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Domain-Specific Expertise of Chemistry Teachers on Context-Based Education About Macro–Micro Thinking in Structure–Property Relations

Ria Dolfing · Astrid M. W. Bulte · Albert Pilot · Jan D. Vermunt

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Abstract This study aims to determine and describe the new domain-specific expertise of experienced chemistry teachers in teaching an innovative context-based unit about macro–micro thinking in structure–property relations. The construct of 'teachers' domain-specific expertise' was used to analyse the new repertoire chemistry teachers need to acquire to teach a context-based unit and achieve the intended effects of the curriculum innovation. A phenomenological approach of exploration and verification of teachers' new repertoire resulted in the description of seven themes. These themes were related to the new aspects of the unit: the context-setting, the teacher's role and the new content. In addition, the results show that the theoretical framework of teachers' domain-specific expertise is feasible for the analysis and description of their new repertoire in the domain of teaching a context-based unit. Further research is necessary to explore the use of the framework from the perspective of teachers' professional development, where affective components in teachers' learning processes play an important role.

Keywords Domain-specific expertise · Teacher learning · Context-based education · Chemistry education · Curriculum innovation

Introduction

Redesigning science curricula, especially when context-based units are included, implies new domain-specific expertise that is not part of teachers' existing domain-specific expertise. A context-based science curriculum implies a new role for teachers in relation to their students and new content is situated in a context setting. This involves new domain-specific expertise, additional to the existing conventional expertise of experienced teachers,

R. Dolfing (✉) · A. M. W. Bulte · A. Pilot
Freudenthal Institute for Science and Mathematics Education, Utrecht University, Princetonplein 5, 3584 CC Utrecht, The Netherlands
e-mail: r.dolfing@uu.nl

J. D. Vermunt
Faculty of Social and Behavioural Sciences, Utrecht University, Utrecht, The Netherlands

and alters teaching in line with the new science curriculum. To implement such a curriculum innovation successfully, adequate professional development is necessary (Van den Akker 1999) in which teachers acquire new domain-specific expertise to be able to achieve the intended effects (Tynjälä 2008; Van Driel 2006).

A programme for professional development should be based on understanding how teachers acquire new domain-specific expertise effectively to teach context-based units successfully. Teachers are professionals, learning and developing their expertise by performing activities in their domain of practice. One of the conditions for designing such a professional development programme is that this expertise is carefully described. Therefore, a theoretical framework is needed to describe what this expertise actually is when innovative context-based units are taught.

This study focuses on describing the new domain-specific expertise, which teachers need to acquire to teach innovative context-based chemistry units in which the context-setting determines an important part of the content of macro–micro thinking in structure–property relations. The study also focuses on the pedagogical approach used including a new teacher's role in class (Meijer et al. 2009). This detailed information on how and what should be planned is a necessary first step before professional development programmes for teachers can be designed.

Theoretical Framework for Describing Teachers' Domain-Specific Expertise

The theoretical framework draws upon two perspectives: (1) a construct to describe teachers' domain-specific expertise; and (2) an analysis of the new aspects of the context-based unit: (i) the context setting, (ii) the teacher's new role, (iii) the new content.

Teachers' Domain-Specific Expertise

Domain-specific expertise is mostly described within the construct of pedagogical content knowledge (PCK) (Shulman 1986, 1987). With respect to context-based chemistry units, however, the construct of PCK could be confusing. In PCK, the focus is on the relation between specific content knowledge and pedagogical knowledge (Lee and Luft 2008). 'Context' within the construct of PCK is often defined as the school situation in which the teacher teaches (Lee and Luft 2008). This makes it necessary to use a different construct where 'context' has a different meaning, as in 'context-based education'. 'Context' in context-based education is conceived as a setting within which the student's behaviour and mental experiences are situated, using the relationship of extra-situated background knowledge and specific language (Gilbert 2006). In addition the 'context' must provide the basis for developing coherent 'mental maps' of the content so that students experience learning chemistry as relevant and they feel a sense of ownership of what is to be learnt. In this study, the focus on teachers' acquisition of new domain-specific expertise depends on (i) the situated setting when a context-based unit is taught (ii) the specific role of the teacher to let students feel the relevance of learning chemistry and ownership of what they learn and (iii) the specific content organised in coherent 'mental maps'. Consequently, the new domain-specific expertise teachers need to acquire is not only related to content knowledge and pedagogical knowledge, but also to the context setting. This implies the acquisition of integrated new domain-specific expertise across all aspects of teaching a context-based unit. Therefore, a theoretical framework is needed in which the new domain-specific expertise can be described holistically, acknowledging the interrelationship of (i) the context setting, (ii) the teacher's role and (iii) the new domain-specific content.

Based on the studies of Sternberg (Cianciolo et al. 2006; Ericsson et al. 2006; Tynjälä 1999), expertise is defined as 'the ability to perform successfully'. An expert can be considered as a multi-dimensional prototype representing a central or 'prototypical' category by demonstrating common expertise that is characteristic of a specific domain (Ropo 2004). A similar definition of this 'common' expertise for one specific category of experts can be found in the 'common' part of teacher knowledge related to a specific domain (Verloop et al. 2001). This common part of knowledge represents knowledge shared by a certain group of teachers performing within a specific domain; for example, teaching a particular curriculum to a particular category of student. It involves explaining certain kinds of content or performing certain teachers' roles to this specific category of students. This knowledge is mostly acquired by experience. Based on the definition of Stenberg, new domain-specific expertise of a 'prototypical' teacher in this study could be described in themes formulated as abilities to perform successfully in the domain of teaching a context-based chemistry unit. In this, 'successfully' is defined as teaching the unit in such a way that according to the teacher, the intended effects of the curriculum innovation are achieved.

The expertise of such a prototypical teacher is described by seven general characteristics (Tynjälä 1999). These characteristics of expertise should be considered as a holistic framework (Smith and Strahan 2004). Therefore, the interrelationships between the characteristics of expertise can be considered as shown in Fig. 1. An expert teacher is characterised by their use of advanced problem-solving processes (1) when teaching context-based units and achieving the intended effects. The use of advanced problem-solving processes in the teacher's specific domain of practice requires a large repertoire of declarative and procedural knowledge (2). In addition, it requires advanced knowledge organisation (3) for the teacher to know what intended effects he/she has to achieve (effect), how he/she has to achieve the intended effects (actions) and when and where he/she has to act to achieve the intended effects (situations) (Dunphy and Williamson 2004; Sternberg 1999).

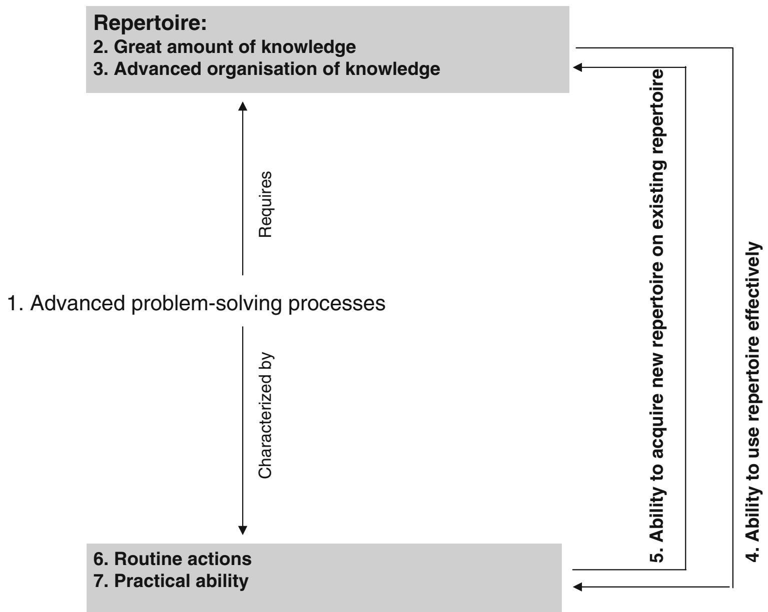

Fig. 1 Interrelationship of the characteristics of expertise

The teacher's advanced problem-solving processes (1) lead to successful performance in class, when the teacher has the practical ability (7) to execute the (routine) actions (6). Since teachers' knowledge is mostly acquired by experience, an expert teacher is characterised by using his/ her repertoire effectively (4) and expanding his/her repertoire as a result of acting in domain-specific situations (5) when teaching context-based units in class.

Teachers' expertise is deeply embedded within teaching practice. The description of new domain-specific expertise is strongly related to teaching a context-based unit. This study focuses on describing the new repertoire (2&3) teachers need to acquire and show in practical ability (7) and (routine) actions (6) in class, when teaching a context-based unit and achieving the intended effects. The themes in the new repertoire are formulated as abilities and are described in terms of Dunphy and Williamson's (2004) dimensions effect, actions and situations. The described abilities need to be part of the teacher's repertoire to teach a context-based unit and achieve the intended effects.

Expertise recognises the diversity of abilities that is the basis for a successful performance using repertoire effectively to teach context-based units, involving (i) the context-setting, (ii) a specific teacher's role and (iii) the new content. Ericsson argued that expertise exists in degrees rather than in an all-or-nothing fashion (Ericsson et al. 2006). Expertise includes domain-general information-processing capabilities which recognise differences between domains. One could reasonably say that an expert brings a richer repertoire to problem situations than novices in certain domains of practice and, as a result, has the ability to solve such problems more effectively. Experts are faster and more efficient in their problem-solving and seem to arrive at new and appropriate solutions to problems within their domain. Experts in the same domain can be different from each other by having different repertoires, although all are categorised as experts (Ropo 2004; Smith and Strahan 2004), so expert teachers all teach the same context-based units, and can show different actions to achieve students' intended learning effects.

Within curriculum innovation aimed at a context-based curriculum neither teachers nor curriculum designers and researchers are full experts in the domain of teaching these innovative context-based units, since they are still under development. What new domain-specific expertise teachers need to acquire to teach these units and achieve the intended effects must finally be determined by teaching these units in class followed by evaluation and reflection on this teaching together with the designers. When teachers prepare and execute a unit and reflect on teaching this unit, events can be described in which teachers make explicit or show what effects they tried to achieve and what actions they took in what situations to achieve these effects. To describe the new domain-specific expertise, events describing the teacher's actual actions in specific situations to achieve certain student effects can be interpreted and categorised in themes in teachers' repertoire, as described in the previous paragraph. Such described events could give more insight into the preferred intended events: that is, intended effects and preferred actions in specific situations that are intended by the designers of the curriculum innovation. Similarities and discrepancies between the described events and the preferred events could provide more insight into the actual teacher's repertoire, as well as the additional repertoire teachers need to acquire.

Analysis of the New Aspects of Innovative Context-based Units

Within the international trend towards innovations in science education (Pilot and Bulte 2006), this study considers context-based education as the learning of science content in social activities (Bulte et al. 2006; Prins et al. 2008; Westbroek et al. 2010). In such context-based education students are provided with meaningful problems (Lijnse and

Klaassen 2004) for which they need to develop the intended coherent content, such that they experience their learning as relevant and they feel a sense of ownership of what is to be learnt. Within such a vision, chemistry is considered as a social activity; chemical knowledge is used as a tool to execute a task, which involves solving a problem, and participants are motivated to use and develop knowledge (Meijer et al. 2009). Based upon this vision, the designed innovative context-based unit involves social activities to develop food products or to improve the properties of a food product in a project team. This project team, consisting of the students as project members and the teacher as a senior member, is required to use the necessary relations between the desired properties of the food product and the structures within the product (structure–property relations) to solve the problem. Whilst addressing this problem, the team is expected to feel the need (need-to-know basis) to use and develop more knowledge about these relations. An example of such a unit is given in the Appendix.

The main learning effect for students in this example of an innovative context-based unit is macro–micro thinking using meso-levels (Meijer et al. 2009). When addressing the food problem, students start with an implicit use of macro–micro thinking which is expanded during the project when they explain and predict the properties of the food product on macro-, meso- and micro-levels. This macro–micro thinking is made explicit to students by letting them map their developed knowledge in a conceptual schema (Fig. 2) of structures and related properties of a material, and formulating the structure–property relations in 'IF …, THEN …' sentences at the end of the project. In this conceptual schema, a material is considered as a system (macro-level) containing several subsystems (meso-levels). Relevant structures at different meso-levels can be assigned to appropriate scales.

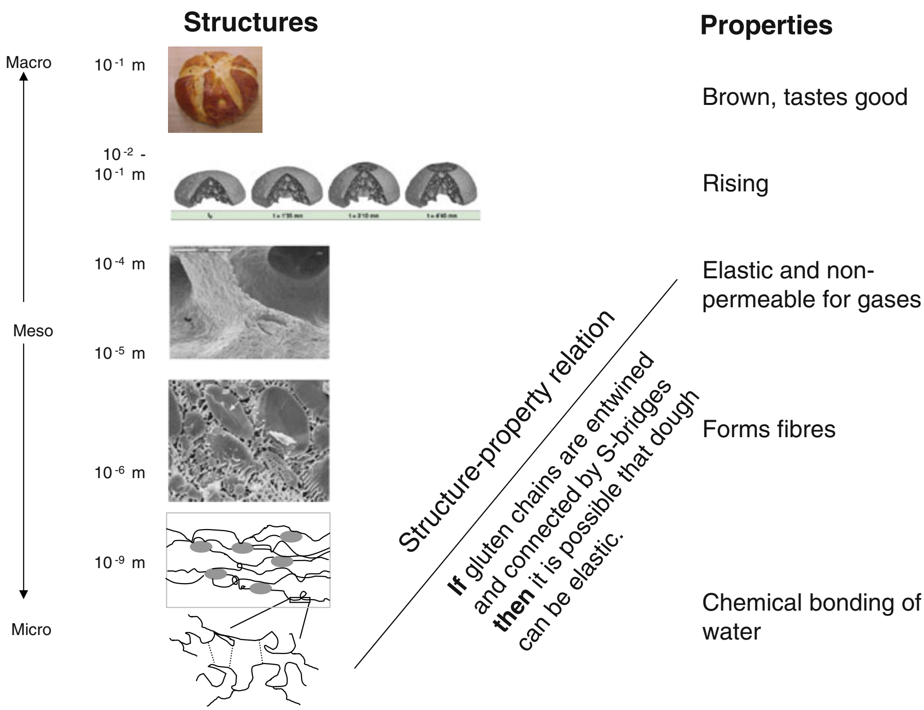

Fig. 2 The conceptual schema showing explicit use of structure–property relations in wheat bread (Meijer et al. 2009)

To address the specific context, it is necessary to ‘zoom’ into the structures within a certain product to relate the properties of this product at a certain level to underlying structures, and to study structure–property relations on different levels of a product. In Figure 2, the exemplary product is wheat bread. The system of relevant nested structures and properties and the explicit relations between structures and properties form the backbone of this macro–micro thinking. Depending on the type of problem (e.g. in this example, the development of gluten-free bread), a number of different meso-levels are relevant and a certain set of explicit structure–property relations are necessary until sufficient structures, properties and interrelations are available to address the problem at hand. Structuring of atoms and/or ions at the micro-level in a certain pattern should only be used when it is necessary to address the problem when developing a food product with the desired properties. For teachers, teaching this content of macro–micro thinking using meso-levels is new in their classroom practice, since conventional macro–micro thinking is directed towards the learning of particles such as molecules and atoms, which are directly related to macroscopic phenomena (Taber 2009).

Following the specific context-setting and the content of macro–micro thinking, the teachers are expected to adopt a role as senior members of the project team (Henze et al. 2007) to stimulate students’ self-regulated learning and to encourage a feeling of ownership when addressing the problem to develop a food product. The role of the teacher involves managing and guiding the team of students as they carry out the product development procedures. A teacher, acting as a supervisor, guides their team and monitors the students’ learning process in a different way from the conventional evaluation of correct or incorrect answers (Mortimer and Scott 2003). The teacher’s role is more of an experienced participant of social activity who is expected to be more competent in using conceptual knowledge and macro–micro thinking. Furthermore, they are expected to educate students to participate meaningfully in such social activity.

In summary, in contrast to typical conventional teaching, the teaching of such a context-based unit involves new domain-specific expertise for teachers in terms of: (i) the setting of the context in class with a project team given a problem in product development; (ii) the new teacher’s role as the senior, more experienced, project team member; and (iii) the content of macro–micro thinking in structure–property relations and intermediate ‘meso’ levels. The context chosen determines the nature of the content of macro–micro thinking and the teacher’s role as senior member of the project team. Figure 3 gives an overview of

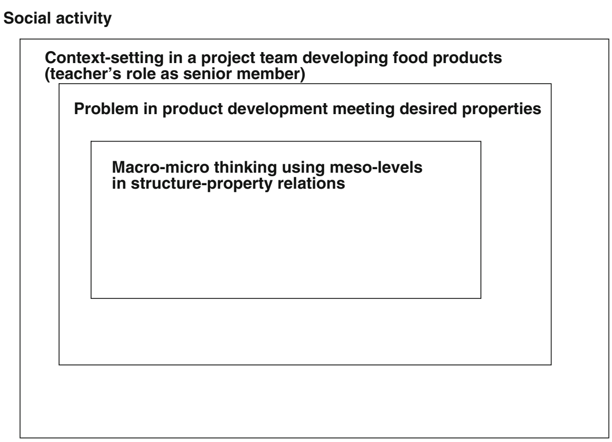

Fig. 3 Overview of a context-based chemistry unit about macro–micro thinking in structure–property relations

the relations between (i) the context-setting, (ii) the teacher's role and (iii) the content in the designed innovative context-based unit about macro–micro thinking using meso-levels in structure–property relations.

Research Question

Using the theoretical framework of the construct of domain-specific expertise in relation to the domain of teaching innovative context-based units, including (i) the context-setting of working in a project team developing a food product, (ii) the teacher's role as senior member of a project team, and (iii) the content of macro–micro thinking in structure–property relations, we pose the following research question:

What new domain-specific expertise do experienced chemistry teachers need to acquire in order to teach an innovative context-based unit about macro–micro thinking, using meso-levels in structure–property relations?

Method

To investigate what kind of new domain-specific expertise a teacher needs in order to teach innovative context-based units we use a two-step phenomenological approach (Creswell 2007). In the first step, the expertise is explored, based on two case studies, A and B. In the second step, the explored expertise is extended and verified in a broader field, by interviewing teachers who teach similar context-based chemistry units.

Step One: Exploration of Expertise

There is an international trend to implement context-based curricula (Pilot and Bulte 2006), which are being developed in secondary schools in the Netherlands. In this respect, case study A is based on the teaching of a context-based chemistry unit by two teachers in a Dutch upper-secondary class in their own school situation. This case study included the preparation of both teachers to teach a particular unit, the execution of this unit in class and the evaluation and reflection of this execution. The preparation consisted of a discussion between the two teachers and the designer of the unit. In addition, the teachers carried out some of the practical activities from the unit. The designer of the unit discussed (i) its context-setting, (ii) the teacher's role and (ii) its content with the teachers, concentrating on the teachers' understanding of the intended effects to be achieved by teaching the unit. This preparation consisted of two meetings. Since the unit was taught by two teachers, they had to have intermediate meetings to fine-tune their lessons. During the evaluation and reflection, the designer, together with the teachers, evaluated the effects set for the students during preparation and the difficulties the teachers might face in teaching the unit. The whole teaching of the unit took three weeks during regular lessons at school. In total, this unit included 20 lessons, each consisting of 50 min of class teaching time. Because of the explorative character of this study, this took longer than would have been necessary if only one teacher had taught the unit or if the teachers had been more experienced in teaching context-based units. During the project the teachers were observed and interviewed by the researcher (First Author, RD) as a participant observer (Creswell 2007), to gather data to find out what kind of new domain-specific expertise they used compared with their conventional teaching. In the interviews, the teachers and investigators recalled events about the intended effects of each lesson, the extent to which the effects were or were not achieved, what actions they executed differently compared with their conventional teaching, and what they intended to change in the next lesson. These events were clustered and analyzed, resulting in the description of the repertoire under possible themes (an intermediate stage between events and themes) needed to teach innovative context-based units (this analytical procedure will be explained in detail in 'Analysis and Findings'.). These possible themes were formulated as new abilities required apart from those of the teachers' conventional teaching. They were related to (i) the context-setting, (ii) the teacher's role and (iii) the content of a context-based unit (Fig. 4).

Case study B was the implementation of the same context-based unit as in case study A in a laboratory situation taught by one teacher, who was part of the research team (Second Author, AB). In this case study the project took a full week, during a specially designed project week. At the end of each day, the teacher and the designer of the unit reflected on experiences and discussed the anticipated progress. In addition, they reflected on the whole project week after it was finished. The teacher's observed actions and arguments about the intended effects of her actions were described in events. These events were added to the emergent possible themes of case study A. The possible themes for acquiring a new domain-specific expertise were then adapted and condensed into themes and theme descriptions including effects, actions and situations.

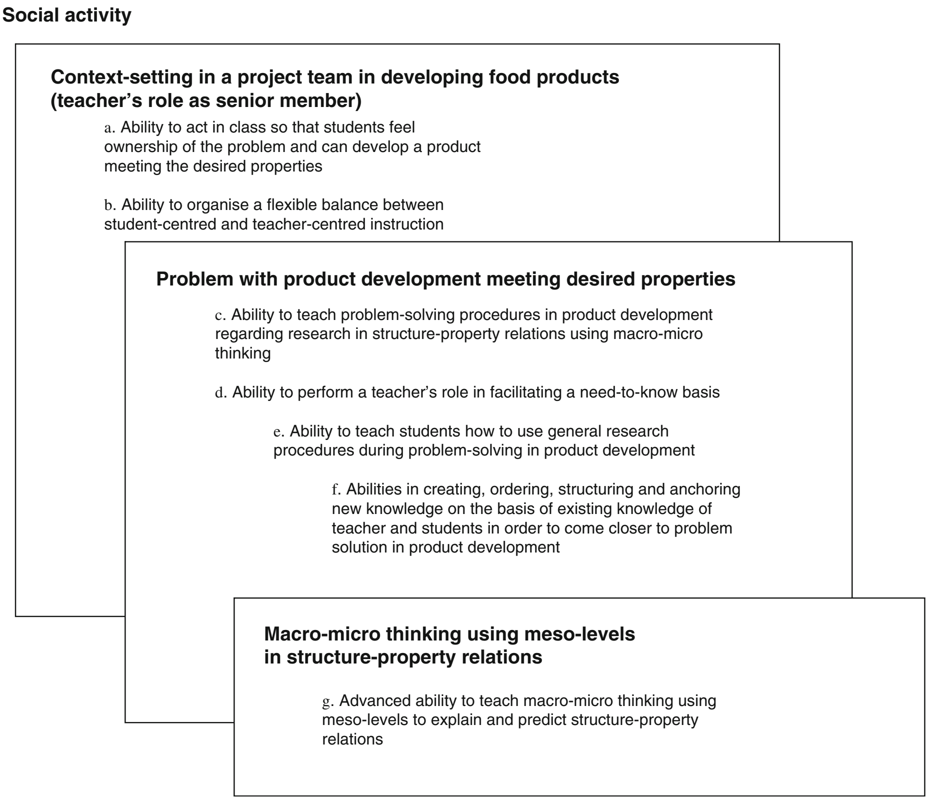

Fig. 4 Themes in teachers' new repertoire related to (i) the context-setting, (ii) the teacher's role and (iii) the content of a context-based unit

To validate the results of the two case studies, two strategies were used (Creswell 2007): 'member check' and 'peer review'. The teacher of case study B watched video fragments of her own teaching while judging her own actions (member check). Then she was interviewed about her interpretations of what happened during the teaching in those fragments and the appropriate actions used to achieve the intended effects. In addition, she was interviewed about the actions that could be used in these fragments when the intended effects were apparently lacking and alternative actions had to be applied. These interpretations were linked to the descriptions of the themes and the descriptions were adapted or expanded when necessary. The peer review of the video fragments gave a critical analysis of methods, meanings and interpretations and was carried out by the third author of this paper.

Step Two: Verification of Expertise

The themes that emerged from the two case studies were verified in a phenomenological research design (Creswell 2007). Therefore, five Dutch upper-secondary class teachers in the field were interviewed. In semi-structured interviews the experiences of these teachers of similar context-based units were used to verify and further specify the themes. Therefore, a semi-structured interview scheme was constructed using the themes and theme descriptions emerging from the case studies as topics. First, teachers were asked to talk about their experiences in teaching the context-based units. Meanwhile, the researcher asked questions to clarify the issues. Second, when teachers did not mention any events in a specific topic, the researcher asked the teacher specifically to talk about experiences of that specific topic. During the interviews, the questions focused on finding additional information to determine themes, adjust the dimensions of themes and enrich the theme descriptions.

After analysis of the interviews, the resulting themes and theme descriptions were validated through another 'peer review' (Creswell 2007). The peer reviewer had no connection with this study. She examined whether or not the theme descriptions were supported by selected fragments from the interviews. In addition, in discussion, the theme descriptions were adapted in consensus, reformulated if they needed to be more specific and expanded as necessary.

Participants

The two teachers in case study A had 36 and 7 years of experience. These teachers were acquainted with context-based education and the design of the context-based unit. That is, they were more informed and experienced compared with their colleagues in the field. The designer of the context-based unit was a chemistry teacher with ten years experience in secondary education who was carrying out a PhD project for three years on design-based research on a context-based unit. The researcher was a PhD student with two years of teaching experience in secondary education.

The teacher of case study B had five years experience in secondary education and seven years in academic classes, and was involved in designing the units (Second Author, AB). Therefore she was acquainted with the theoretical background of the design and the intended effects of the unit.

The students in both case studies were aged between seventeen and nineteen years old. They were in the upper-secondary class of pre-university education and had not participated in context-based education before.

The interviewed teachers were Dutch upper-secondary class chemistry teachers involved in an educational programme of teachers exploring the use of innovative context-based chemistry units in their lessons. They had one year of experience in teaching innovative context-based chemistry units designed on the same principles described in Fig. 3.

Materials

The unit used in case study A and B involved a project team developing a gluten-free food product using corn bread as an example. The students had gradually to (re)construct a conceptual scheme (Fig. 2) for the development of gluten-free bread during their problem-solving procedures, and then generalise it for gluten-free food products using structure–property relations and macro–micro thinking with intermediate 'meso' levels as key elements. A more detailed description of the outline of the unit including the problem description and activities that students executed can be found in the Appendix.

The two units carried out in the educational programme and taught by the interviewed teachers for verification of the description of new domain-specific expertise are based on the same principles (Fig. 3) as the unit used in the two case studies, A and B. Two units about macro–micro thinking in 'unbreakable' ceramic beakers and 'improved' absorption material for nappies were addressed by the students (Meijer et al. 2009).

Data Collection

In case study A, the field notes of the first author of this paper, who participated as a participant observer (Creswell 2007), were used to guide the data collection in the teacher's, actions and assessment of their practical abilities (characteristics 2&3 and 6&7, Fig. 1). During the observations and discussions, special attention was paid to the abilities of the teachers to (i) set the context within the classroom when a project team was working on food products, (ii) perform the teacher's role as a senior member of the project team and (iii) teach the content of macro–micro thinking in structure–property relations (Fig. 3). Video/voice recordings were collected for all preparation meetings and lessons on the execution and evaluation of/reflection on teaching the innovative context-based unit. In addition, the teachers filled in reflection forms (characteristics 2&3, Fig. 1) after every lesson to recall events. During case study B, all lessons were video- and audio-taped (characteristics 6&7, Fig. 1). The semi-structured interviews were audio-taped and the interviewer (First Author, RD) collected field notes.

Analysis and Findings

Data analysis and findings are presented separately for the exploration of new domain-specific expertise and the verification of this expertise. The analysis resulted in the description of seven themes (a–g, Table 1), regarding teachers' new domain-specific expertise needed to teach innovative context-based chemistry units about macro–micro thinking in structure–property relations. The seven themes are described in the dimensions: effect, actions and situations. As an example, the analysis of one theme (theme g, Table 1) is used to illustrate how the analysis resulted in the determination and description of all themes.

Table 1 Theme descriptions in teachers' new domain-specific expertise

	Effect on students and teacher	Actions	Situation
a. Ability to act in class so that students feel ownership of the problem and can develop a product meeting the desired properties	• The teacher creates a learning environment where students become problem-owners by having the authority and responsibility to solve the problem	• The teacher arranges for the problem to be assigned by an external authority • As a senior project member, the teacher approaches the students as project members in a project team and guides them to execute activities to find a problem solution • The teacher constructs an overview of the activities and procedures, monitors and guides the students to achieve the intended effect of the unit and values student contributions to discussions on decision-making in the product development procedures	• There is a clear division between the times when students execute their research activities alone and when the teacher is involved
b. Ability to organise a flexible balance between student-centred and teacher-centred instruction	• The teacher determines the balance between student- and teacher-centred activities by organising and adapting activities depending on student input and stimulating the independent learning of students.	• The teacher notices when the students need teacher involvement and when students can do the activities on their own • The teacher allocates time to monitor the learning process of students to gain confidence in students achieving the learning effects	• When the project team decides how an activity has to be carried out, the teacher responds quickly to adapt the planned activities to maintain the intended learning effects
c. Ability to teach problem-solving procedures in product development regarding research in structure–property relations using macro–micro thinking	• The teacher is more experienced in following product development procedures and general research procedures but does not have a straight solution to the problem. Teacher and students expand their knowledge and practice by trying to change the structure of a product to produce the desired properties	• The teacher makes sure the students follow activities in product development that lead to problem solution • The teacher teaches the students knowledge about, and skills in, procedures in product development in the related context-setting by valuing students' contributions during discussions	• First activities in product development procedures are mostly induced by the teacher; later, students initiate more and determine the activities needed to solve the problem

Table 1 (continued)

	Effect on students and teacher	Actions	Situation
d. Ability to perform a teacher's role in facilitating a need-to-know basis	• The teacher follows the structure of the unit, the kind and order of activities that guide the students according to the need-to-know basis by offering information when the students need it to solve the problem	• The teacher has a good understanding of the need-to-know basis and how it is processed in the structure of the unit to achieve the desired learning effects for students • The teacher respects and trusts the ability of the students to find the information they need to solve the problem without explicitly introducing the information to them	• When there are unexpected situations, the teacher has to be able to adapt the activities keeping the need-to-know basis intact
e. Ability to teach students how to use general research procedures during problem-solving in product development	• The teacher succeeds in teaching students to execute experiments in a scientific way to gather information about (possible improvements of) the product	• The teacher provides information on how to execute scientific research by gathering information from scientific sources, designing experiments, executing safe and accurate laboratory practice and formulating research reports • The teacher helps with and corrects general research procedures • The teacher discusses possible research procedures that could solve the problem • The teacher helps students in selecting sources of information, understanding text and tables, etc. • The teacher structures choices and results from experiments, leading to the next activity in the problem-solving procedure	• During group discussions on designing experiments to develop and improve products, the teacher guides students in general research procedures

f. Abilities in creating, ordering, structuring and anchoring new knowledge on the basis of existing knowledge of teacher and students in order to come closer to problem solution in product development	• The teacher adds new information and insights to existing information, so students are able to identify missing knowledge to solve the problem	• The teacher relates student contributions, reported results and conclusions and new information from activities to the problem solution • The teacher collects reported results in an orderly manner in a plenary session of the group to be able to see patterns in the results and draw conclusions • The teacher adds new steps to the procedure, gains information or results for the overall picture leading to problem solution	• During plenary group discussions, when results are reported, conclusions are drawn and decisions are made about the following step in the product development procedure, the teacher has to order, structure and anchor student contributions in the overall picture of the project
g. Advanced ability to teach macro–micro thinking using meso-levels to explain and predict structure–property relations	• The teacher is more experienced than students in explicitly using macro–micro thinking to relate the properties of a material to a certain level of underlying structures	• The teacher indicates continuously on what macro-, meso- or micro-level the project team is referring to in the various activities and makes this explicit to the students • The teacher helps students to achieve their learning effect of macro–micro thinking by letting them formulate structure–property relations like 'IF a product has structure X, THEN the product has property Y'	• During plenary group discussions, the teacher has to be continuously aware which macro-, meso- or micro-level students are referring to and make this explicit to the students using language consistent with the level

Exploration of Expertise: Finding and Describing Themes

The aim of the analysis was to determine the themes in the repertoire of experienced chemistry teachers when teaching a context-based unit about macro–micro thinking in structure–property relations (see the interrelationship of the characteristics in expertise, Fig. 1). It was decided that field notes taken during lessons and meetings in case study A should be used as a primary data source, because these data gave the best insight into the teachers' repertoire in terms of the intended effects, actions and situations when teaching the unit and how the teachers actually acted in class beyond their conventional repertoire. A first exploration of possible themes in their repertoire resulted from the interpretation of data about the teachers' actual actions and abilities and their understanding of the intended effects of the innovative context-based chemistry unit about developing a gluten-free corn bread.

First, relevant fragments of field notes were selected. Criteria for fragments were that they contained (parts of) events: teacher's actions and/or achieved effects on students in situations related to (i) setting the specific context, (ii) performing the teacher's role as a senior project team member and/or (iii) teaching the new content of macro–micro thinking. The fragments were labelled, categorised and summarised as events in relation to the research question. The description of events gave an insight into which possible themes in the teachers' new repertoire could be determined that were not part of the teachers' existing repertoire. Fragments were labelled, categorised and summarised in four categories of events:

1. When preparing for the unit, the teachers linked their knowledge about gluten to their existing knowledge about proteins (which they addressed in micro-level terms). In addition, they expected that the students would need the same knowledge about proteins in order to achieve the effect of developing knowledge about gluten. Therefore, they taught a chapter of a general chemistry textbook about proteins before they taught the unit about developing a gluten-free corn bread, to ensure that the students knew enough about proteins.
2. During execution of the unit teachers often related properties on macro-level to structures on micro-level without explicitly including relevant meso-levels.
3. During the execution of the unit, the teachers focused on macro-level and practical procedures. The instructions to students about how to improve gluten-free corn bread required a trial-and-error procedure, rather than an argued procedure on how to develop a food product when improving the gluten-free corn bread.
4. It was difficult for the students to understand on what level (macro-, meso-, micro-) they were reasoning, thinking or arguing about the improvement of the gluten-free bread. The teachers used implicit terminology to point out properties on a certain level. They used explicit terminology for properties at a macro-level when referring to properties on a meso-level, and vice versa. In addition, the teachers used the terms 'structure' and 'property' without giving or negotiating a clear definition. Sometimes they used the term 'property' when they referred to 'structure', and vice versa.

These four core events indicate that teaching macro–micro thinking using meso-levels in structure–property relations in class was not part of the teachers' existing repertoire. Teachers needed to acquire this repertoire to have the practical ability to teach the content of this macro–micro thinking. To facilitate chemistry teachers to acquire the new domain-specific expertise when teaching macro–micro thinking in structure–property relations, a professional development programme requires activities which expand the teachers' repertoire with respect to this new content. Based on this analysis, a possible theme explaining one of the requirements for teachers at this point was formulated as follows:

> Suitable knowledge about macro–micro thinking using meso-levels for describing structure–property relations.

The possible themes were further specified and refined into themes and theme descriptions using data from case study B. The themes gave more insight into what new domain-specific expertise is needed to expand teachers' repertoire for teaching the context-based units about macro–micro thinking in structure–property relations. Video recordings of case study B were analysed in chronological order. During the analysis of the video data, events related to the possible themes determined in the analysis of case study A were selected. Subsequently, the themes were summarised and reorganised into the following dimensions: effect (what to achieve); actions (how to achieve); situations (when/where to achieve).

The four described events and other events were described and categorised within the possible theme mentioned above about macro–micro thinking; such events comprised, for example (case study B):

1. During a plenary discussion (Activity 6, Appendix) of the project team, the teacher attempted to stimulate the students' ideas for improving the properties of gluten-free bread by considering a deeper structure within the structure of bread (meso-level, Fig. 2). In a question-and-answer interplay, she expected certain answers. As a result, this interaction of short answers and questions made the students guess the 'right' answers instead of really relating properties on a macro-level to structures in a meso-level.
2. In a plenary discussion about the choice of additives to replace the gluten in bread for the improvement of the properties of corn bread (Activity 8, Appendix), instead of the teacher linking properties at macro-level to structures at meso-levels, it ended in a discussion about what percentage of the additives should be used in the recipe for baking bread. None of the students made the connection between structures and properties; nor did the teacher make the connection explicitly. She focused on arguments about why certain compositions were chosen. As a result, for the students, the baking of the bread with the desired properties became a trial-and-error procedure.
3. During plenary discussion (Activity 10, Appendix), the teacher tried to get students to scale structures at meso-level and link to the properties at macro-level. The teacher reasoned directly from macro-level to micro-level, instead of bridging the gap between macro-level and micro-level by using meso-levels explicitly.
4. During discussion (Activity 14, Appendix), students did not explicitly apply macro–micro thinking by using meso-levels when reasoning about the project. The discussion only included macro-properties and micro-structures. The teacher did not lead the discussion in the intended direction nor structure the decisions made.

Although the teacher in case study B was more acquainted with the theoretical background of macro–micro thinking in structure–property relations, knowledge about teaching this new content in class was not part of her existing repertoire. Chemistry teachers need to acquire the new domain-specific expertise to be able to teach macro–micro thinking in structure–property relations to students. This expertise involves not only suitable knowledge about macro–micro thinking in structure–property relations, but it also requires knowledge about teaching this new content to students as well. Based on these events, the possible theme mentioned above could lead into the theme with a better explanation of what it is about and formulated as:

> Advanced ability in teaching macro–micro thinking using meso-levels to explain and predict structure–property relations.

This theme can be described in dimensions. The 'effect' in students that the teacher intended to achieve, when teaching the innovative context-based unit, is that students gain the ability to relate properties of a material at a certain level in the conceptual scheme (Fig. 2) to the underlying structures. Therefore, expertise is needed to facilitate teachers in order to anticipate students' comments and to give them feedback. For example, the 'actions' the teacher could take in class are indicating and communicating constantly about what macro-, meso- or micro-level the project team are referring to at several stages of the project work, and guiding students in their formulation of structure–property relations like 'IF a product has structure X, THEN the product has property Y'. Through the teacher exercising a greater awareness of language use, students may gain more insight into the relevant meso-levels that the teacher and the students refer to during the project work. This analysis eventually led to the specific description of this theme, summarised in Table 1 as 'theme g'.

Additional analysis of the recordings and field notes from the intermediate meetings showed that the teachers of case study A were very insecure about their teaching and did not have much expectation that students would achieve their learning effects. They showed reluctance in organising student-centred instruction and in allowing the students to work independently, since they reported a lack of trust in the students' ability to work in a self-directed way. In addition, they showed scepticism about the curriculum innovation before they taught the unit (the preparation meetings).

The teacher in case study B also experienced difficulties. In the introduction of the unit to the students, she proved to have a good overview of (ii) the teacher's role and (iii) the content. She demonstrated a more student-centred approach and students were responsible for finding a solution to the problem by developing a gluten-free corn bread. Halfway through teaching the unit (activity 9 and 10, see Appendix), however, the teacher's confidence in students' ability to achieve their learning effects decreased. She 'took charge again' and her teaching became more teacher-centred. Consequently, students showed less ownership of the problem and less motivation to finish the unit. On reflection (member check), she attributed her decreasing confidence to two causes. The first was a lack of earlier experience with this new way of teaching macro–micro thinking using meso-levels; Fig. 1 shows that repertoire can only be acquired (characteristic 5), and can only take place, when there is an earlier experience in terms of practical ability (characteristic 7) and actions (characteristic 6) in situations of the specific domain. Second she was personally overloaded in dealing with all new aspects of (i) the context-setting, (ii) the teacher's role and (iii) the new content together.

Verification of Expertise: Verifying Themes and Theme Descriptions in a Broader Field

Semi-structured interviews were analysed according to the themes (a–g) and the dimensions (effect, actions, situations) in the description of these themes. For this verification, relevant fragments of the interviews were selected and classified within the dimensions of the themes. Further analysis of data led to confirmation of the themes and theme descriptions and did not lead to adjustments, supplements or specifications of the themes. The peer review procedure led to minor adaptations and further specifications of the theme descriptions to formulate themes more clearly. The data gave more insight into the relevance and importance of the themes from a teacher's point of view and the emotions involved when teachers changed their practice.

Teachers focused more on (i) setting the context and (ii) performing their new teacher's role than on addressing (iii) the new chemistry content of macro–micro thinking. In particular, the intended effect that students learn by developing a product faded away when the teachers started to discuss how to teach the unit in class. When the teachers reported their experiences of teaching context-based units, they largely mentioned their problems and solutions in (i) setting the context and (ii) performing their teacher's role; for example, organising student-centred instruction, motivating students to work in project teams, their own role in class when students worked in teams, etc. Teachers focused mostly on the organisational part of (i) setting the context and did not, for example, focus on guiding the students and making them own the problem. Furthermore, carrying out general research procedures such as understanding literature, laboratory procedures, writing reports, etc. required more effort than expected. Four teachers (of the five) in the verification group focused on the practical and organisational problems surrounding these research procedures. Problem-solving procedures to develop a product with the desired properties disappeared into the background. Additionally, when teachers reported on teaching context-based units for the first time and changing their teaching practice in class, they showed a lot of emotions. One teacher was not sure she would teach the unit next year, because she said: 'I have to do the innovation all on my own. I thought I was a good teacher, but this is too much change at once'. Teachers had a strong feeling of responsibility towards students achieving their learning effects. One teacher observed: 'I failed to make the students understand macro–micro thinking'. When they taught context-based units, they had a lot of concerns about whether students were able to achieve the intended learning effects or not. Teachers were insecure about what students learned and were supposed to learn (effects, Table 1). Another teacher mentioned being concerned about the students' preparation for higher education. He said: 'I still make sure that the students achieve all the learning goals from the old curriculum alongside the "new chemistry" just to make sure they would not fail at their next level of education'.

Summarising the findings of this analysis, we note that the themes were related to (i) the context-setting, (ii) the teacher's role and (iii) content of the context-based unit about macro–micro thinking in structure–property relations. This is shown in Fig. 4. To facilitate teachers' acquisition of new domain-specific expertise in (i) setting the context, they need to enable students to take ownership in solving the problem that is assigned (Theme a). In addition, teaching a context-based chemistry unit requires teachers acquiring new domain-specific expertise in structuring a different balance between student-centred and teacher-centred instruction in class compared with their conventional teaching (Theme b). Teachers require new domain-specific expertise to teach problem-solving in product development in class. For that, teachers require domain-specific expertise in demonstrating problem-solving procedures for product development (Theme c). The intended effect of giving students a problem is to motivate students to learn chemical content on a need-to-know basis. Therefore, teachers need new domain-specific expertise to perform (ii) a teacher's role to demonstrate problem-solving procedures and teach (iii) content on a need-to-know basis (Theme d). The ability to demonstrate problem-solving procedures on a need-to-know basis requires new domain-specific expertise in demonstrating general research procedures to find new knowledge in order to come closer to a problem solution (Theme e). Therefore, teachers need new domain-specific expertise in creating, ordering, structuring and anchoring new knowledge on the basis of existing teacher and student knowledge (Theme f). Since the content of macro–micro thinking using meso-levels is new to teachers, teachers need new domain-specific expertise in teaching macro–micro thinking (Theme g).

Discussion and Implications

This study focused on new domain-specific expertise that chemistry teachers need to acquire in order to teach innovative context-based units about macro–micro thinking in structure–property relations. This involves expertise in (i) the context-setting, (ii) the new teacher's role in class and (iii) the new content of macro–micro thinking. The new domain-specific expertise was described and summarised in Table 1 and Fig. 4.

Expertise was defined as the ability to perform successfully in a specific domain. The new domain-specific expertise described in themes, formulated as abilities, needs to be acquired by the experienced chemistry teachers in this study to teach context-based units about macro–micro thinking in structure–property relations and to achieve the intended effects. Using data of teachers in different situations, we were able to describe new domain-specific expertise that teachers needed to acquire for teaching the innovative context-based chemistry units. The theoretical framework allowed a holistic view of the characteristics of expertise related to all aspects of the domain of teaching these units, acknowledging the interrelationship of (i) the context-setting, (ii) the teacher's role and (iii) the new content (Fig. 4). The results can be described and explained within this framework.

Seven themes (a–g) in this domain-specific expertise were determined. Each theme was described in three dimensions: effect, actions, situations (Table 1). Considering the explorative nature of this study, acknowledging the fact that each expert teacher performing in the domain of teaching innovative context-based units shows different successful actions to achieve students' intended learning effects and the completely new content of macro–micro thinking (Fig. 2), this leads to a realisation that there are a variety of ways of demonstrating this new domain-specific expertise. To describe teachers' abilities within the construct of PCK (Shulman 1986, 1987) and relate these abilities to aspects of a new pedagogical approach, new content using the definition of 'context' as the school situation, the construct of expertise allows us to describe the abilities needed within the interrelationship of (i) the context-setting, (ii) the new teacher's role and (iii) the content of macro–micro thinking (Figs. 3 and 4).

Although the theoretical framework provides a holistic view of expertise related to the interrelationship of (i) the context-setting, (ii) the new teacher's role and (iii) content of macro–micro thinking (Fig. 4), two new interrelated aspects emerged from our analysis: 1. experiencing cognitive overload; 2. dealing with teacher's emotions. These characteristics are important for the new domain-specific expertise needed for this teaching.

The cognitive overload (Cowan 2001; Kalyuga et al. 2003; Paas et al. 2003; Sweller et al. 1998) experienced by teachers in both case studies could be explained by the fact that, although they were experienced in teaching, they were beginners at teaching this context-based unit. This is related to the fact that the teachers were insecure (Smith and Strahan 2004). Teaching this new context-based chemistry unit brought many new situations in which teachers required too much new domain-specific expertise. Consequently, they could not fall back on their routine actions and repertoire. To cope with this overload, the teachers fell back on their conventional role in class with a teacher-centred approach. As a result, the students also adapted and took their conventional role in class. The intended effects of the context-based unit, to let students feel ownership of the problem in a social activity, were not achieved. Falling back on routine actions and repertoire can be considered as a coping strategy to deal with the stress caused by work-related change (Brown et al. 2002). This stress could be related to teachers being insecure about their own abilities and consequently having less confidence in student leaning effects (Evers et al. 2002). Teachers need to expand their repertoire, which involves expanding well-organised knowledge (characteristics 2&3, Fig. 1) as a result of experience in classroom practice (characteristics 6&7, Fig. 1) to act routinely and so prevent overload.

In addition, we found that emotions of teachers play an important role in teaching a context-based chemistry unit for the first time; emotions towards the curriculum innovation, teachers' insecurity about students and, indirectly, about their own performance. Teachers' emotions could not be described using the construct of expertise, as defined in this study. The construct of expertise lacks an affective characteristic necessary to describe teachers' emotions when participating in a professional development programme; for example, attitudes and emotions of teachers towards the innovations in chemistry education; the learning process of their students; and their own practice as a teacher. Attitudes and emotions could influence the teacher's perspective of experiences during classroom practice (characteristics 6&7, Fig. 1) and consequently the development of knowledge to expand teachers' repertoire when acquiring new domain-specific expertise to teach this innovative context-based unit. How teachers' attitudes and emotions influence the acquisition of their expertise by their teaching of the context-based chemistry unit should be further studied.

A professional development programme based on one cycle of preparation, execution and reflection cannot facilitate the acquisition of all new domain-specific expertise. One cycle can only develop an initial basis for expanding new domain-specific expertise over a period of a few years. Based on this study, a professional development programme to teach context-based chemistry units about macro–micro thinking in structure–property relations could help teachers to avoid cognitive overload during the execution of the unit by expanding their repertoire to teach this context-based chemistry unit (Stolk et al. 2009a, b). This could result in teachers having a positive view of their experiences of teaching innovative context-based units. Consequently, teachers would have confidence, develop a positive attitude towards curriculum innovation and become motivated to acquire new domain-specific expertise in the following years as they teach the innovative context-based units.

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Appendix

Table 2

Table 2 Below is an outline of the innovative context-based chemistry unit about macro–micro thinking in structure–property relations, including the assigned problem to solve and activities to be performed by students to develop gluten-free food products using bread as an example

	Activity	Description
Context-setting	1	In a videotape a senior scientist (external authority) introduces the problem of coeliac disease: some people cannot digest gluten in wheat bread but they can eat corn bread. Corn bread, however, does not have the same properties as wheat bread. . The senior scientist defines the problem of this project: the development of gluten-free corn bread with the same properties as wheat bread. This leads to a discussion between teacher and students about the development of a project proposal

Table 2 (continued)

	Activity	Description
		and the procedure for solving this problem. Students formulate initial ideas about the procedure. To examine what properties cause gluten in wheat bread students bake several breads of corn and variable amounts of wheat breads.
Definition of the problem in product development	2	Following the experiment in activity 1, students relate the variable amount of wheat to the properties of bread. This means searching for an alternative to gluten to add to corn dough to obtain at least the same properties of the bread.
	3	During a group discussion students adapt their project proposal for developing a gluten-free corn bread. They notice they need more knowledge about the given additives for gluten in order to choose one which enhances the properties of corn bread.
Extension and use of knowledge by using macro–micro thinking with structure–property relations	4	Hydrocolloids are known alternatives to all kinds of food products. In the light of an article about hydrocolloids as alternatives to gluten to improve wheat bread, students make a selection of hydrocolloids that might improve corn bread based on superficial arguments on macro-level.
	5	Several loaves of corn bread with different hydrocolloids are baked. This is the first attempt at gluten-free corn bread by students. The bread still does not have the desired properties. More knowledge about how gluten causes the desired properties in wheat bread is needed to obtain an argued selection of hydrocolloids.
	6	Students are provided with a second article which gives detailed information about the baking process of wheat bread. Using the information in the article students search for more knowledge about the elastic property caused by structures at a meso-level containing gluten to obtain more information for arguments to select hydrocolloids.
	7	To understand the second article, students need to develop a meaning for the core concepts ‘structure’ and ‘property’, A series of photos evokes the students’ intuitive ideas about these essential concepts.
	8	A group discussion about information of the given article in activity 6 leads to the next step: carrying out experiments like the ones presented in the article about the baking process of bread. These experiments are necessary to understand which structures at a meso-level containing gluten are related to the elastic property of bread and how to select possible hydrocolloids to be added to corn flour as an alternative to gluten.
	9	Students carry out two additional experiments with corn dough containing different hydrocolloids and variable amounts of these hydrocolloids. The obtained results do not point towards one conclusion. It is expected that more knowledge will be needed about the structures at meso-level containing gluten networks and the way these structures are built up for an argued selection of

Table 2 (continued)

	Activity	Description
		hydrocolloids to add to the corn dough.
	10	A third article is introduced containing information about the chemical structure of gluten (zooming into the structures at meso-level of activity 9) as strangled long polymers which can form an elastic network.
	11	In the light of this information criteria can be derived for selecting hydrocolloids as an alternative to gluten. Examples are: the hydrocolloids must form long hydrophilic chains; they must have a small number of interconnections; they must have long side groups.
	12	The properties caused by the selected hydrocolloids at macro-level are tested in a second experiment. Students bake corn breads containing the selected hydrocolloids. Students explain the results using the information in the articles.
	13	Students give each other feedback on their formulated explanations about structure–property relations in bread.
Reflection on product development procedures and thinking process of macro–micro thinking	14	During a group discussion, questions are addressed to the students about the purpose of their project. Students are motivated to reflect on their knowledge about product development procedures and their macro–micro thinking process in structure–property relations.
Reflection and transfer	15	To (re)construct the thinking process of macro–micro thinking, students have to make the results of the product development procedures explicit in a conceptual schema of structure–property relations.

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