

Strategies to support teachers' professional development regarding sense-making in context-based science curricula

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Abstract

The aim of this study is to develop more understanding about strategies to support teachers' professional development in curriculum innovations, in which pedagogy and content change simultaneously compared to the conventional curriculum. A pre-existing framework, including strategies for professional development, was adapted, implemented, and evaluated from the perspective of teachers' sense-making in teaching context-based science curricula. This framework guides the design of activities that support teachers' development in three new aspects of teaching context-based science units: setting a context in class, performing a new teaching role, and teaching new content. In a case study, six teachers in secondary education participated in a professional development program based on the adapted framework. A qualitative inner-case analysis was conducted to describe teachers' sense-making during the program, in terms of the categories "assimilation," "accommodation," "toleration," and "distantiation." Results showed that teachers participating in the professional development program successfully assimilated and accommodated all three aspects; however, the process of teachers' sense-making of

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the new content followed a different path compared to the processes of the other aspects. The relation between these results and the adapted framework are discussed to retrieve strategies for planning professional development programs to support teachers in curriculum innovations.

KEYWORDS

context-based science education, curriculum innovations, secondary school, sense-making process, teachers' professional development

1 | INTRODUCTION

Redesigning science curricula in secondary education in terms of inquiry-based, problem-based, or context-based curricula often implies the teaching of new domain-specific content and implementing new pedagogical approaches that are not part of a teacher's regular practice (Brouwer et al., 2012). To successfully implement these new curricula, adequate professional development (PD) is needed to support teachers in accommodating the new aspects of the innovative curriculum in their teaching practice (Van den Akker, 1999; Vos et al., 2011). Ball and Cohen (1996) mentioned that curriculum materials could be a source of PD (Ball & Cohen, 1996) in content knowledge and pedagogy. Based on a study regarding teachers using innovative units in the classroom, Vos et al. (2011) found, however, that additional PD was needed to achieve the intended outcomes of the curriculum innovation. Following Schuchardt et al. (2017), who related the need for additional PD to differences in intended learning outcomes, this might be due to the specific intended learning outcomes of this particular curriculum.

To organize additional PD, teachers working together in collaborative settings is reported as a promising strategy for teacher learning and development (Butler et al., 2004; Vescio et al., 2008); educational innovation (Bakkenes et al., 2010); school improvement (Harris & Jones, 2010); and the teaching and development of curriculum units (George & Lubben, 2002). The strategy of collaborative learning has been used to enhance teachers' beliefs that they can succeed in implementing innovation in their own school situation (Abrami et al., 2004). It provides teachers with the opportunity to regularly think about their practice and the uncertainties and dilemmas of teaching with colleagues (Rosebery & Puttick, 1998).

The study draws upon the specific knowledge-base in which collaborative curriculum design was used as a vehicle for sustainable curriculum innovation and effective teacher learning (Pieters et al., 2019). Our studies contributed by focusing specifically on developing more understanding about how to support teachers in teaching context-based science curricula, as an exemplar of an innovative curriculum in which content and pedagogy changed simultaneously compared to teaching the conventional curriculum (Stolk et al., 2012; Vos et al. (2011). From earlier studies, however, we found two problems that we needed to address (Dolfing, 2013).

The first problem was that a lack of understanding of the new content hindered teachers' development during the PD program (Dolfing, 2013; Stolk et al., 2012). This was in coherence with Van Driel et al. (1998). They already mentioned that teachers' expertise in teaching the (new) content is a prerequisite for further experience and therefore development in and beyond a PD program. On top of that, Armour and Yelling (2004) described that teacher's understanding of the new content could have serious consequences regarding continuous PD in relation to teaching the innovative curriculum. In this study, we took up the challenge to develop a PD program to support

teachers in teaching new content and using new pedagogy simultaneously by engaging them in collaborative curriculum design activities.

The second problem we encountered was that it was challenging to capture and describe teachers' development in teaching new content and using new pedagogy simultaneously during PD programs to support teachers in teaching context-based science units (Dolfing, 2013). A similar problem was concluded by Westbroek et al. (2019), based on a review study about teachers' PD, namely, that in many studies measurements of knowledge development often were either rather fragmented and domain-specific or very general and elusive and that teachers' development as a result of participating in collaborative design activities was hard to capture. In an attempt to address this problem, we chose to describe teachers' PD from the perspective of teachers' sense-making processes in curriculum innovations (Luttenberg et al., 2013) because we expected that this perspective could help in capturing and describing teachers' development in this specific curriculum innovation in more depth for teaching new content as well as in using new pedagogies simultaneously.

Ketelaar et al. (2012) described that for adequate PD, teachers make sense of the new aspects in content and pedagogy in light of their own knowledge, beliefs and experiences, as well as the situation in which they find themselves, and the design and message of the policy for implementation. According to Luttenberg et al. (2013), this process of sense-making involves that teachers interact between their own frame of reference concerning teaching within the specified domain, and their perception of the new aspects and situational demands that are inherent in innovations, resulting in the personal interpretation of these innovations. McArdle and Coutts (2010) added that the process of sense-making necessarily involves negotiating meaning and determining the significance of ideas and actions, making it a social process. They describe that each professional teacher seeks ways of accommodating ideas in individual practice and values them in relation to ideas shared in the community of practice. Studies describe teachers' PD from the perspective of sense-making in communities of practice (Ng & Tan, 2009), in situations where school policies and standards change (Allen & Penuel, 2015), when teachers familiarize themselves with a new pedagogy regarding the implementation of a new teaching role (Ketelaar et al., 2014) or the teaching of new content (März & Kelchtermans, 2013). This study contributed by describing teachers' sense-making processes in teaching new content and using new pedagogy in the particular setting of a PD program in which teachers collaboratively perform curriculum design activities.

This study aimed for developing more understanding about strategies to support teachers' sense-making processes to accommodate effectively the new content as well as the new pedagogy. The specific research question was formulated as: *"To what extent does the sense-making process during a professional development programme, based on a designed framework, relate to teachers' accommodation of the new aspects in content and pedagogy of teaching context-based science curricula?"* In the next sections, we will elaborate on teachers' sense-making processes in curriculum innovations, the new aspects in implementing context-based science curricula, and the design of teachers' PD.

1.1 | Teachers' sense-making processes in curriculum innovations

Sense-making is considered to be an active, cognitive, and emotional process in which a person attempts to fit new aspects and demands into existing knowledge and beliefs (Spillane et al., 2002; Van Veen & Lasky, 2005). Sense-making is described as the development in a social setting of teachers' understanding and perceptions of new aspects in content and pedagogy related to teaching innovative curricula compared to teaching conventional curricula (Spillane et al., 2002). It is widely known that teachers' values and beliefs influence their implementation of innovative curricula, consciously, and unconsciously (Pajares, 1992; Yerrick, 1997). By making sense of new aspects in innovative curricula, teachers manage the uncertainty caused by mixed messages, inconsistencies, and conflicting goals with which they are confronted in their practice when multiple aspects of the system are changing (Allen & Penuel, 2015). In this study, teachers' sense-making processes in curriculum innovations, as such, were

considered to be searches for agreement between each teacher's personal frame of reference in teaching the conventional curriculum and the frame of reference of implementing a context-based curriculum. Teachers' frame of reference could be influenced by factors such as teachers' expertise, perceptions of student learning and curriculum, tolerance for discomfort, and identity (Remillard, 2005). In addition, in the interaction between teachers and innovative curriculum materials, factors regarding the design of the material, such as representations of concepts, learning objectives, student activities, the structure, and layout could play a role in teachers' sense-making processes.

In earlier studies, teachers reacted differently when confronted with a new curriculum (Dolfing, 2013), which might be related to different types of sense-making. The model of Luttenberg et al. (2013) describes the different types of sense-making that could be espoused by a teacher when confronted with the new aspects of a new curriculum. The model distinguishes two dimensions and four types of sense-making (Figure 1). The first dimension represents whether or not the new aspects of the innovative curriculum match or mismatch teachers' practices (including knowledge, skills, and attitudes) and beliefs about teaching in the specific domain. The second dimension refers to the extent to which teachers' own frame of reference or perception of implementing the new curriculum predominates at a particular point in time (own frame of reference/new frame of reference). For example, teachers could focus primarily on aspects of the new curriculum without considering their current practice. Conversely, they could focus on their current practices and the adaptations that are required when implementing the new curriculum. When combined, the two dimensions of teachers' sense-making identified above produce four possible types of sense-making: assimilation; accommodation; toleration; and distantiation. These types of sense-making will be elaborated in the following sections.

The first type of sense-making is assimilation, in which teachers recognize aspects from their current teaching practice, expertise, experiences, and personal background in science that could be useful when teaching the new curriculum. They then attempt to adapt to the new aspects in ways that match with their personal frame of reference. This results in a variation of existing aspects within their frame of reference. For example, teachers could recognize or search for aspects of pedagogy and/or content in the new curriculum that are already part of their current practice. In this way, they will not need to expand their frame of reference; instead, they only need to use their experience when implementing the new curriculum.

The second type of sense-making is accommodation, in which teachers transform their frame of reference in such a way that it matches with the new aspects. When teachers gain experience in teaching the new curriculum and reflect on these experiences, they need to find possibilities to expand their current practice by including the new aspects in content and pedagogy. Therefore, they need to develop an understanding of the aspects and find ways to implement them into the school curriculum.

The third type described is toleration, whereby the teacher accepts the new aspects but at the same time maintains his or her own frame of reference. The teacher holds separate perceptions about teaching the conventional curriculum and implementing the new curriculum. Teachers could consider the implementation of

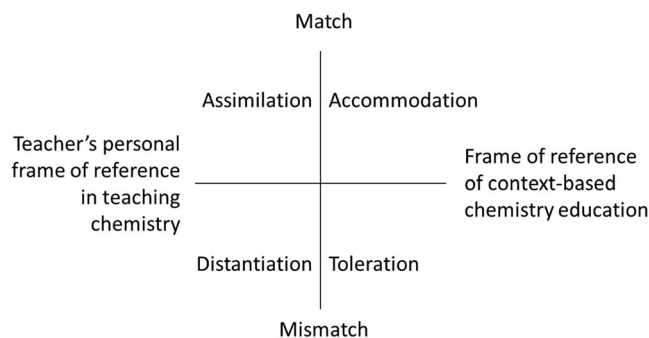


FIGURE 1 The two dimensions and four types of teachers' sense-making regarding curriculum innovation (e.g., Luttenberg et al., 2013)



the new curriculum to be something totally different from teaching the conventional curriculum. When teachers only tolerate the new aspects in content and pedagogy, they focus more on the process and conditions for implementing the new curriculum, and less on the substantive aspects. They implement new aspects separately from their current practice, so they could switch from one curriculum to another. This is demonstrated when teachers focus on the process of students taking part in activities, while either ignoring or not consciously knowing what learning outcomes students should achieve.

The last type of sense-making is distantiation, whereby the teacher consciously or unconsciously rejects the new aspects and continues to teach based on his or her initial frame of reference. Distantiation could be caused by feelings of uncertainty, stress, and incompetence, thereby reducing teachers' self-efficacy and self-esteem (Brown et al., 2002; Kokkinos, 2007), especially in relation to new content (Hingant & Albe, 2010; Tuvi-Arad & Blonder, 2010). Uncertainty about the science content, dilemmas in their teaching practice and students' abilities, and how teachers deal with this are as much a part of teaching as teachers' content knowledge and pedagogical experience (Rosebery & Puttick, 1998). In earlier studies, distantiation was demonstrated in teachers' coping strategies to avoid this stress and uncertainty (Dolfing, 2013; Evers et al., 2002; Parker & Martin, 2009; Stolk et al., 2012). These coping strategies included blaming the (lack of) abilities of the students and questioning the quality of the lesson materials, or expressing the intention to drop out of the particular PD program.

Different combinations of the four types of sense-making in relation to the new aspects in content and pedagogy in the new curriculum can be espoused by one teacher during the process of sense-making (Ketelaar et al., 2012; Luttenberg et al., 2013). In this study, the intention is to ensure that teachers make sense of the new aspects in teaching context-based science curricula by means of the PD program. Teachers need to therefore assimilate the aspects, by recognizing and implementing the useful aspects that are part of their current practice and accommodate them by expanding their teaching practice when gaining experience in teaching the context-based science curriculum. It is undesirable for teachers to only tolerate or distantiate themselves from new aspects. When teachers tolerate new aspects during the program, they could easily abandon them afterward, and development would not be continued after the PD program. When teachers distantiate themselves from new aspects, they do not develop their teaching practice regarding context-based science education (Dolfing, 2013).

1.2 | The new aspects in context-based science education

Within the international trend towards innovations in science education, this study considers context-based education as the learning of science content in social activities (Bulte et al., 2006; Westbroek et al., 2010). In such context-based curricula, students are provided with meaningful problems (Lijnse & 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 learned. Context-based curricula are increasingly used in addressing the major challenges that science education faces: lack of clear purpose; content overload; incoherent learning by students; lack of relevance to students; and lack of transfer of learning to new contexts (Gilbert, 2006; Gilbert et al., 2011).

In context-based curricula, authentic practices are used as a context for learning (Gilbert et al., 2011) in line with the sociocultural activity theory (Prins et al., 2016). In this respect, authentic scientific practices are interpreted as the totality of human work situated in society. Within such authentic scientific practices, it is expected that student activities, teaching roles, content and tools are connected logically, and the relevance of these are clear among students. Context-based science education involves similar aspects compared to other theories of learning. It involves, for example, aspects such as conducting research activities similar to inquiry-based learning (Forbes, 2011), and problem-solving procedures similar to problem-based learning (Schmidt et al., 2011). This study does not focus on discussing the nature of context-based science education itself, only when it is relevant and related to teachers' sense-making processes.

This study is situated within the curriculum innovation of context-based science education in the Netherlands (Bulte et al., 2006; Meijer, 2011; Prins et al., 2016). A snowball effect was created in which in a bottom-up approach more and more teachers were engaged in developing and teaching the context-based curriculum, through participation in collaborative settings, like the one described in this article. This study was carried out at the stage just before the innovation was scaled up nationally and the first collaborative settings were organized. This curriculum innovation involved the design of innovative context-based science units (Meijer et al., 2009; Prins et al., 2011; Westbroek et al., 2010). Specifically, these context-based units involved three new aspects regarding the content and pedagogy: (i) setting a context in class; (ii) performing the new teaching role; and (iii) teaching new content (Dolfing et al., 2012). This is represented in Figure 2 and will be elaborated in the following paragraphs.

1.2.1 | Context-based science units as used in this study

In units as used in this study, the context-setting involves the social activity of solving a problem in product development (i), while the students are motivated to use the content about structures and the properties of materials that are used to develop the desired product as a tool to solve the problem (iii). To synthesize the materials with the desired properties, students should first explain the properties of the material by studying the structure and substructures of the material. For example, to improve the quality of ice cream, students must gain information about the formation of ice crystals, as well as the properties of emulsions, fat, and protein networks. When students are required to explain why Dyneema®, a high-performance polyethylene fiber, is strong and light, they need to study polymer chemistry, crystalline structures of polyethylene, and production processes of macromolecules. This means that the content is interdisciplinary in nature and often taught indirectly during problem-solving procedures when it is relevant for students to come closer to a problem solution. In addition, explaining and predicting material properties involves skills in relating macroscopic properties to interacting (sub-)structures at meso-, micro-, and nano-levels (macro-meso-micro thinking; Meijer, 2011).

1.2.2 | The context-setting

The context-setting (i) as stated in these units, requires teachers to organize and manage project teams, consisting of students and the teacher, who are assigned to solve a problem in product development as if they are employees in a company's research and development department. In line with this, teachers could use a variety of collaborative learning activities to support student learning in project teams. The problems presented in the units are derived from authentic research subjects in the fields of, for example, material science (e.g., developing a strong and light polyethylene fiber), food technology (e.g., improving the quality of ice cream after refreezing), or engineering (developing parts of a new model solar car). This is represented in Figure 2(i, a). To gain information about the context-setting, the specific product and materials, and the problem to be solved, students need to perform general research activities like searching the literature and developing and performing experiments (i, c).

In the conventional curriculum, teachers are often used to teaching content directly to the students, or they use contexts as examples to illustrate how the content is used in practice. In this context-based science curriculum, the context-setting and problem statement determine the content and skills that need to be taught to solve the problem. Teachers need to accommodate the new aspect of setting such a context in class, and need to be aware of the relationship between context-setting, problem statement, content and skills. In order for students to develop the content and skills, teachers need to provide support when students need it to come closer to a problem solution (i, b).

1.2.3 | The new teaching role

In the conventional curriculum, teachers often perform the role of the expert who knows the answers to the questions in the book and knows what conclusions should be drawn from research activities. In addition, the teacher often evaluates student answers to questions from the teacher or from the book as “right” or “wrong”

i Context-setting of a project team solving a problem in product development

a. Ability to teach problem-solving procedures in product development: e.g. develop a product made of a composite of different materials.

b. Ability to teach according to facilitate a need-to-know basis: e.g. provide support in learning the specific content and skills when students need it to come closer to a problem solution.

c. Ability to teach students how to use general research activities during problem solving in product development: e.g. support students to find information about structure-property relations of materials by conducting literature research and experiments.

ii Teaching role as senior member of the project team

d. Ability to act in class so that students feel ownership of the problem to develop a product meeting the desired properties: e.g. motivating the students to take ownership of solving the problem.

e. Ability to organise a flexible balance between student-centred and teacher-centred instruction: e.g. stimulate students' self regulated learning.

f. Ability to create, order, structure and anchor new knowledge on the basis of existing knowledge of teacher and students; so one comes closer to a problem solution in product development: e.g. providing students with overviews and summaries, and support students in gaining more information about the structures and properties of materials.

iii Teaching the new content

g. Advanced ability to teach the new content about structures and properties of materials indirectly when students need it as a tool to solve the problem in product development: e.g. structure-property relations of materials to design a composite product.

FIGURE 2 New aspects involved in teaching context-based education in terms of (i) setting the context in class, (ii) performing the new teaching role, and (iii) teaching the new content (e.g., Dolfig et al., 2012)



(Mortimer & Scott, 2003). In the context-based curriculum, the teacher acts as the senior member of the project team (ii) and guides the students in product development procedures and research activities. Teachers are more experienced in, for example, performing research activities, setting up experiments and finding literature to obtain more information about materials and products. By performing this new teacher role, the teacher motivates the students to take ownership of solving the problem (ii, d), and thereby indirectly the learning of the content and skills that are needed as a tool to reach a problem solution. Consequently, teachers use different pedagogical approaches, stimulating students' self-regulated learning, to create a different balance in student- and teacher-centered instruction compared to teaching the conventional curriculum (ii, e). Instead of being the all-knowing expert, the teacher helps students to create, order, structure, and anchor new knowledge of the basis of existing knowledge. They provide students with overviews and summaries and help students to relate conclusions from experiments to theoretical knowledge from books, guiding students in formulating questions, and searching the Internet for more information (ii, f).

1.3 | The new content

In the conventional curriculum, the content is often organized according to the chapters in the study book (e.g., thermodynamics, organic chemistry, and genetics). In the context-based science units, the content being taught depends on the problem to be solved, as stated by the context-setting (Meijer, 2011). For teachers, teaching this content of macro–micro thinking using meso-levels in structure–property relations is new in their classroom practice (Dolfing, 2013; Dolfing et al., 2012), 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). Therefore, teachers need to make sense of the aspect of teaching new content (iii) about macro–meso–micro thinking to study structure–property relations in a variety of materials that are not part of the conventional curriculum.

1.4 | PD to support teachers' assimilation and accommodation of new aspects in context-based science curricula

To successfully implement context-based science curricula, it is recommended to support teachers in assimilating and accommodating the new aspects of (i) setting the context in class, (ii) performing the new teaching role, and (iii) teaching new content. Teachers require substantial support in learning to use new curriculum materials. They need to learn about the content, goals, approaches, and underlying assumptions of the curriculum they are being asked to use (Remillard, 2005; Vos et al., 2011).

1.4.1 | Strategies to support PD

Studies have been conducted to retrieve strategies for effective PD of teachers (Avalos, 2011; Garet et al., 2001; Penuel et al., 2007; Van Veen et al., 2010), and specifically in collaborative settings (Borko, 2004; Brouwer et al., 2012; Stoll et al., 2006; Vescio et al., 2008). There seems to be a certain agreement on general strategies—for example, active learning, collaboration, sharing experiences, reflection, activities focused on content knowledge and close to teachers' classroom practice—as being effective in enhancing teacher learning and development. The challenge is to apply these strategies in specific situations to support teachers to develop in a certain direction. More specifically, when the curriculum innovation involves new content and pedagogy, specific strategies need to be implemented to support teachers in both simultaneously.

PD is often focused on teachers' reflections on their practice, and attention is paid to participate in collaborative settings (Hildreth & Kimble, 2004; Nicolini et al., 2003). This reflection could be limited (McArdle & Coutts, 2010), however, because it could be seen as shallow and concerned with technical aspects (Halliday, 1998), as well as insufficiently critical when teachers reflect alone and face no challenges to their thinking (Day, 1993). Teachers find it difficult to reflect on their practice and could become defensive when invited to open up about their own established practice. Teachers would benefit from opportunities to read and examine a new curriculum with colleagues, making their interpretations and decisions explicit to themselves and others. Therefore, teachers' PD preferably takes place in PD programs in which teachers learn collaboratively (Swan et al., 2002). In addition, a central goal of such an activity would be for teachers to openly and actively engage in participating with a curriculum guide (Remillard, 2005).

The strategy of collaborative learning has been used to enhance teachers' beliefs that they can succeed in implementing innovation in their own school situation (Abrami et al., 2004). It provides teachers with the opportunity, with colleagues, to regularly think about their practice and the uncertainties and dilemmas of teaching (Rosebery & Puttick, 1998). Based on these notions, there is a strong scientific interest in teachers' learning and development (Van Eekelen et al., 2006; Vermunt & Endedijk, 2010), especially with respect to collaborative settings as a strategy to implement curriculum innovations. PD through participation in a collaborative setting could improve science teaching self-efficacy for teachers with varying levels of experience and interest. Teachers with a high sense of self-efficacy for teaching could set higher goals, be less afraid of failure, and find new strategies when old ones fail (Velthuis et al., 2015). To support PD, we focused on engaging teachers in collaborative design activities in which they prepared curriculum materials and student activities together, guided by a coach, and forming a shared sense of actions, experiences, teaching values, and personal qualities.

1.4.2 | A framework for PD

Stolk et al. (2012) described a framework for teacher PD in teaching context-based curricula. A framework, guiding the design of development activities and/or instructional events can be considered as a component of instructional design theory (Prins et al., 2016). An instructional design theory relates specific instructional events to learning processes and learning outcomes identify instructional conditions that optimize learning outcomes and provides a rational description of causal relationships between procedures used to support learning (or PD) and the behavioral consequences of learners' performances.

Based on Galperin's theory for the internalization of actions (Arievitch & Haenen, 2005), the framework for PD consists of distinct phases, with explicit modes of development, such as preparing, planning, instructing, or reflecting. In addition, within each phase pedagogical functions are described that link the PD activities with a spectrum of learning objectives, such as motivation, sense-making, and knowledge demand. This framework could be used as a guideline when designing PD programs to support teachers in a collaborative setting, to make sense of the new context-based science curriculum.

To support teachers' assimilation and accommodation of the new aspects involved in teaching context-based science curricula, it is essential that the framework includes functions to encourage teachers to recognize useful aspects from their conventional teaching practice to implement when teaching context-based science education (assimilation), to gain experience by adapting their teaching practice integrating the new aspects of teaching context-based science education, and to reflect together on the incorporation of the new aspects into their teaching practice (accommodation). The original framework presented by Stolk et al. (2012) includes these functions. Before and during the preparation phase, teachers are intended to become aware of their current practice (Figure 3, functions A–C), obtain an introduction to the new aspects of teaching the new curriculum and to assimilate the aspects they recognize from their own practice by interacting and preparing a context-based science unit collaboratively, guided by a coach (Figure 3, functions C–E). In the instruction phase, teachers are intended to

Phase	Functions	Example PD-Activity
Initial	A. Connect to teachers' views on context-based education B. Reveal 'useful' teachers' initial experiences and expertise	A. Brainstorm making a mind-map B. Develop a lesson plan using success events from teachers' regular practice
Problem analysis	c. Let teachers discover differences and similarities among their views on teaching the conventional content and teaching the new content d. Let teachers explore strategies for teaching the new content e. Provide the opportunity for teachers to define their learning goals f. Provide the opportunity to apply their experiences and expertise in practice g. Give teachers the opportunity to reflect on their teaching and learning experiences h. Examine teachers' development by creating the opportunity for teachers to produce a product i. Evaluate teachers' development	c. Workshop about an exemplar student activity including the new content and pedagogy d-i. Plan, instruct and reflect on a lesson in the own school situation including students' and teachers' learning objectives
Preparation	C. Let teachers discover differences and similarities among their views on context-based education and the context-based unit D. Let teachers explore strategies for teaching the context-based unit, give examples, and present conditions for use E. Provide the opportunity for teachers to define their learning goals	C-E. Study and adapt the particular unit, prepare lesson plans to instruct the unit in teachers' own school situation
Instruction	F. Provide the opportunity to apply the domain-specific expertise in practice	F. Instruct the unit in teachers' own school situation
Reflection	G. Give teachers the opportunity to reflect on their teaching and learning experiences H. Examine teachers' development by creating the opportunity for teachers to produce a product I. Evaluate teachers' development	G-I. Sharing and discussing teachers' experiences of instructing the unit H. Adapting the strategies to teach the unit again in the future

FIGURE 3 A framework, adapted from Stolk et al. (2012), for the professional development (PD) of teachers teaching context-based science units, including an additional phase of problem analysis of the new content

gain experience with the new aspects of context-based science education (Figure 3, function F) by teaching the unit in their own school. In the reflection phase, teachers are intended to accommodate the new aspects they experienced by finding possibilities to incorporate the new aspects of context-based science curricula in their teaching practice and school curriculum (Figure 3, functions G–I).

It was found, however, that a PD program based on the framework of Stolk et al. (2012) led to a lack of understanding in teachers regarding teaching the new content (Dolfing, 2013). When preparing the unit, teachers mostly focused on the practical aspects of teaching the context-based science unit and focused less on the new content. This caused the teachers to be hindered in making decisions concerning teaching strategies related to the two other aspects: (i) setting the context in class and in (ii) performing the new teaching role. Therefore, the framework of Stolk et al. (2012) was adapted to support teachers' assimilation and accommodation of new content and pedagogy simultaneously. Figure 3 presents the adapted framework, including phases, functions, and exemplary PD activities that could contribute to the achievement of particular learning objectives. This framework guides the design of activities that support teachers' development in the new aspects of teaching context-based science curricula embodying new content and pedagogy. The design of this adapted framework will be elaborated upon in the following paragraphs.

1.4.3 | Adaptations

Voogt et al. (2011) conducted a review study of nine key publications concerning teacher design teams, in which they identified and described teachers' learning processes that contributed to teacher development. Based on this review, it was concluded that, especially in the preparation phase, the design teams paid explicit attention to content knowledge and understanding, often by reading literature or in discussions guided by an external facilitator. It was recommended that at the start of the learning trajectory of a teacher design team, the clarity of all aspects, goals and tasks, is crucial (Handelzalts, 2009; Voogt et al., 2011).

Westbroek et al. (2019) described based on their review, that many studies started with a personal design problem teachers' experience in their teaching practice. In these studies conducting a problem analysis was a first but crucial step in the educational design process as described by McKenney and Reeves (2012) to stimulate teachers in identifying and formulating their personal problems regarding their teaching practice with personal wishes for improvements. The authors concluded that *"what ultimately motivated teachers to re-design their teaching practice was not a new scientific insight on how to do things, but a deeply felt and experienced problem in their own teaching practice. This focus also determined how teachers evaluated success."* They added that as a response to a personally felt need for redesigning, teachers mainly began by drawing upon their own expertise to improve their learning environments. This would be a useful phenomenon to implement productively to foster teachers' sense-making processes in curriculum innovations.

Inspired by Handelzalts (2009), Voogt et al. (2011), and Westbroek et al. (2019), it was hypothesized that teachers would first need to conduct proper problem analysis and identify personal design problems in their own teaching practice, concerning the new content and pedagogy, to prevent their development from being hindered during the rest of the program. The mechanism would be that during the problem analysis teachers become aware of the similarities and differences between teaching the context-based curriculum and the conventional curriculum and how the new aspects could help in solving their personal design problems. When they recognize aspects that are already part of their teaching practice, expertise and/or personal background, and become aware that not everything about teaching the context-based unit is new, this could prevent teachers from experiencing an overload that could hinder their development during the PD program. This might make it easier for teachers to accommodate the new aspects in their current practice.

Since major decisions in teaching are (implicitly or explicitly) made before or at the start of the program (Handelzalts, 2009), an additional "phase" could be planned before teachers prepare to teach the unit and before they are required to focus on all three aspects of context-based science curricula simultaneously. Including an additional phase could be a strategy to stimulate teachers' problem analysis on teaching the new content and pedagogy.

In light of teachers' sense-making, additional functions should be fulfilled in the phase of problem analysis in which teachers assimilate the aspects by becoming aware of their current practice of teaching content and pedagogy in the conventional curriculum (Figure 3, functions a–c), being introduced to the new content in the context-based science unit, and recognize useful aspects of teaching this content in their current practice (Figure 3, functions c–e). In addition, teachers are intended to gain experience with teaching the new content and pedagogy (Figure 3, function f) by teaching the content in their own school. In addition, teachers reflect on the new experience to find possibilities to incorporate the new aspect of teaching the new content into their teaching practice (Figure 3, function f–i). In terms of phases and functions described in the framework of Stolk et al. (2012), this means that the additional phase involves the functions c–i (Figure 3), which need to be fulfilled regarding the new content (preparation, instruction, and reflection).

Rosebery and Puttick (1998) describe that student performance and achievements can play a key role in facilitating teachers' preparations for teaching new content. Teachers need opportunities to engage in sense-making processes so that their experiences in learning science content and their explorations of their students' learning mutually shape one another (Rosebery & Puttick, 1998). Relating teacher development to student learning



by developing and implementing lesson material about the new content using new pedagogical approaches could therefore be an appropriate strategy (Fishman et al., 2003). Although this study does not focus primarily on the actual learning outcomes of the students, using teacher perceptions about the learning of their students could support teachers to become aware of their current practice, the differences in teaching the new curriculum and what competencies they need to support their students to achieve the intended learning outcomes. Taking this into account, in the preparation phase-specific activities could be planned in the PD program to help teachers formulate and relate their own learning goals to the intended learning outcomes of students (Figure 3, function and activities d–i). The intended student outcomes could involve the specific learning outcomes of the unit, or more general learning goals and achievements of the curriculum innovation (Ryder & Banner, 2011).

To foster and sustain change in ideas and teaching practice in teaching science content and inquiry, Akerson (2009) developed a PD program focused on contextualizing PD in terms of a community through which teachers could situate their learning in their own teaching practice, interact with other teachers to socially develop new ideas and distribute learning over different situations, such as learning individually, in groups and through tools and materials. They found that teachers became aware of their changes in views once they struggled with their concepts in science in their own teaching and discussed their struggles within the PD community (Akerson, 2009). In addition, teachers acquire a deeper understanding of content when reflecting on how to teach students (Fernandez, 2005). Similarly to the studies of Dolfing (2013) and Stolk et al. (2012), Fernandez (2005) showed that only during their instructional activities in class teachers did experience (a lack of understanding of) how to teach certain content. With reference to Akerson (2009) and Fernandez (2005), to conduct a problem analysis on teaching the new content, activities could be planned whereby teachers prepare, instruct and reflect on a lesson in which they teach new content in their own classes (Figure 3, functions and activities d–i).

To prepare teachers to teach this lesson, a workshop would be an appropriate activity to introduce the new content to the teachers (Scribner, 1999), as it offers teachers an example of how to teach the new content in class and gives them insight into the preferred conditions for teaching such content in their own school situation (Figure 3, function and activity c). In addition, it prevents teachers from spending too much time discussing practical and organizational issues of teaching the unit, and provides them with concrete images of future practice for teaching the unit (Handelzalts, 2009; Scribner, 1999). McNeill and Knight (2013), however, found that high school teachers, who participated in workshops, developed pedagogical content knowledge regarding the content and student conceptions of argumentation, but they struggled with developing teaching instructional strategies to implement argumentation into their conventional science curriculum. They suggest that for effective PD, teachers should be provided with tools and materials they can use directly in class (McNeill & Knight, 2013). This implies that the workshop, besides focusing on the new content and student conceptions, also explicitly should focus on instructional strategies and provide them with tools and materials to implement the new content in their conventional science curriculum.

In other words, the additional strategies incorporated into the framework of Stolk et al. (2012) involve an additional phase of problem analysis. In this phase, teacher learning, student learning, and curriculum materials come together in a (quick) iteration of preparation, instruction, and reflection on teaching the new content and using new pedagogy. Functions c–i of the framework need to be fulfilled accordingly in order for teachers to become aware of their current practice, be introduced to the new content, compare and recognize differences and similarities, gain experience in teaching the new content and pedagogy, and reflect on the new experiences to find possibilities to incorporate the new content and pedagogy into their teaching practice and school curriculum. Teachers' preparations for teaching new content and pedagogy should involve activities to link student learning outcomes to teachers' own learning goals, as well as a hands-on activity or workshop that involves an example that teachers could use directly in class. The phase of problem analysis and functions are nested in the framework of the PD program (Figure 3).



2 | METHODS

A multiple case study approach was conducted (Creswell, 2007), which involved six teachers who, guided by a coach, prepared in a collaborative setting to teach a context-based science unit. The coach was experienced in both developing context-based science units and organizing PD activities for teachers. Because each teacher could espouse different types of sense-making during PD, each teacher was considered as a single case. In this section, the procedure for designing the PD program and the adaptations to the framework are described, including the phase of problem analysis of the new aspects in content and pedagogy.

2.1 | Procedure for the designing and implementing of the PD program

The PD program was planned by the coach and the researcher (first author), who organized two sessions to plan the program in detail. In the sessions, they discussed teachers' intended learning outcomes and the stumbling blocks that might occur in light of the adapted framework. Agreement was achieved concerning the activities needed to fulfill the required functions. The coach, having experience and tacit knowledge about teaching context-based science units, provided agendas for the meetings of the PD program, including the schedule of activities. The agendas were placed in the research perspective to make sure that collected data would give insight into teachers' sense-making in teaching the context-based science unit. The coach steered the practical and organizational perspective so that the sequence of activities in the program was coherent with achieving the collaborative actions of teaching the unit.

In total, the program consisted of eight meetings of 3 h each planned over 8 months. The preparation phase consisted of five meetings planned over 2 months. The phase concerning the problem analysis of the new content and pedagogy involved the first three of these meetings planned within 6 weeks. After the phase of problem analysis, two meetings were planned to prepare the entire module collaboratively to teach in class. In the instruction phase, the teachers taught the unit in one class of around 25 students in their own school. During the instruction phase, one intermediate meeting was planned. The evaluation and reflection phase was spread over two meetings, one directly after the instruction phase and one about 3 months later. The full program, including the phases, functions, and agendas of the meetings, is presented in Table A1. The program was developed similarly as described in earlier studies (Dolfing, 2013; Stolk et al., 2012). The phase of problem analysis was new and therefore it is described in detail in the following paragraphs.

In the first meeting of the program, the coach introduced the teachers to the framework of context-based science education by giving an introduction and overview of the three aspects of context-based education: (i) context-setting; (ii) the new teaching role; and (iii) the new content. In addition, the coach compared these aspects with similar aspects in the conventional curriculum (function c, C). Teachers then participated in a workshop that involved them jointly experiencing the activities of a lesson as an example of teaching the new content in class, and they shared prior experiences and values in teaching the conventional curriculum in relation to the context-based science unit. Homework after the meeting was to plan a lesson about the new content about structure–property relations, teach it to the teachers' own students (functions d, f, h, and l), and reflect collaboratively on their teaching strategies in the second meeting (function g). It was emphasized that teachers should integrate the new content within their regular program and in their own school situation. For example, when a teacher needed to teach about phase transitions of “water” according to the conventional curriculum, the teacher was asked to develop a lesson about the content of macro–micro thinking using the structure–property relations of the substance “water.”

After sharing their experiences in the second meeting, teachers were asked to link them to their personal frame of reference by thinking of successful events in their regular lessons that resulted in the intended student learning outcomes. To link student learning outcomes to teachers' own learning goals, the coach introduced a four-step approach (function c). This approach started by focusing on what the intended outcomes were for students



(first step) and what students needed to do according to the activities in the unit to achieve these outcomes (second step). The teachers then defined what they needed to do to support and guide the learning process of the students (third step) and what they needed to develop to be able to perform these teaching actions (fourth step).

After defining what to teach and learn in terms of learning objectives of students and teachers, the third meeting focussed on how to use collaborative learning approaches to plan and organize student activities to support them in working in project teams to solve a problem in product development (function c). During the meeting, teachers redeveloped a lesson plan that was already part of their conventional curriculum using collaborative learning activities (function d). Homework after the meeting was to instruct the lesson, including the collaborative learning activities, into their own school situation (function f) and adapt the unit using the new insights and experiences developed during the first three meetings (function d, h).

During the program, the coach was the primary facilitator in the sessions. The researcher was present in the background. During the instruction phase, the researcher visited the teachers in the school to collect data about their teaching practice (see Section 2.4). The coach created a safe learning environment by starting each meeting asking about teachers' experiences when performing the homework assignments. Then the other teachers could ask clarifying questions. As a response, the coach asked teachers to formulate their learning experiences based on what they had shared. When the teachers had difficulty describing their experiences, the coach asked reflective questions to stimulate sharing. This procedure prevented teachers and coaches from becoming judgmental about one another's practice. This start created a safe and productive learning environment in which to implement the PD activities as planned.

2.2 | Participants

Teachers were recruited during a national conference for science teachers in secondary education. The main criterion was that they taught science in lower secondary education, comparable with the 8–9th grade in the American school system, and did not have previous experience in teaching context-based curricula. In the Netherlands, the science curriculum in lower secondary education is a combination of Physics and Chemistry and is similar nationwide. Teachers were encouraged to engage in the PD program by recounting their personal interest in the curriculum innovation, describing the problems in their school situation that could be solved by teaching the context-based units and taking advantage of the chance to work together and share experiences with teachers from other schools. In addition, they were motivated by the opportunity to contribute to and give advice about curriculum innovation. Although the teachers volunteered to participate, nevertheless, the schools received remuneration, and the offer of free intensive coaching and PD for their staff to prepare for the upcoming curriculum innovation. All teachers gave informed consent for participation and publication.

The group comprised of six teachers (all pseudonyms) teaching the conventional curriculum in secondary schools. The teachers came from six different schools spread over the country. The teachers all taught the same conventional curriculum in lower secondary classes, which prepared for the preacademic science subjects in higher preacademic education (grades 10–12). This was the national standardized curriculum in the Netherlands of 2010. Table 1 provides information that teachers revealed before and during participation in the PD program that turned out to be relevant in relation to their sense-making processes.

The coach had 25 years of experience as a science teacher and was one of the pioneers in the early days of this particular curriculum innovation. He was one of the first designers of context-based units in the Netherlands and taught these units at his own school. Before participating in this study, the coach gained 2 years of experience in coaching teachers to teach these and other context-based units when the curriculum innovation was implemented on a larger scale. The researcher (first author), a PhD student with 2 years of experience in teaching in secondary schools, guided the workshop about the new content, and observed the activities during the sessions.

TABLE 1 Participant information teachers revealed before and during the program

Teacher	Experience (year)	Background and teaching situation
Tom	3	Tom was a teacher in only lower secondary education. Before working as a teacher, he had worked in adult education and obtained his PhD in Science
Eva	5	Eva was a teacher in only lower secondary education and taught at a school in which the experimental part of the curriculum was outsourced to teaching assistants, who were responsible for the lab facilities
Patricia	2, 5	Patricia was a teacher in lower and higher pre-academic education and was a very structured and organized teacher. She prepared very detailed course materials and study guides for students to follow for every topic of the conventional curriculum
Jason	0, 5	Jason just graduated from his teaching degree, taught in lower and higher preacademic education. He worked, according to himself, at a conservative science department, consisting of teachers who strongly valued the conventional curriculum. He was interested in new approaches but saw hurdles to implement them in his department
Julia	3	Julia was a teacher in lower and higher preacademic education. She worked, according to herself, at a conservative science department, consisting of teachers who strongly valued the conventional curriculum. She, however, was interested in trying new teaching approaches
Rick	8	Rick was a teacher in lower and higher preacademic education. He considered to implement a science curriculum consisting of only context-based units. In his school, the teachers mostly took responsibility for the theoretical part of the curriculum. The responsibility of the practical part was mainly outsourced to technical teaching assistants

The students being taught were 14 or 15 years old. All were in a lower secondary school class, had similar previous educational backgrounds in science (the national curriculum) and had not participated in context-based education before.

2.3 | Materials

The context-based science unit involved setting the context in class, during which time project teams of students and the teacher as a senior member were assigned to the task of solving a problem in product development. The assignment involved developing a light and “unbreakable cup” made of a composite of a variety of materials, such as clay, paper, plastics, latex, and Styrofoam. In a product development procedure, consisting of two cycles of gaining information, developing, testing and improving the cups, the project teams needed to know more about the structures and properties of these materials to solve the problem of designing the cups. To gain this knowledge, the project teams were required to carry out general research activities, such as reading literature and conducting experiments, to acquire more information about the structure and properties of the materials. The module addressed concepts regarding structure–property relations in general and concepts used in the field of material science depending on the materials used. In addition, the module addressed learning objectives related to design and research competencies in product development.

The assignments, activities, and materials used during the PD program are described in Table A1.

2.4 | Data collection and analysis

Data were collected that gave insight into teachers' processes of sense-making in relation to teaching the context-based science unit. Data collection focused on teachers' personal frames of reference in comparison to the new frame of reference including the new aspects of (i) setting the context in class, (ii) performing the new teaching role, and (iii) teaching the new content during the program. Similar data sources were collected which could be compared to reveal teachers' sense-making processes overtime during the program. In addition, different data sources were collected which could be triangulated to describe teacher's sense-making at a certain moment in time during the program. Table 2 provides information about the purpose of the data and what and when data were collected. Data instruments revealed information about:

1. teachers associations and insights about context-based education through mind maps (word webs on paper in which teachers demonstrate the outcomes of an individual brainstorm and present their associations with context-based education);
2. teaching products such as the lesson materials, lesson plans, and student assessments that were designed or adapted for instruction;
3. teachers' written and spoken evaluations and reflections about instructing the lesson plans and unit in their own school situation, their experiences, own performance, and student outcomes (e.g., an audio-taped interview, teachers' logs); and video recordings and protocols of meetings.

Because of the interrelated nature of the aspects of context-setting, the teaching role, and the content in the context-based science unit, data analysis was focused on describing teachers' processes of sense-making in all three aspects simultaneously. The different data sources at a certain moment in time containing information about a single teacher were combined and analyzed in a qualitative way and in chronological order. All data related to the participation of each teacher during the program, no selection took place at this time, were divided into quotations. The quotations that provided information about teachers' sense-making at a certain moment in time were then selected, clustered according to the specific moment during the program, and coded in terms of the new aspects involved in teaching context-based science curricula as described in Figure 2(a-g) and the particular teacher(s) involved.

To analyze teacher's sense-making, quotations from video recordings of the meetings and the interview at the interface of preparation and instruction were selected as primary data sources. In these quotations, teachers revealed their frame of reference for teaching the conventional curriculum and their perspectives on teaching the context-based curriculum. In addition, we triangulated this information with information from quotations of the secondary data sources in the same cluster, such as teachers' mind maps, lesson plans, students' assessments, lesson material, teachers' logs, and written reflections.

An inner-case analysis (Miles & Huberman, 1994) was conducted, in which teachers' processes of sense-making in (i) setting the context, (ii) performing the teaching role, and (iii) teaching the new content were classified by in-depth (thick) descriptions based on the categorized quotations. The in-depth descriptions related to a teacher's process of sense-making in the new aspects (i-iii) at a certain moment in time were then interpreted as "assimilation," "accommodation," "toleration," or "distantiation" using the descriptions and examples of the types of sense-making as described in the Introduction and Table 3.

The interpretations were validated in a "peer review" procedure (Creswell, 2007) by the first and second authors. The second author interpreted independently the coded and clustered quotations together with the in-depth descriptions in the same categories, as described above. The results were compared with the interpretations of the first author. It was found that out of 41 groups of clustered quotations (5–10 per teacher), two groups were interpreted as accommodation by the first author and interpreted as assimilation by the second author. The first and second authors discussed the difference in interpretations intensively to find an agreement.

TABLE 2 Data collection during the program

Phase	Time	Data source	Purpose
Initial	Preparation before meeting 1 conducted in teachers' local situation	One assignment per teacher, including a mind map, lesson plan & materials, and student assessments	Catching teachers' initial views, backgrounds, experiences and expertise on teaching context-based education
Problem analysis	Meeting 1	<ul style="list-style-type: none"> - Video recording and protocol of the meeting - One initial lesson plan per teacher about new content and pedagogy 	Catching teachers' sense-making processes while discussing the new content and pedagogy when developing the lesson plan
	Meeting 2	Video recording and protocol of the meeting	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers reflect on the instruction of their initial lesson plan in their own school situation
	Meeting 3	<ul style="list-style-type: none"> - Video recording and protocol of the meeting - One improved lesson plan per teachers about new content and pedagogy 	Catching teachers' sense-making processes while discussing the new content and pedagogy when improving their lesson plans based on their newly insights and experiences
Preparation of the unit	Meeting 4	Video recording and protocol of the meeting	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers reflect on the instruction of their improved lesson plan in their own school situation and implement their new insights when discussion initial ideas about how to adapt the unit
	Meeting 5	<ul style="list-style-type: none"> - Video recording and protocol of the meeting - Lesson materials, lesson plans and assessment instruments to teach the unit 	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers discuss about how they adapted the unit and how they will instruct the unit in their own school situation
Instruction of the unit and reflection upon instruction	Instruction of the unit in teachers' own school situation	<ul style="list-style-type: none"> - Video recordings of each teachers' first or second lesson: After the lesson - Interview, including the making of a mind map, with each teacher after the recorded first or second lesson, in which the teacher and researcher watched the entire video together, they analyzed and discussed what 	Catching teachers' sense-making processes about the new content and pedagogy when reflecting on the instruction of the unit in their own school situation, their experiences and especially their struggles. The mind map revealed their new insights when compared with the mind map made in the initial phase

(Continues)

TABLE 2 (Continued)

Phase	Time	Data source	Purpose
		<p>happened during the lesson to stimulate teachers' sharing of experiences in a video recall procedure (Welsh & Dickson, 2005)</p> <ul style="list-style-type: none"> - Each teacher's log consisting of teachers' two weekly reflections of about half a page 	
	Meeting 6	Video recording and protocol of the meeting	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers reflect on how they taught the first part of the unit and the intermediate student learning outcomes and discuss how they will continue to the instruction of the unit in their own school situation
	Instruction of the unit in teachers' own school situation	Each teacher's log consisting of teachers' two weekly reflections of about half a page in which teachers described their experiences during instructions following a protocol of questions (Bakkenes et al., 2010)	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers reflect on how they taught the second part of the unit and the final student learning outcomes
	Meeting 7	Video recording and protocol of the meeting	Catching teachers' sense-making processes while discussing the new content and pedagogy when teachers evaluate instructing the unit in their own school situation and expressing their experiences, emotions, and feelings regarding students learning outcomes
	Meeting 8	<ul style="list-style-type: none"> - Video recording and protocol of the meeting - Each teacher's written evaluation and reflections including a mind map 	Catching teachers' sense-making processes while reflecting on teaching the unit and participating in the program, as well as incorporating the expanded experiences and expertise by adapting strategies for teaching the unit again in the future. The mind map revealed their new insights when compared with the mind map made in the initial and instruction phase

TABLE 3 Examples of teacher behavior being interpreted according to the different types of sense-making

Type of sense-making	Description
Assimilation	Teachers *Recognize useful aspects from their current practice, expertise, experiences, and personal background in science (education) *Implement these aspects when teaching a context-based science unit
Accommodation	Teachers *Gain experience in teaching context-based science curriculum by trying to implement the new aspects into their teaching practice *Reflect on their experiences in teaching a context-based science unit *Expand their current practice by finding possibilities to include the new aspects in content and pedagogy into the school curriculum
Toleration	Teachers *Consider the context-based science curriculum as totally different from the conventional curriculum *Focus on the process of and conditions for from implementing the new curriculum, and not on substantive aspects *Switch between the conventional and context-based curriculum instead of integrating the new aspects into the school curriculum *Are not aware of what students need to learn when performing the activities presented in the unit
Distantiation	Teachers *(Un)consciously reject the context-based science curriculum. *Keep their current teaching practice *Demonstrate coping strategies (e.g. blaming the students' lack of abilities, questioning the quality of the lesson material) *(Express the intention to) drop out the PD-program

The interpretations of the results of both authors, in general, were comparable. Member checks were not performed during the program, as they would have had too great an influence on the process of sense-making, whereas, after the program, member checks would result in teachers' rational responses concerning their intuitive, emotional process of sense-making.

3 | RESULTS

Because teachers' process of sense-making in the three aspects of a context-based science unit occurred simultaneously in a collaborative setting and the interpretations were based on the in-depth descriptions, the results are described chronologically according to the phases of the PD program. As an example of a case analysis conducted to describe every individual teacher's process of sense-making in teaching a context-based science unit, the results of teacher Tom are described in detail (Figure 4). Tom was chosen, because he of all teachers was most expressive, both in spoken and written language, in describing his perspectives about how to teach science and his learning experiences during the PD-program. His quotations speak for themselves the most and provide clear descriptions about the process he went through during the PD-program. The data and results of the case analysis are described and presented according to Luttenberg et al's. (2013) model (Figure 1) at four moments in time and are illustrated with quotations accordingly, using data accordingly: (A) during the initial phase; (B) after the phase of problem analysis; (C) at the interface of the preparation and instruction phase; and (D) during the reflection phase.

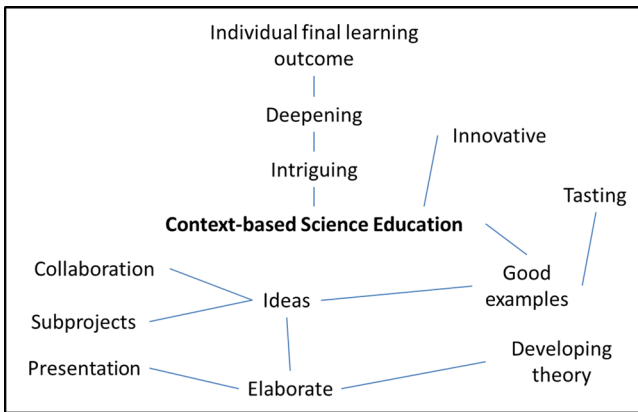


FIGURE 4 Tom's mind map [Color figure can be viewed at wileyonlinelibrary.com]

Then the results of all teachers are described and presented in Figure 5, and an overview of the results of the other teachers is then provided in Figure 6. These results are further elaborated, clarified, and illustrated.

3.1 | Tom's process of sense-making of context-based education

3.1.1 | Initial phase

Before the program, Tom said he had no experience in teaching context-based science units, but when triangulating this with his mind map and lesson plan, he demonstrated some understanding regarding the aspect of context-setting by associating context-based science education with collaborative learning in project teams (Figure 4). In his mind map, he associates context-based science education with groups of students developing theory, based on ideas arising from good examples. This relates to the aspect of the context-setting (i, a–c).

In the first meeting, Tom reported on his deepening personal understanding of constructing theory based on experiments and his research skills developed during his PhD trajectory. When confronted with the unit, he used this part of his experience and expertise to find recognizable aspects in the unit. He revealed an understanding of theoretical models and scientific literature concerning student learning and used this to gain an understanding of

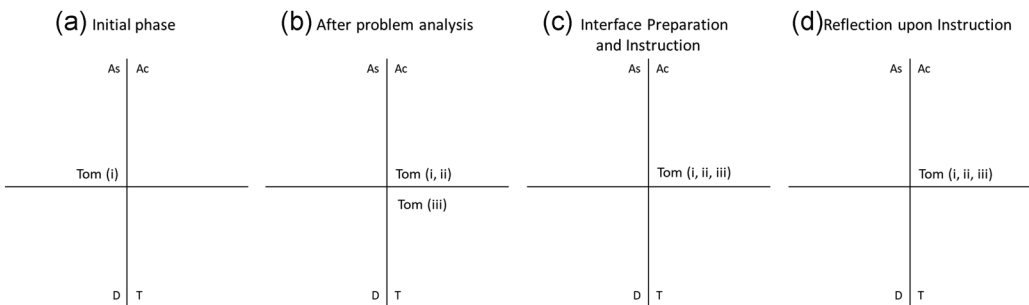


FIGURE 5 Results of Tom's sense-making of three new aspects of teaching a context-based unit—(i) setting the context in class, (ii) performing the new teaching role, and (iii) teaching the new content—at four moments during the professional development program. Each quadrant represents one of the four types of sense-making: Ac, accommodation; As, assimilation; D, distantiation; T, toleration

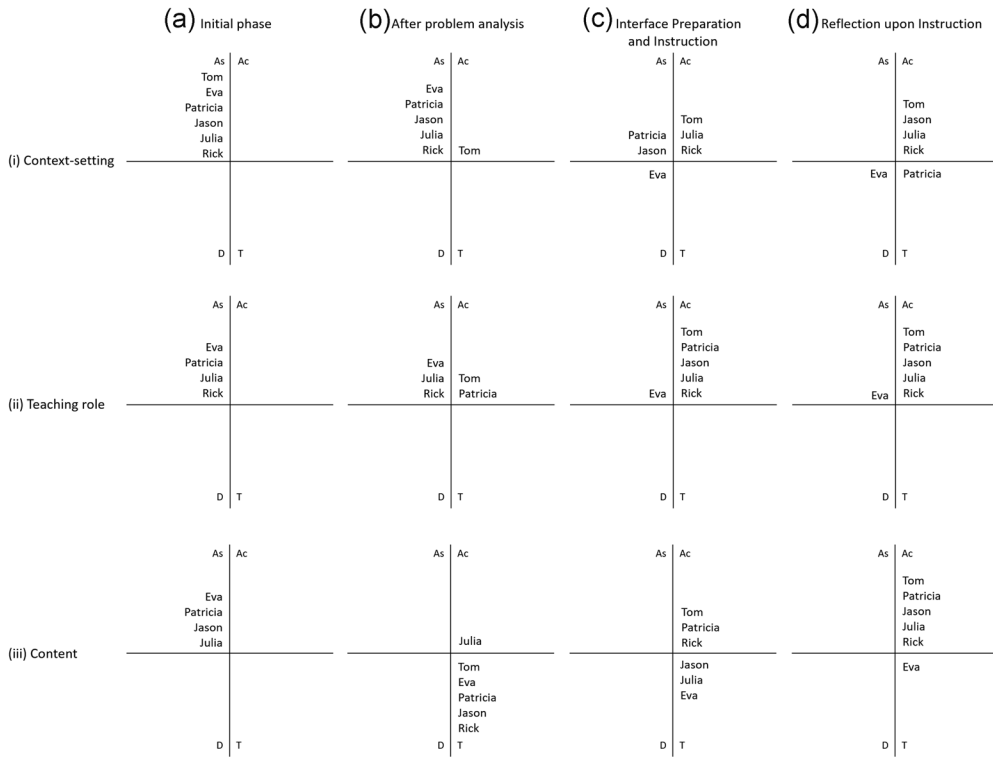


FIGURE 6 Overview of the results of teachers' sense-making of the new aspects of teaching a context-based unit at four moments during the professional development program. Each quadrant represents one of the four types of sense-making: Ac, accommodation; As, assimilation; D, distantiatio, T, toleration

events in his and other classes. Tom's motivation to join the program was that he liked the unit when he read it, recognized aspects from his former work and practice, and wanted to see how students responded to this method of teaching. He was therefore assumed to have assimilated these aspects regarding setting a context in class. This is represented in Figure 5a as "Tom (i)" in the "Assimilation" quadrant. Tom did not demonstrate any prior understanding or experiences in the aspects of performing the new teaching role or teaching the new content of structures and properties of materials.

3.1.2 | After problem analysis

In the second meeting, Tom said he had decided to plan a lesson about making ice cream as a product because the theme in his regular lessons was "water." He assigned the students to project teams to solve the problem of developing ice cream meeting certain quality criteria, emphasizing that, to develop the best ice cream, students needed to learn how to perform general research activities, such as lab work, designing experiments, reading literature, presenting results, and so forth. Tom demanded that the students should acquire adequate research skills to test the quality of ice cream, and asked students to look closely at the structure of the ice cream to assess and improve the quality. When students started to ask questions, however, Tom said he realized he did not know what students needed to find to solve the problem of improving the quality. When he shared his uncertainty with

the students, he noticed that they became uncertain as well. The following quotation from the protocol of the second meeting illustrates this:

Tom: "I had no idea where I wanted to go with the lesson. I shared that with the students, and that was a shock to them. [...] It was surprising to see what a tumult arises in a relatively open assignment, and thus how little open assignments I give to the students."

Tom explained this experience as showing that the students were not used to open assignments. He reflected in the second meeting that he needed the students' results of the assignment on making ice cream to think about what he wanted to achieve. Tom said he realized that he never provided "open" assignments to the students, and he was surprised that students shared his insecurity during the lessons. He reported in his reflection on this lesson that, in class, he had realized that he did not know what learning outcomes he wanted to achieve for the students.

Tom continues: "[.....] Regarding macro-micro thinking, I asked the students to look closely at the structure, but I did not know where I wanted to go in that area. The unit did not provide sufficient support in this."

Coach: "How did you provide the students with information about macro-micro thinking?"

Tom: "I have not yet fully arrived at that stage, the students still find it very difficult. I suffer together with them."

The coach summarizes Tom's learning outcomes based on his reflection:

- Describe what you want to achieve
- Students find it very difficult
- If you want to improve the quality of ice cream, what has that to do with the structure of ice cream?

Tom responded: "I want to see what I will get back from the students [in the next lesson], and based on their input I will see how I will implement the lesson differently, and what I have to provide."

These data collected during the phase of problem analysis suggested that Tom tried to make sense of (i) setting the context in class regarding project teams who were assigned to solve a problem in product development by performing general research activities, (ii) performing the teaching role by implementing a different balance between student- and teacher-centered approach (open assignments), and (iii) teaching the new content regarding the structures and properties of ice-cream (Figure 5b).

Tom continued to assimilate teaching general research activities, which were part of his experiences as a PhD researcher. Although he was close to distancing himself from the new curriculum due to his insecurity and that of his students, he accommodated the aspects regarding teaching problem-solving procedures in product development and managing project teams in the class. Tom accommodated his role as a teacher and his skills in using pedagogical approaches with this "open" assignment. This is represented in Figure 5b as "Tom (ii)."

He reported that he knew there was new content involved in solving problems concerning the quality of ice cream; however, he realized that he did not know what learning objective he should achieve in the lesson concerning the structure and properties of ice cream. Tom also said that the lesson material he had decided to use did not provide support. He reported in his lesson plans that his own learning goal for teaching the unit was to decide what learning outcomes he wanted the students to achieve. This shows that he was not properly prepared regarding the teaching of new content, but he realized during the implementation of the lesson that he needed to

develop a greater understanding of the structures and properties of ice cream to teach this to the students. Although he assimilated and accommodated the aspects of (i) setting the context in class and (ii) performing the new teaching role, this was interpreted, based on the description in Table A1, that Tom only tolerated the aspect of (iii) teaching the new content. This is represented in Figure 5b as “Tom (iii).”

3.1.3 | At the interface of preparation and instruction

In the next phase, when Tom prepared the unit, he demonstrated further assimilation and accommodation of the aspect of context-setting (Figure 5c). In the interview, Tom described how he compared the processes and products from the project teams in class to motivate students to achieve the best learning outcomes. Tom planned to emphasize to the students that the intended learning outcome was for them to learn how to do research and expand their research skills. He explained in the interview that he wanted to assess the students by letting the project teams make research posters. He said that students needed to show on the poster that there were several ways to solve the problem in product development, and he planned to organize a symposium so students could learn from each other's results and value the content of the posters (Figure 5c Tom (i)).

Tom accommodated the aspects regarding the new teaching role by using pedagogical approaches different to those used in his regular lessons (Figure 5c Tom (ii)). During the recorded lesson, he instructed the students to do the activities in the unit independently and ask him when they had questions, instead of telling them directly what they needed to do and learn. In the interview at the interface of preparation and instruction, Tom said that he monitored the learning of the students by collecting their work in a group folder. He explained that he checked the results of their work unnoticed when students called him to ask a question. In this way, the students kept their ownership of solving the problem. In the interview, Tom argued that context-based science education was very personal compared with his conventional plenary lessons, and was a very good way to differentiate between students. He kept an overview of the activities and gained knowledge by starting every lesson with a total overview of the activities in the unit and ending it with a short summary.

In the interview, Tom demonstrated that he had accommodated the new content and no longer felt any insecurity about teaching it (Figure 5c Tom (iii)), because he explained that he had studied the structures and properties of ice cream to be able to teach this content to the students; however, he decided not to teach the content directly to the students. This following cluster of quotations from the interview illustrates Tom's accommodation of the new content:

Tom: “I used macro–micro thinking implicitly by instructing students to look at the structures and properties on a macro level and relate that to substructures on micro- or meso-levels. I'm not planning to make the macro–micro thinking explicit to the students, because based on how students learn, the way of thinking is different for every student.”

Tom: “I want the students to use words such as macro, meso, micro, structure and property in the right way.”

Tom: “Before I participated in the professional development programme, I had a totally different idea of structures. I thought of pure structures of atoms, molecules and chemical bonding, but now I have a broader view on structures and properties.”

Tom explained that he used the content implicitly in his lessons by instructing students to improve the quality of ice cream by using knowledge concerning the structures and properties of water, solutions, and ice cream, without pointing it out explicitly. Instead of making the content explicit, he wanted the students to use the proper



language and terms regarding the structures–property relations during problem-solving procedures, which they could only do when they understood the specific content. In light of his understanding of student learning, Tom argued that every student has a different way of thinking. He reported that, during preparation, he shifted his understanding of the science content into a broader perspective.

3.1.4 | Reflection upon instruction

In the reflection phase (Figure 5d), Tom expressed positive feelings about teaching the unit, confirming what he reported in the interview and sharing additional examples from his experiences in teaching the unit. Tom gave a questionnaire to the students and gave an interpretation of the results during meeting 7:

“The students indicate that the assignments were too open. They do not know what to look for. Students like to have ‘a well-fitted box of materials’ instead of searching in a completely open space. This surprised me. I did this to see how this would work for me. And actually, it offers a lot of possibilities that you do not use in a plenary setting. Plus, I work at a ‘Dalton school’, which is a school that stimulates collaborative learning, and hadn’t yet used this approach yet. This [unit] does offer that possibility. You have to be very strong in yourself as a teacher and be very sure of the content presented in the material. You have to see the questions coming from students far in advance. There is a very different way of testing. It goes more from traditional questions to assessing the process.”

Tom let the students present their results on a poster. He used the posters to assess the students’ learning outcomes. He reported on this experience:

“[.....] Also, the teaching assistants assessed the posters fanatically and they also demonstrated that they have a lot of knowledge about composites. [.....] It saves time, and they have more knowledge about working with materials. Students are very sharp, but do not know what is required of them. You therefore have to start with units earlier. A unit is a mix of practical and classroom teaching. You have to know very well where you want to be at the end of the lesson. I composed the groups and used the roles in the group to structure lessons and give instructions. I use everyone’s personality. Students evaluated the project as really difficult, but it was positive. [.....]”

In his reflections, Tom demonstrated his further accommodation of the new teaching role (Figure 5d Tom (ii)), which involved new approaches compared to his conventional teaching practice in relation to keeping an overview of students performing activities during the lessons and supporting students in structuring new knowledge of the basis of their existing knowledge. Tom found that context-based science education requires a completely different way of assessing students, which he suggested involved a shift from assessing facts and conceptual knowledge to assessing and monitoring procedural knowledge, group processes, and products. In addition, Tom demonstrated to have assimilated and accommodated the new teaching role by explaining how he managed project teams in class in a very structured way and how he used the roles of students within the teams to give instructions to the project teams. He related the roles of the students within the project teams to his knowledge of different learning patterns of students and ways of collaborative learning.

Regarding the relationship between the aspects of setting a context in class and teaching new content, Tom expressed how a teacher requires a broad perspective concerning solving the problem in product development, to anticipate students’ questions well in advance. In the second reflection meeting, Tom added that in the unit, the new content and the aspect of problem-solving were the main intended learning outcomes for students. Tom reported during the final meeting:

"I want to make macro–micro thinking using structure–property relations known to students and need to study the principles. I did not have enough time for teaching the unit. The solution was to work together with teaching assistants. What could work well is that you have to maintain good contact with your teaching assistants. I would have liked a digital learning management system. I started working more using a helicopter view instead of taking full control. I know what students need to learn, but it does not matter how they learn it. Learning to collaborate was a goal, and it surprised me that the roles in the groups worked out that well. There was competition among the groups, and there was collaboration among the groups. I do not know what I would do differently. There are many different units. If I am insecure, the students are also insecure."

Tom reported that the only way one could teach context-based units was if the teacher had comprehensive knowledge of the content of the unit. In this way, Tom showed that he saw possibilities to fit the new content of structure–property relations of a variety of materials into his teaching practice, which is represented in Figure 5d as "Tom (iii)."

3.2 | Collected results of all six teachers

The results for all six teachers are summarized in Figure 6. Horizontally the process of sense-making is presented chronologically per aspect (i–iii). Vertically the figure shows teachers' sense-making per aspect (i–iii) at a certain moment in time. Some remarkable findings in terms of teachers' sense-making will be elaborated upon in this section.

3.2.1 | Initial phase

The findings showed that in the initial assignment and meetings, all teachers demonstrated ideas and associations as part of their current teaching practice that could be related to the aspect of context-setting (Figure 6a(i)). Four out of six teachers demonstrated ideas and associations that were related to the aspects of the teaching role and content as part of their current teaching practice. According to the descriptions in Table 3 this was interpreted as assimilation because they recognized these aspects from their current practice as being part of teaching context-based education. The data did not provide information about Tom's and Jason's process of sense-making in performing the new teaching role, or Tom's and Rick's process of sense-making in teaching the new content at the initial phase of the program.

In the initial phase, several teachers (Eva, Patricia, Jason, and Julia) said they had heard of the new content before (Figure 6a(iii)). Only Jason and Julia, however, demonstrated an understanding of how to teach the content of macro–micro thinking using structure–property relations in context-based units by providing examples of lessons concerning structures and properties of materials and substances. Julia appeared to have picked up some ideas, she learned during a teacher conference and tried to implement this in her lessons, not knowing these aspects were also part of the context-based curriculum until she participated in the PD program. Jason learned about the ideas, but never tried to implement them.

3.2.2 | After problem analysis

Regarding teachers' problem analysis, it was remarkable that although teachers were asked only to focus on teaching the new content (Figure 6b(iii)), they automatically assimilated other aspects and abilities that they recognized from their conventional teaching practice (Figure 6b(i,ii)). For example, regarding the aspect of

performing the new teaching role, Patricia assimilated her way of organizing and planning lessons in detail by keeping an overview of planning and activities during the instruction of the lesson. She accommodated the aspect of the teaching role, however, by organizing a different balance between student- and teacher-centered instructions than that found in her conventional teaching. She explained in the second meeting:

"I did an assignment about whipped cream. First, I did an introduction about macro-meso-micro structures and properties using bread as an example. Then I asked the students the question, which structures ensure that the whipped cream becomes airy and stiff when you make it right? They also had to make a conceptual scheme of the whipped cream [exactly like in the workshop]. The students went to work immediately, I did not have to do anything. I searched and found literature about whipped cream on the Internet and gave this to the students. I asked the students what macro- meso- and microstructures were. Pupils had no problem with that. Then the difficult part came, they had to link the properties to the structures. They understood it but could not find words to describe it. I have never given so many open assignments."

In comparison, Rick created a common knowledge base for all students at the start of his lesson, as he said, "he always did." Because in Rick's school the responsibility of the practical part was mainly outsourced to technical teaching assistants, teaching context-based units required strong collaboration between Rick and the teaching assistants. In this case, Rick did the preliminary and postdiscussion, while the teaching assistants guided the students during the experimental activities. He recognized and was aware that it was important to create such a common knowledge base during the preliminary discussion, and this was interpreted as he assimilated this when teaching the single lesson about macro-micro thinking.

Regarding the aspect of teaching the new content, Eva, Patricia, and Rick copied in detail the workshop to teach their students the new content concerning the structure-property relations of a material, which was not part of the conventional science curriculum. Unlike in Rick's lessons, Eva did not focus so much on the content in the preliminary and postdiscussion, but more on the process of students performing the activities in time. This suggested that different from teachers' sense-making in the aspects of the new teaching role and the context-setting, they were prepared to teach the content, but it did not fit into their personal frame of reference concerning teaching the conventional curriculum. Therefore, they taught the new content as an additional intermezzo to the conventional curriculum. According to the description in Table 3 this was then interpreted as toleration instead of assimilation or accommodation (Figure 6b(iii)).

Jason and Julia tried to integrate the content into their regular lessons, as requested, by choosing a material that was part of the conventional curriculum. The main learning goals that they formulated for teaching the unit involved a partial understanding of the new content concerning the relationships between structures and properties in several materials. At first, for both teachers, this was interpreted as accommodation, because they integrated the content of macro-micro thinking using structure-property into the conventional curriculum. Jason, however, tried to teach the content of structure-property relations in one of his regular lessons because he said he could not deviate from the conventional school program. Although he thought he had integrated the new content into his regular lessons, he reported in the second meeting that his students saw the content as a totally different subject. If only Jason's perspective was taken into account, this could be interpreted as accommodation. Taking the students' perspective into account, it was, however, interpreted as toleration (Figure 6b(iii)), because the students revealed that Jason was teaching the new content as a different subject within the lesson.

Julia put great effort into implementing the new content into her regular lessons. In the second meeting, she reported that she had left out the, according to her, crucial parts of the new content because she was not able to integrate these parts into the topic of that lesson. She noticed that students were not able to learn about structure-property relations by themselves; instead, she needed to help them a lot by using examples and metaphors. In light of her experience, Julia concluded that when students understood the relations between structures and properties, they could also better understand the content of the conventional curriculum.



"I struggled with thinking in terms of micro- and macro, properties and structures in the subject I am teaching now. I took the extremes from macro to micro regarding phase transitions. It was very difficult to describe the properties and structures of liquids, solids and gases. Students could not do that on their own. I tried to let them zoom in, for example, from a beer to molecules. I had to steer and guide them a lot, the students did not do it by themselves. It was difficult for them to translate what they already know in terms of macro-micro, structures and properties. I used many metaphors and examples to clarify it for the students. I asked the students later about what they remembered and that turned out not to be much. You have to repeat a lot for students. They could hardly point out and name the meso-structures. If students can get an insight into structures and properties, they will understand the phase transitions much more easily."

With this, she demonstrated assimilating aspects of her regular teaching role (Figure 6b(ii)) when supporting students to learn the new content. At the same time despite the fact that she did not manage to integrate the content fully into the conventional curriculum, she demonstrated accommodating the aspect of the new content when integrating it in her regular lessons (Figure 6b(iii)).

The data did not give insight into Jason's sense-making in performing the new teaching role at this stage of the program.

3.2.3 | At the interface of preparation and instruction

When preparing and teaching the unit, teachers continued assimilating and accommodating aspects that they recognized from their teaching practice (Figure 6c(i-iii)). Assimilation and accommodation of setting the context and performing the teaching role meant that teachers implemented aspects of their conventional teaching practice and tried new pedagogical approaches respectively regarding monitoring and assessing student learning. They motivated students to take ownership of their problem-solving and gained an understanding of the relation between the problem presented in the context-setting and the content about the structures and properties of materials. Most teachers focused on managing project teams, creating a different balance between student- and teacher-centered instructions, and keeping an overview of organizing and planning activities. Rick, Julia, Patricia, and Tom monitored student learning by collecting student products in a group folder and allowing students to keep a log to evaluate the group processes. Rick also managed the project teams in such a way that they needed to collaborate with each other to find a solution to the problem of developing a product with the desired properties. He said during the interview:

"[.....] I leave them [the students] free. They first have to divide everything [tasks] into the group. They also have to make sure that they communicate everything in the group, which works well with one group but not so well in the other. Because I only have 2 times 45 minutes, there is also little time to provide feedback. I walk around during the lesson to see how far they have got and they also fill in a log, but how deep they learn the theory.....I'm very curious about that. [.....]"

In contrast, Julia focused on how she could motivate and guide the students when they worked in project teams. She explained in the interview:

"[.....] I told them hardly anything about the content, and only told them about the procedure, what students needed to do and what they could expect, but not what they should learn and remember. [.....] It is difficult...when the students are at work, there is nothing to do. I just have a tendency to walk around constantly, to speak to students. Usually, when they are doing regular assignments, they always need some help. Now, however, they only need help at the beginning, the second problem they can do by themselves."



If I do not walk around, they have to figure out what to do themselves. In retrospect, I though, if I had sat still, they would have been better at reading about what they needed to do. [.....]"

Eva focused on students performing the activities in time without addressing the aspects regarding the specific context-setting, therefore this was interpreted as “distantiation” (Figure 6c(i)).

During the interviews, teachers did not reveal much of their sense-making concerning teaching the new content (Figure 6c). They were instead busy with other aspects of teaching the unit, such as managing project teams, organizing experiments in class, keeping an overview of student activities, and so on. Although teachers were not aware of their sense-making in teaching the new content at this stage in the program, they still made sense of the new content indirectly. For example, Jason, and Julia, who were accommodating the new content during problem analysis, were so busy implementing the other aspects that they reported that the content was not the main student learning outcome they wished to achieve. This was interpreted as a reversion to the toleration of the new content. They did not, however, reveal feelings of stress, and demonstrated no coping strategies that could be expected when teachers do not have sufficient understanding to teach the content.

At this stage, like Tom, Patricia, and Rick did accommodate teaching the new content. Patricia explained in the interview that students needed to zoom into the material to explain properties on a macro level. In addition, she focused on students to formulate if...then... sentences to make structure–property relations explicit. Rick described in detail in the interview that he was planning to make the macro–micro thinking explicit to the students. He experienced that students got confused about the word “micro” because it was used in different ways in the unit, for example, “micrometre” and microscope. Rick considered the most important learning outcome for students was that they could describe the structures and properties of different materials and explain the properties by these structures. Jason, Julia, and Eva still considered the content as something additional to the curriculum.

3.2.4 | Reflection upon instruction

During instruction, Eva did not accommodate any aspect of teaching this context-based science unit (Figure 6d(i–iii)). She only assimilated the aspects she recognized from teaching her conventional curriculum and did not actively try to accommodate unfamiliar aspects of teaching the unit. For example, Eva explained that she had an assistant who prepared and instructed the research activities for the students. As a teacher, she could distantiate herself from teaching research activities and skills, however, she was still involved in planning the activities when teaching the unit. Eva also reported that she had problems understanding the content of the unit, saying that the phase of problem analysis was helpful in preparing her and the students for the new content and working in project teams. She stayed, however, very focused on the process in the classroom and assimilated this role when teaching the context-based lessons and unit. Eva reported in the interview that her role in class was not very different from her usual role.

In the reflection phase, all teachers, with the exception of Eva, assimilated and accommodated the aspects of the context-setting and the new teaching role that they recognized from their personal frames of reference at the start of the PD program. Contrary to what they reported in the interview, teachers reported in the first reflection meeting at the end of the program that the new content of structures and properties of materials would be the most important student learning outcome to achieve when teaching the unit the next time. Eva, however, mentioned:

“Things went well, I have structured it well. They were not allowed to ask too many questions, but I did watch over time. I did let them fill in the logs, later they did it themselves. Because they work with a lab assistant, the group always had to be at the same point [in the module]. I always collaborate with the assistant this way. I do this to learn, and also the students had to get used to modules. I did not let the students make cups, because I did not get to that. I did have to steer the groups, next year I would like to do it in a freer way”

With the exception of Eva, all teachers showed full accommodation of the content. They also appeared to understand the similarities and differences between teaching the new content in context-based science units and teaching the content in the conventional curriculum. Teachers were happy with their achievements, and all wanted to teach one or more context-based units in the next school year.

3.3 | Summary

In summary, during the PD program, the science teachers accommodated the new aspects of teaching this context-based science unit in their teaching practice. Teachers struggling with the new content during the phase of problem analysis and at the interface of preparation and implementation, which was interpreted as toleration, seemed contrary to the intended mechanism that when during the problem analysis recognize aspects that are already part of their teaching practice, expertise and/or personal background, it would make it easier for teachers to accommodate the new aspects. For five out of six teachers, however, it did not prevent them to accommodate the new content when teaching the unit in class. Jason, in particular, made great progress in accommodating the new aspects.

The results showed that, with the exception of Eva, teachers successfully assimilated and accommodated all three aspects (i–iii). The process of sense-making regarding the context-setting and the teaching role mainly followed a straight path from assimilation to accommodation (Figure 6). Regarding the new content, however, the process of sense-making followed a path from assimilation to accommodation via toleration.

4 | CONCLUSION AND DISCUSSION

This study focused on developing more understanding about strategies for adequate PD in teaching context-based science curricula, as an exemplar of curriculum innovations in which teachers are confronted with new pedagogy and new content simultaneously. The aim was to support teachers' assimilation and accommodation of three new aspects of teaching context-based science units: (i) setting a context in class; (ii) performing the new teaching role; and (iii) teaching the new content. The results of this study showed that five out of six teachers who participated in a PD program, based on the adapted framework of Stolk et al. (2012), assimilated and accommodated all three aspects (i–iii). This study contributed to the knowledge-base about PD through collaborative curriculum design (Pieters et al., 2019), first of all by capturing teachers' process of sense-making regarding the new pedagogy and content simultaneously during the PD program. Second, based on these descriptions the most remarkable finding was that teachers' sense-making processes followed a different path for the new content compared to the new pedagogy. These different pathways should be taken into account when planning activities to support teachers' sense-making processes. To retrieve strategies for adequate PD, the influence of the additional phase on teachers' sense-making and its implications for designing PD programs are further discussed.

Tolerating the new content seems to be an important step for teachers' further development when preparing, instructing, and evaluating a context-based science unit. The phase of problem analysis, including the quick iteration of preparation, implementation, and evaluation of a lesson plan concerning the new content gave teachers the opportunity to try to teach the new content on a low profile in one lesson. This fostered teachers' toleration of the new content. During this phase, teachers realized what the new content involved and what they needed to develop to teach the new content in class. This provided teachers with the opportunity to better prepare for teaching the context-based unit.

Since the content of the new curriculum was significantly different from that of the conventional curriculum, we could not expect teachers to accommodate the new content directly. Comparing the conventional and new curriculum, teachers assimilated parts of the content and pedagogy they recognized from their teaching practice,

earlier studies or work, or from other resources. During preparation, two teachers appeared to be ahead and accommodated some parts of the content directly after the phase of problem analysis. When teaching the unit in class, however, they found that the content of the unit was more complex and as such they “fell back” into toleration. Nevertheless, this did not seem to hinder their development during the implementation and reflection phase. Experiencing a lack of understanding of the content during the implementation of the unit may even have stimulated their development.

In this study, we confirmed that different combinations of the four types of sense-making could be demonstrated within one teacher (Ketelaar et al., 2012; Luttenberg et al., 2013) at different times during the program and in relation to different new aspects involved in teaching context-based science curricula. Based on the results of this study, however, one could add that when teachers are confronted with a curriculum innovation, they have a tendency first to assimilate the aspects they recognize from their own frame of reference about teaching the conventional curriculum, as shown in similar studies among biology teachers (Wieringa, 2012; Wieringa et al., 2011). Even when they are required to focus on integrating the content into their own teaching, they first focus on assimilating recognizable aspects in performing the new teaching role or setting the context in class. Teachers' sense-making of the new content often appeared to occur through processes of toleration followed by accommodation. This was especially demonstrated in the case of Eva. At the end of the program, she still only tolerated the new content. This might have hindered her in accommodating the other two new aspects of teaching the context-based unit. Participating in the program supported her in teaching the context-based unit, however, this was not enough for her to accommodate all three aspects. It did not, however, provide her with a negative experience, and like the other teachers, she was likely to try to teach the unit again.

Fernandez (2005) reported that it is only during lesson implementation that teachers become fully aware of their lack of understanding of subject matter content. We can add that providing teachers with a hands-on activity that they can use directly in class and linking the student learning outcomes to teachers' own learning goals about the new content offer teachers the opportunity to interact with students and focus only on the new content, without the hassle of the other new aspects involved in context-based science curricula and practical issues. Social interaction with students in class is essential in terms of teachers' sense-making of the new content. Teachers use interaction with students to formulate their own learning goals. They project their sense-making onto students and formulate expectations. When these expectations do not match the actual student learning outcomes, teachers become motivated to gain a deeper understanding of the new content.

Handelzalts (2009) and Voogt et al. (2011) reported that an adequate problem analysis of the curriculum innovation, including the opportunity to interact with students, is a prerequisite for successful PD. Based on the results of this study, we can contribute that, especially when curriculum innovations simultaneously include new teaching content and pedagogy, a “special” phase of problem analysis of teaching the new content prevents teachers from focusing only on the assimilation of pedagogy they recognize from their own practice and distancing themselves from teaching the new content. The quick iteration of preparing, instructing, and evaluating a lesson plan creates a balance for teachers between focusing on the differences and focusing on the similarities between teachers' personal frame of reference and the frame of reference for teaching the new curriculum. Pointing out the similarities could stimulate teachers to assimilate aspects and abilities they recognize from their teaching practice, whereas focusing on the differences could increase teachers' insecurity and result in a greater chance that teachers will distance themselves from the new aspects of context-based science curricula. A good balance of the two is necessary for successful PD regarding the new aspects of curriculum innovations.

4.1 | Suggestions for developers of PD activities

The conclusion and discussion led to the following strategies by which PD could support teachers in curriculum innovations wherein the content and pedagogy change simultaneously. First, the main new aspects of teaching the

unit could be determined, with special attention given to the new content, since it is a prerequisite for thinking about teaching strategies and pedagogical approaches (Van Driel et al., 1998). Before teachers prepare to teach innovative units in class, they could be facilitated in orienting themselves to these new aspects. In PD programs, specific activities should be planned to stimulate teachers to conduct a problem analysis on teaching new content and pedagogy, as they do not do so automatically regarding the content. When teachers are not sufficiently supported in developing content knowledge, their (lack of) content knowledge influences their confidence in teaching science (Kind, 2009) and hinders them in making sound design decisions (Fernandez, 2005). An adequate phase of problem analysis requires a quick iteration of preparation, instruction, and reflection in relation to any particular new aspect. Second, in this phase, a balanced focus could be created regarding the differences and similarities between aspects of the conventional and the new curriculum to support teachers in assimilating, tolerating, and/or accommodating the new aspects into their teaching practice and the school curriculum. Third, the activities in the phase of problem analysis could involve a hands-on activity that teachers can use directly in class so that they experience for themselves how to teach the new aspects to their students. Linking student learning outcomes to teachers' own learning goals could stimulate teachers' development and accommodation regarding the new curriculum.

4.2 | Limitations

The validity of this study is subject to several limitations. Our adaptation of the framework was carried out in the initial stage of implementing a curriculum innovation. Whether the framework is applicable more generally in PD programs requires further investigation. The results are based on sense-making processes regarding specific context-based science units addressing the new content of structure–property relations in materials. Furthermore, the results are based on six teachers only. In addition, as teachers make sense of the curriculum innovation in a social process influenced by their own expertise, their own school situation and the conventional curriculum (Ketelaar et al., 2012; Spillane et al., 2002), sense-making in teaching context-based curricula could be influenced by many factors in group dynamics (Forsyth, 2010), by teachers' expertise, perceptions of student learning and curriculum, the design of the lesson material, tolerance for discomfort, and identity (Remillard, 2005). This study did take these factors into account when they appeared in the data. Other factors, however, that were not recorded in the data may have had an influence on teachers' sense-making processes during the program. We claim that participating in the PD program supported teachers to assimilate and accommodate the new aspects in teaching context-based curricula. Based on prior research (Vos, 2010), it is known that providing teachers with only the context-based unit is not sufficient to successfully implement the context-based curriculum. In addition, prior attempts to develop PD programs did not lead to sufficient teacher development and preparation to implement the new curriculum (Dolfing, 2013; Stolk et al., 2012). What, however, the exact mechanisms are in teacher development in relation to the steps in the program needs to be further investigated.

4.3 | Further research

Besides the mechanisms regarding the influence of participating in the program on teachers' sense-making processes, further research is required to evaluate the applicability of the framework of this PD program to education in the mono-disciplines (e.g., Biology, Physics) and in other related innovations (e.g., inquiry-based, problem-based, and competence-based curricula). In addition, further research could give insights into how to balance the bottom-up approach of creating an atmosphere that respects teachers' professional identities and ownership, and a top-down approach of stimulating teachers to come out of their comfort zone and experiment in their classrooms to implement a new curriculum. Teachers' professional identities are mostly determined by the fact that they

possess more knowledge about the specific discipline than do their students. When this situation changes, as in this curriculum innovation, we must take into account the consequences and effects on teachers' self-efficacy and self-esteem when designing PD activities. In addition, we need to be aware of the differences among teachers in relation to their development regarding new pedagogy compared to new content. The framework for PD as presented in this study guides the design of activities that support teachers' accommodation of both the new content and pedagogy of teaching context-based science curricula.

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APPENDIX

TABLE A1 Summary of the professional development program proposed to support teachers teaching new content with a new pedagogy

Phase	Functions	Activities
Initial	<p>A. Connect to teachers' views on context-based education</p> <p>B. Reveal 'useful' initial experiences and expertise of teachers</p>	<p>Assignment to describe teachers' personal frames of reference in a mind map. This mind map involved their initial associations and their views and ideas concerning the new aspects in context-based science education and the relations between them. In addition, teachers reported on lesson plans, lesson materials, and student assessments that, from their perspective, involved aspects of context-based science education (functions A, B). They also reported their motivations and expectations regarding participation in the professional development program</p>
Problem analysis	<p>c. Let teachers discover differences and similarities between their views on teaching conventional content and teaching new content</p> <p>d. Let teachers explore strategies for teaching the new content</p> <p>e. Provide the opportunity for teachers to define their learning goals</p> <p>f. Provide the opportunity for teachers to apply their experiences and expertise</p> <p>g. Give teachers the opportunity to reflect on their teaching and learning experiences</p> <p>h. Examine teachers' development by creating the opportunity for teachers to produce a product</p>	<p>Meeting 1. Introduction to teaching new content and pedagogy</p> <ul style="list-style-type: none"> • Getting acquainted with each other • The coach and researcher present the task and purpose of the program that the teachers should achieve, including an introduction and overview of the three aspects of the particular context-based science curriculum implemented in this project: (i) context-setting, (ii) the new teaching role and (iii) the new content. In addition, the coach compares these aspects with similar aspects in the conventional curriculum (function c, C). The presentation was followed by clarifying questions and discussion to reach agreement and consensus (function c) • Performing a workshop to let teachers jointly experience the activities of a lesson as an example to teach the new content in class (function c), followed by introducing the new pedagogy including the new teaching role by making lesson plans for one lesson about this content (functions d, h). In the workshop, scientific articles were provided concerning the structures and properties of a variety of materials. • Share prior experiences of teachers in teaching context-based units (functions A, B) <p><i>Homework:</i></p> <ul style="list-style-type: none"> • Instructing the lesson in teachers' own school situation and integrate the new

TABLE A1 (Continued)

Phase	Functions	Activities
	i. Evaluate teachers' development	<p>content and pedagogy within teachers regular program (function f)</p> <ul style="list-style-type: none"> • Thinking of “successful events” in teachers' experience when teaching the conventional curriculum (functions A, B) <p>Meeting 2. Definition of teachers' learning goals</p> <ul style="list-style-type: none"> • Teachers discuss and reflect upon their teaching strategies and student outcomes from teaching the new content (function g, i) • Teachers share their “successful events” and report them on a joint poster. These events involve teacher actions, student activities, situations, etc. that, according to the teacher, had the intended student learning outcomes. By thinking of and sharing these events, teachers are stimulated to reveal their expertise, values, views, and ideas, which offered insights into their frame of reference that might have been useful when they taught the unit (functions b, d) • To support teachers in formulating their own learning objectives, teachers follow the four-step approach (functions d, e, j): <ol style="list-style-type: none"> 1. Define intended student outcomes 2. Relate intended student activities to the outcomes 3. Explore teachers' actions to achieve the intended student outcomes 4. Define teachers' learning goals in accordance <p><i>Homework:</i></p> <ul style="list-style-type: none"> • Optional: Improve and instruct the improved lesson plans (functions g, h) • Study the unit, student activities, and outcomes in detail to teach in teachers' own school situations (function d). Prepare the activities in the unit together with the teaching or lab assistants at school <p>Meeting 3. Performing collaborative learning approaches</p> <ul style="list-style-type: none"> • The coach introduces various collaborative learning approaches that could be applied when instructing the unit (function c) • Teachers make lesson plans for one lesson about an actual issue in the conventional curriculum using one or more collaborative learning approaches (managing project teams) (function d)

(Continues)

TABLE A1 (Continued)

Phase	Functions	Activities
		<p><i>Homework:</i></p> <ul style="list-style-type: none"> • Instruct the lessons, including the collaborative learning approaches, in teachers' own school situations (function f) • Adapt the unit for teachers' own school situations using the new experiences and expertise teachers acquired by instructing the lessons (functions d, h)
Preparation of the unit	<p>C. Let teachers discover differences and similarities between their views on context-based education and the context-based unit</p> <p>D. Let teachers explore strategies for teaching the context-based unit, give examples, and present conditions for use</p> <p>E. Provide the opportunity for teachers to define their learning goals</p>	<p>Meeting 4. Planning to instruct the unit</p> <ul style="list-style-type: none"> • Sharing experiences of and reflecting on instructing the lessons, including collaborative learning approaches (function G) • Reporting and discussing the adaptations of the unit by following a collaborative learning approach (function D) • Elaborating in a discussion the intended teaching actions necessary to achieve the intended student outcomes and teachers' learning goals (functions D, E) <p><i>Homework:</i></p> <ul style="list-style-type: none"> • Making lesson plans, including teachers' learning goals and a midterm student assessment (functions D, E, H) <p>Meeting 5. Planning</p> <ul style="list-style-type: none"> • Reporting and discussing the lesson plans and student assessments (functions D, E) <p><i>Homework:</i></p> <ul style="list-style-type: none"> • Making definitive versions of the unit, lesson plans, and students' assessments (functions D, E, H)
Instruction of the unit and reflection upon instruction	<p>F. Provide the opportunity to apply teachers' experiences and expertise in practice</p> <p>G. Give teachers the opportunity to reflect on their teaching and learning experiences</p> <p>H. Examine teachers' development by creating the opportunity for teachers to produce a product</p>	<p>Instructing first part of the unit in teachers' own school situations (function F)</p> <p>Meeting 6. midterm evaluation and reflection</p> <ul style="list-style-type: none"> • Sharing experiences and discussing the instruction of the lessons, lesson plans, and adapted unit based on the outcomes of the midterm student assessment (functions G, H, I) • Sharing and discussing individual problems experienced during instruction (function G, I)

**TABLE A1** (Continued)

Phase	Functions	Activities
	I. Evaluate teachers' development	<ul style="list-style-type: none"> • Preparing the lesson plans and the final student assessment for the second part of the instruction (function H) <p><i>Homework:</i></p> <ul style="list-style-type: none"> • Final lesson plans and student assessment (function H) <p>Instructing second part of the unit in teachers' own school situations (function F)</p> <p>Meeting 7. Evaluation and reflection</p> <ul style="list-style-type: none"> • Expressing experiences, emotions, and feelings while instructing the unit (function I) • Sharing and discussing the intended student activities and student outcomes of the unit, the problems experienced during instruction, teachers' development, etc. (functions G, I) <p>Meeting 8. Reflection and incorporation</p> <ul style="list-style-type: none"> • Reflecting on teaching the unit and participating in the program, as well as incorporating the expanded experiences and expertise by adapting strategies for teaching the unit again in the future (functions F, G, H, I)