry is largely about learning non-spontaneous phenomena and concepts. Learning the abstract is challenging for all students but in particular for students taught in their second language. This study investigates the contribution of discussions scaffolded by created representations during modeling, a need highlighted by Clement and Rea-Ramirez (2008) and Passmore and Svoboda (2012) and communicative situations in teaching chemistry, which according to Berland and Reiser (2009) and Duschl and Osborne (2002) rarely occur in science classes. As stated earlier, due to an increase of linguistical heterogeneity in classrooms all over the world there is an urgent need to investigate teaching strategies in the multilingual context. This study meets this need and explores modeling in the multilingual context to investigate how second language learners' descriptions of non-spontaneous polymeric chemistry concepts are affected by modeling.

Several scholars (e.g., Allchin, 2011; Chin and Osborne, 2010) have highlighted the importance of letting students discuss chemistry in a learning context, to explore and practice conceptual use, and to be able to develop the language of chemistry, that is, chemish. This study shows that the discussion is an important mediating tool that enables a learning situation based on the students' ZPD, but we want to empathize the importance of combining discussions with mediating artifacts, in the multilingual context, when developing chemish. Our results demonstrate that created representations were used as tools for both thinking with a concept or phenomena but also to express experience. Our results illustrate that the created representations during modeling were used by the students to visualize the invisible and abstract, a result in line with other studies (e.g., Gilbert and Justi, 2016; Mendonça and Justi, 2013).

When analyzing students' concept descriptions in comparison to excerpts from students' discussions and representations created during modeling, the results show that a progression in students' polymeric concept descriptions influenced by discussions. This result is in line with other studies that highlight the fact that second language learners develop their use of scientific language (Abir and Dori, 2013; Ehdwall and Wickman, 2018), conceptual development, and clearer understanding of relevant concepts (Allchin, 2011; Chin and Osborne, 2010) when conducting a more student-active approach in chemistry. During the modeling-activities, the students were allowed to identify conceptual misunderstandings but also conceptual flaws.

Furthermore, our results show that the process of creating representations supported communication and conceptual use. This result is supported by Duran et al. (1998) who showed a progression in second language learners' scientific language when constructing meanings through mediating artifacts (diagrams). We argue that the students in the multilingual context used their representations as scaffolds during communication when explaining to each other, leading to a possible progression in concept descriptions. We want to highlight that created representations scaffolded second language learners' ability to express themselves and that there is a great need to use different resources for communication when teaching and learning chemical concepts in the multilingual context.

We argue, when conducting teaching in a multilingual context, student discussions, and visualizations of concepts might be even more important for second language learners since they simultaneously need to develop both a second language and chemish. Discussing and visualizing concepts is crucial for learning and understanding the formalized language of chemistry. When analyzing the students' discussions, it is prominent that students talked their way through the process of modeling by questioning, explaining, and clarifying concepts thus polymer chemistry to each other. This is in line with Repice et al. (2016) that state collaboration in small groups in chemistry improve learning for the individuals but also for the group. We see collaboration between students as an important factor reflecting a possible progression of concept descriptions.

In summary, this study presents data from 16 second language learners and 14 first language learners. As such, the study can only draw conclusions based on this particular group of students and does not provide any basis for generalization of results to a wider population. This might be a limitation, but at the same time, deep studies of students' communication and activities are important, and much can be learned from descriptions of particular groups of students in particular learning contexts, in this case, modeling-activities. Despite few investigated students, conclusions and implications for teachers can be drawn from modeling as a teaching design to develop chemish. These conclusions can be used in wider contexts by teachers teaching chemistry in multilingual classes.

To end, an aspect that emerges from our work is the need to conduct more studies on other types of student active approaches, besides modeling-based ones, in the multilingual context. Such studies could give us other aspects and teaching tools when teaching and working in schools with linguistically diverse student populations. We also acknowledge that modeling- based contexts need to be used in teacher education to highlight the importance of the role of representations when teaching in the multilingual context, to scaffold chemistry discussions, to offer an opportunity for expression in different modes (not only verbal) and to develop conceptual use. Finally, we state that we believe this type of teaching is beneficial for all students, in all chemistry classrooms, not only multilingual.

Ethics Statement

The ethical considerations in the way the project were conducted are described under the methods section. The ethical considerations were reviewed and further supported by the ethical committee at the university. The authors declare that there is no conflict of interest.

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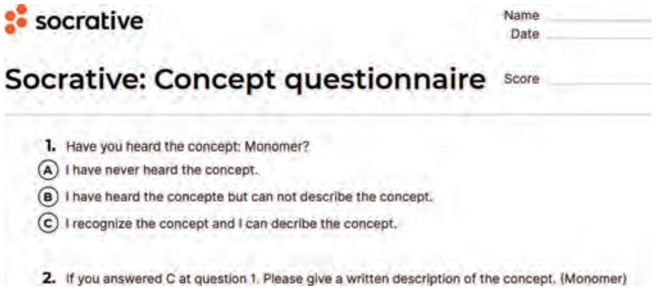
APPENDICES

Appendix 1: One example from the Concept questionnaire exemplifies the concept monomer



Name

Date

Socrative: Concept questionnaire

Score

1. Have you heard the concept: Monomer?

Ⓐ I have never heard the concept.

Ⓑ I have heard the concepte but can not describe the concept.

Ⓒ I recognize the concept and I can decribe the concept.

2. If you answered C at question 1. Please give a written description of the concept. (Monomer)

Appendix 2: Number of correct concept descriptions before and after modelling for second language learners. Concepts selected for deductive analysis during the modelling-activities are bolded

Concept	Number of students who could give a correct concept description before the MBT- activities (n=16).	Number of students who could give a correct concept description after the MBT-activities (n=16).
Monomer	6	16
Polymer	8	16
Polymerization	6	15
Condensation reaction	2	8
Radical polymerization	1	9
Functional group	6	8
Intermolecular bonding	10	14
Cross linking	2	5
Low-density polymer	6	8
High-density polymer	5	10
Amorphous structure	5	15
Crystalline structure	5	13
Thermoplastic	2	8
Thermosetting plastic	1	5