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Article

Fostering Teachers' Learning through Materials Featuring Research on Early Cancer Diagnosis as a Context

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ABSTRACT: Development of teacher pedagogical content knowledge (PCK) is a crucial aspect of teacher learning that can be supported by high-quality materials. In this study, 16 chemistry teachers in The Netherlands used teaching and learning materials situated in the context of research on tumor detection. Teachers' encounters with these learning materials and the development of teacher PCK were investigated using teacher logbooks, card-sorting activities, content representation (CoRe) tasks, and semistructured teacher interviews. Analysis of the results showed that most teachers used strategies that were new to them and made few adaptations to the teaching sequence and activities proposed in the teacher guide. Moreover, growth in teacher PCK for chemical bonding was observed, primarily related to instructional strategies and representations, and to a lesser extent related to three other PCK components (knowledge of curriculum, student understanding, and assessment). The data suggest that the materials facilitate teacher learning by enabling positive classroom experiences and by supporting teachers to expand their instructional repertoire for the topic of chemical bonding, in particular hydrogen bonding.

KEYWORDS: *high school chemistry, inquiry-based learning, molecular recognition, authentic contexts*

INTRODUCTION

Professional development is important for teachers, and is crucial for improving student motivation and understanding.[1] Models and criteria for the professional development of (science) teachers have been thoroughly investigated.[2−5] Professional development can be offered in many ways,[6] for instance, through attending workshops or conferences, and (video) coaching. A common and scalable approach to facilitating teacher professional development is through educative learning materials.[7] Educative materials have long been defined as those that are designed to promote teacher learning in addition to student learning.[8,9] Such materials contain features that meet many of the criteria for robust professional development:[4] they center on classroom teaching, provide preferred instructional strategies, can be aligned with reforms in education, and can be used to help teachers develop their pedagogical content knowledge (PCK). Examples of features in educative learning materials that promote teacher learning are information on the underlying rationale, guidance on student alternative conceptions, and suggestions for (new) instructional strategies. This can be helpful for most areas of teaching and learning, especially those that are challenging for teachers, such as an out-of-field topic area (e.g., socioscientific issues[10]). One challenge frequently experienced by secondary-level science teachers relates to anchoring student learning experiences in engaging contexts.[11] Building on previous work,[11,12] this study uses cutting-edge chemistry research as an engaging context for students and their teachers. Specifically, this study investigates how educative materials set in the context of university research on early cancer diagnosis can enhance teachers' PCK about chemical bonding, especially hydrogen bonding. As described subsequently, teacher logbooks, card-sorting activities, content representation tasks and semistructured teacher interviews were used to investigate how 16 chemistry teachers in The Netherlands used educative materials to help them situate learning in the context of research on tumor detection over the course of three to six lessons (240−300 min).

THEORETICAL FRAMEWORK

PCK

Pedagogical content knowledge (PCK) can be considered to be the integration of pedagogical knowledge and content knowledge needed to teach a specific topic, and was first described by Shulman.[13,14] Many researchers have investigated PCK and developed models to illustrate the relevance of PCK

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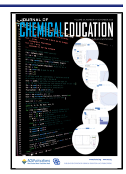

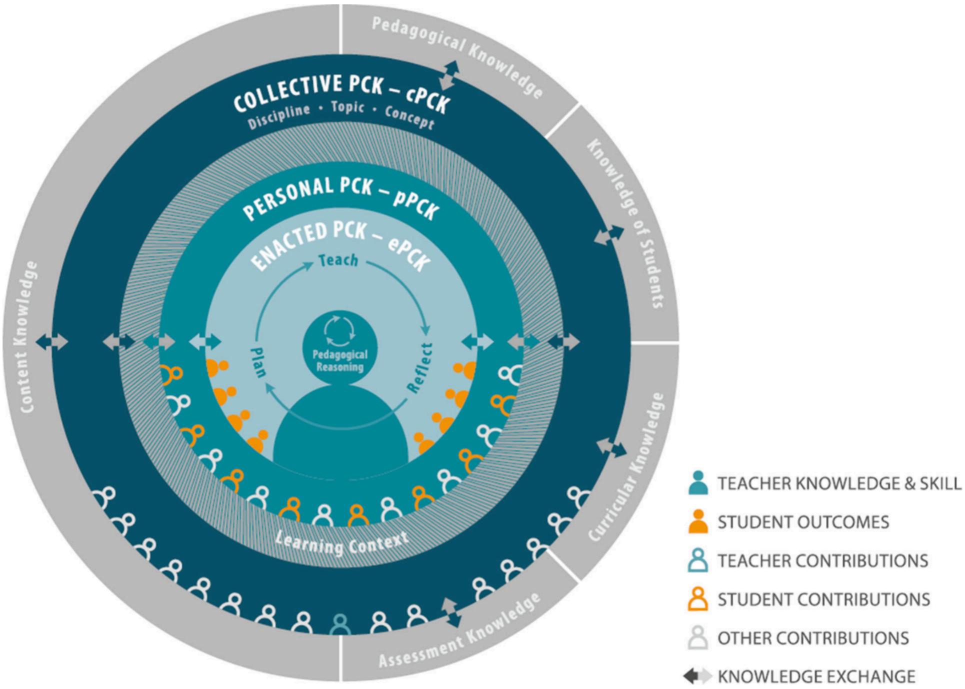

Figure 1. Refined consensus model of PCK as presented by Carlson et al.[19] Reproduced with permission from ref 19. Copyright 2019 Springer.

to specific topic areas.[15−18] The refined consensus model of PCK[19] builds on this work, and is shown in Figure 1. This model distinguishes three layers of PCK: that which is broadly shared - *collective PCK* (cPCK); individual - *personal PCK* (pPCK); and present in action - *enacted PCK* (ePCK). As this paper focuses on pPCK and ePCK the following section further elaborates on each of these layers before describing the components of PCK.

PCK Layers. The specific knowledge used by a teacher in a particular context working with a distinct group of students represents ePCK. This is used in preparation, execution and evaluation of the lesson.[20] Teachers adapt their teaching to a particular group of students they are teaching (e.g., grade 10 or grade 12) in a specific situation. Therefore, the activities a teacher uses in class are based on teacher professional knowledge (e.g., content knowledge on a specific concept) and previous experiences (e.g., successful strategies). The PCK repertoire an individual teacher draws on the knowledge and skills they use determines how they teach, and is referred to as pPCK.[20] This is the knowledge a teacher possesses based on their experience (which strategies work for developing students' conceptual understanding) and their professional development (e.g., scientific literature, in-service professional learning, teacher development teams). As can be seen in Figure 1, there is a bidirectional knowledge exchange between ePCK and pPCK: On the one hand, ePCK is the part of pPCK that is used in a specific situation; on the other hand, ePCK can enrich or enlarge pPCK.[19,20] While previous research has shown that usable and educative features of curriculum materials are potential resources for teacher professional development,[7,21] further study is needed to understand whether and how such features contribute to teacher pPCK and ePCK in general, and specifically in relation to engaging context-based learning.

PCK Components. Four PCK components have been described within each of the aforementioned layers to the refined consensus model,[22] as well as elsewhere.[e.g.16,17,18] One component of PCK is knowledge of the curriculum. This is important because teachers need to know the formal (e.g., national) curriculum and how it is structured (for instance, to have the necessary prior knowledge), as well as the learning goals for a topic and what resources are available.[16] For example, in the teacher guide important aspects of an assignment on hydrogen bonding were illustrated, so teachers can acquire the proper subject matter knowledge, and can understand the purpose of the assignment. Another component is teacher knowledge of student understanding. This includes knowledge about alternative conceptions students may have and possible sources thereof, as well as knowledge of what concepts students perceive as difficult. An example of this is the addition of a scheme showing difficulties and possible sources of alternative conceptions when learning about bond types[23] in the teacher guide. After reading this, teachers can avoid using language that contributes to the formation of alternative conceptions, like anthropomorphic language. A third component of PCK is knowledge of instructional strategies and representations when teaching a certain topic. Teachers especially need to know when to use a specific strategy or representation, and the strengths and weaknesses of various options.[23] For instance, the objective of creating a concept map and the necessary teacher actions were described in the teacher guide. This is important, because teachers then know what the use of concept maps is, and how they can help students when creating them. The fourth component of PCK pertains to content-specific knowledge of assessment. This includes understanding both formal and informal assessment strategies that are appropriate for the topic. In this case, the learning materials contained assignments in which students have to estimate their mastery of the learning goals, and the teacher guide suggested teachers to discuss this. By doing so, teachers can see that discussion of the mastery of learning goals can be an useful way for students to learn. Although existing scholarship suggests that usable and educative features of instructional materials can support

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Table 1. Pre- and Post-CoRe Completed by Raph (Translated from Dutch)[a]

Prompts	Big idea: "Molecular compounds are soluble in water when molecules of this compound can form hydrogen bonds with water molecules."
1. Learning goals: What do you intend the students to learn about this concept? What are the learning goals?	*What are molecular compounds? What are hydrogen bonds and which functional groups are involved?* *Micromacro solubility*
2. Importance: Why is it important for students to know (or be able to do) this?	*Hydrogen bonds play a major role in biomolecules, also in new materials (self-healing polymers).* *Apply concepts in other contexts.*

3. Curriculum later: What else do you know about this idea (that learners do not yet know)?	• *Biomolecules + enzymes*
	• *Distinguish from other bond types*
	  • *Boiling point*
	  • *Reaction mechanism (stabilization of nucleophiles)*

4. Difficulties: What challenges or limitations do you run across when teaching this concept?	• *Students involve all hydrogen atoms in a molecule in hydrogen bonds.* • *Polar bonds, δ+ δ- is experienced as difficult by students* • *Difference between dipole−dipole interactions and hydrogen bonding* • That other N- and O atoms can also be involved in hydrogen bonding
5. Learner thinking: What knowledge about student thinking (including alternative conceptions) influences your teaching of this concept?	*The things mentioned for number 4* *How many hydrogen bonds can be formed around one atom?* ↑this question was not asked by students while working with these materials!
6. Other factors: What other factors influence your teaching of this idea?	*I would like to visualize it so you can eliminate misconceptions faster.* Be more precise with the definitions I use (for instance, van der Waals bond/interaction instead of "molecule bond"[b])
7. Teaching procedure: Which materials do you use? How do you design your lesson (prior knowledge, content and activities)?	• *Textbook, including assignments* • *Exercises from a Web site* • *Direct instruction* • *Many questions back and forth* • *Much time to practice in class* • Figure from a scientific article with question
8. Formative assessment: How do you ascertain learner understanding (e.g., diagnostic assessment, dialogue, etc.)?	• *Discuss assignment in class and individually* • *An assignment in which student have to draw* • *Have students repeat or summarize in their own words* • *Formative test* • Have students present to each other

[a]Legend: Italicized black text = Raph's pre-CoRe; plain black text = Raph's post CoRe (added); the underlined text was present in the pre-CoRe, but was underlined by Raph in the post-CoRe [b]This is the literal translation of the Dutch word "molecuulbinding." This term is used in some Dutch chemistry textbooks, and is another word for Vanderwaals interaction.

teacher learning,[7,21] greater insight is needed to understand whether and how such features contribute to the development of specific PCK components, especially when using authentic contexts.

Encounters with (Context-Based) Teaching and Learning

Anchoring Student Learning in Engaging Contexts. Previous research has shown that students can be highly motivated when learning is situated in engaging contexts.[24−26] To situate learning in motivating contexts, it is important that context-based learning materials include problem-based and student-centered activities. Contexts need to relate to a valuable community of practice for students, use subject-specific language, and connect with students' prior knowledge.[11,27] An example of an engaging context that meets these criteria is cutting-edge-research contexts,[28] which can be especially motivating for students in preuniversity education.[11,12]

Usable and Educative Materials. When teachers work with context-based materials, it is important that these materials are both usable[29] and educative[7] in light of any boundary conditions that are present (e.g., state curricula or syllabi for chemistry). Usable materials are complete (e.g., provide a clearly understandable teacher guide) and congruent with teaching practice (e.g., align with formal requirements). Robust materials also contain research-based pedagogical approaches. Furthermore, the context in which the teaching and learning is situated needs to have distinct added value. Various features can help make materials educative for teachers. The underlying rationale must be clear, especially when the learning materials are new to teachers.[30] Educative materials present opportunities to learn, for example, about using new learning strategies or assignments, to help teachers expand their instructional toolbox. When carefully designed and explicitly attuned to relevant areas, teaching and learning materials can support teacher development of PCK.[31]

Focus of This Study

The engaging context used in this study was a cutting-edge research project on tumor DNA detection being conducted by the Molecular Nanofabrication lab at the University of Twente.[32] Teaching and learning materials entitled "Early Cancer Diagnosis" rooted in this context were created to guide lessons on the topic of chemical bonding. The approach taken

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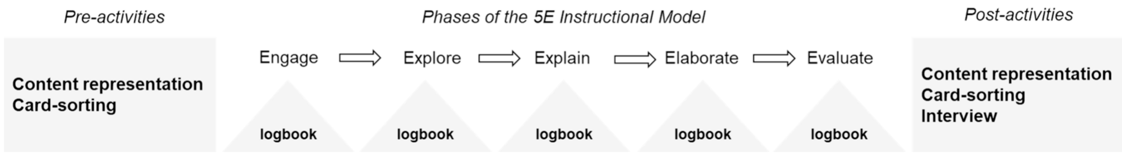

Figure 2. Overview of the data collection procedure.

in the materials was based on the 5E model for science learning:[33] Engage, Explore, Explain, Elaborate and Evaluate. As only one of the participating teachers knew this specific model prior to taking part in this study, we can say that the model itself is not widely known among Dutch chemistry teachers. However, what it stands for matches what many participating teachers consider important.

Students were working in groups on assignments, as if they were researchers. By completing assignments, preparing and executing an experiment, and presenting their findings, they learned why knowledge on chemical bonding is important for current research on detecting tumor DNA. In addition to learner worksheets, there was a teacher guide that included content support features (e.g., background information on a complicated detection method), as well as usability-related and educative features designed to support the aspects of PCK described in the theoretical framework. An overview of how the usability-related and educative features were designed to foster the development of teachers' PCK components is provided in the Supporting Information. It is important to note that Dutch law only prescribes what to teach and not how to teach; therefore no educative features relating to curriculum were provided. The (Dutch language) learning materials and teacher guide are available upon request.

The aim of this study was to investigate whether and how usable and educative features of materials rooted in the cutting-edge research context of early cancer diagnosis contribute to the development of teacher pPCK and ePCK. Therefore, we formulated the following research question: In what ways do teachers' encounters with context-based learning materials that contain usability-related and educative features contribute to the development of their ePCK and pPCK?

■ METHODS

A mixed-methods design[34] was used to investigate how usability-related and educative features contributed to the development of teacher pPCK and ePCK. The data from three sources (card-sorting activities, content representation (CoRe) tasks, and teacher logbooks) were quantified, and data from the teacher interviews after working with the learning materials, were analyzed qualitatively.

Participants

This study was carried out with 16 upper secondary preuniversity level chemistry teachers at 12 different schools in The Netherlands. The participants consisted of 11 men and 5 women, whose teaching experience ranged from 0.5 to 25 years. Most participants responded to an open request from the first author to use the learning materials, while five teachers were encouraged by a colleague to participate. The learning materials were used by 11 teachers to introduce chemical bonding in grade 10, and by 5 teachers to practice for the final chemistry exams in grade 12. Salient characteristics of the participating teachers can be found in the Supporting Information. Fifteen teachers used the context-based learning materials for three to six lessons (240−300 min). Two teachers shared the same class, and one teacher was unable to complete the materials due to the COVID-19 pandemic.

Procedure and Data Sources

Teachers used a teacher guide and learner support materials including usability-related and educative features that were rooted in the context of early cancer diagnosis and focused on chemical bonding concepts. Before and after using the materials, teachers participated in two activities: a card-sorting activity, inspired by Friedrichsen and Dana[35] and Louws et al.,[36] and a CoRe task, based on a design described by Loughran et al.[37] A sample of a pre- and post-CoRe is presented in Table 1. In addition, teachers completed a logbook after finishing each of the 5E phases. The logbook contained four questions each time, and was completed through a smart phone app. To mitigate partial or missing data, three items were multiple-choice questions about (1) which strategies were new to them, (2) the extent to which the materials were used as described, and (3) which aspects (if any) were adjusted. The fourth item was an open-ended question in which they could give comments and specific details about the implementation. Finally, after using the materials, teachers were interviewed in a semistructured way by the first author. During the interview teachers were invited to think aloud during the card-sorting activities and the CoRe tasks and were also asked to describe their encounters with the materials, and the audio was recorded.

Figure 2 provides an overview of the timing of the data collection through teacher pre- and postactivities, and teacher logbooks, in relation to the five phases enacted in the learning materials. The data collection procedure is detailed in the Supporting Information.

Data Analysis

Three data sources provided both quantitative and qualitative data. For the logbook, multiple-choice responses were tallied per question, per 5E phase, and per teacher. Open-ended responses were summarized. For the card-sorting activity, card positions (describes me, does not describe me) were tallied, as well as the number of changes participants reported pre- to postdelivery. For the CoRe, postactivity changes in relation to each PCK component were specified, and tallied per teacher. Audio recordings of the pre- and postactivities were manually transcribed.

Qualitative analysis was undertaken on the interview data. First, the teachers' responses in the postinterview about their teaching experiences were deductively coded. In addition to one wildcard code ("other"), the coding scheme had three families of codes, as described in the theoretical framework: PCK layers (codes: pPCK or ePCK); PCK components (codes: knowledge of the curriculum, knowledge of student understanding, knowledge of instructional strategies and representations, or knowledge of assessment); and encounters with (context-based) teaching and learning (codes: anchoring student learning in engaging contexts or usable and educative

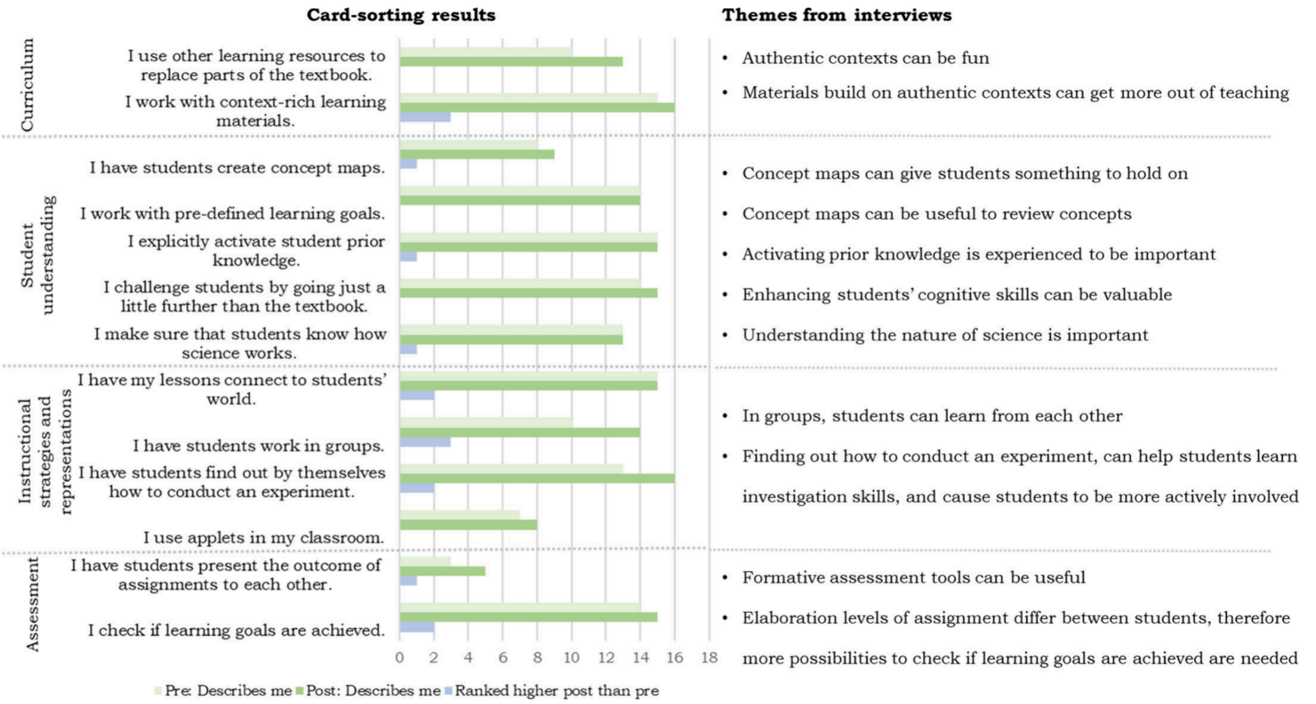

Figure 3. Summary of results per ePCK component.

materials). Next, the interview data were used to interpret the results from the teacher logbooks and post-CoRes. Namely, segments were identified in which teachers described their postimplementation choices in the card-sorting activity and the CoRe task. These fragments were discussed with the second author, and where needed, reorganized per PCK component. For instance, Raph's addition (Table 1) to the CoRe "Be more precise with the definitions I use ···" ostensibly fits with knowledge of instructional strategies. However, when it became clear from the interview that his motivation for this was to mitigate the formation of alternative conceptions, it was then coded as knowledge of student understanding. Quotes from the interviews (given in the next section) have been translated from Dutch.

■ RESULTS

In this section, first the development of the teachers' ePCK per PCK component is described. After that, the development of teachers' pPCK is reported, and finally the teachers' encounter with context-based teaching and learning is specified.

Development of ePCK

Knowledge of Curriculum. As can be seen in Figure 3, the teachers made a total of seven changes altogether in their card sorting after working with the learning materials. Specifically, Ted moved both curriculum-related cards from "does not describe me" to "describes me". He said that he wanted to move the cards because he has now seen that it is fun, and that he can get more out of teaching when using authentic contexts. In the postinterview, Raph said: "I would like to try to replace parts of the textbook with other learning resources" and moved the corresponding card to describes me. Sean also moved the card "I use other learning resources to replace parts of the textbook" in the same way, but did not explain in the interview why he did so. Nick, Oscar, and Pete all said in the postinterview that they would like to use context-rich learning materials more often; they ranked the corresponding card higher (blue bar in Figure 3).

Knowledge of Student Understanding. As shown in Figure 3, the teachers moved only five cards related to student understanding. In the postinterview, both Ian and Raph said that they would like to use concept maps more often, and moved the card "I have students create concept maps" accordingly. Raph indicated that he saw that "it gave the students something to hold on to" whereas Ian started to use concept maps in grade 12 to review concepts from grade 11. Nearly all teachers placed the other cards related to student understanding on "describes me" before working with the learning materials. After working with the learning materials, only a few changes were made in the position of these cards. Pete indicated that for him activating prior knowledge had become more important. Furthermore, in the postinterview, Lily explained that she should challenge students more to come out of their comfort zone, and therefore moved that card to "describes me". In addition, she experienced friction between "learning for the test" and "learning to understand chemistry." She aims to teach students differently, enhance their cognitive skills, and to teach less traditionally. Finally, Gerard found it interesting and important for students to understand the nature of science, which is part of the Dutch chemistry curriculum, but thought that students focused too much on learning concepts. In the future, he wanted students to learn more about the way science works.

Knowledge of Instructional Strategies and Representations. Figure 3 shows that teachers made the most changes (15) in the sorting of the cards related to this component. In particular, seven teachers moved the card about students working in groups. Ian, Lily, Vicky, and Yves moved this card to "describes me". For instance, Yves said: "I want students to work more in groups; I noticed that there are many advantages in students learning from each other." Despite moving the card to "describes me", Vicky mentioned she

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Table 2. Summary of Results per pPCK Component

	CoRe results		Themes from interviews
	Total number of changes	Teachers who made changes	
Curriculum	6	Fay, Ian, Lily, Oscar, Raph, Ted	• Teachers experienced friction between learning for the test and learning chemistry • Students need to learn more in authentic contexts and see the application of concepts
Student understanding	6	Gerard, Nick, Pete, Raph, Sean, Wendy	• Teachers learned alternative conceptions that were new to them • It is important to consider the cognitive load of a context
Instructional strategies and representations	15	Gerard[a], Lily, Nick[b], Pete[b], Raph[a], Sean, Ted, Wendy[a]	• It is important to start with engaging students to motivate students by connecting with students' or teacher's own experiences • It is crucial to use precise language and definitions • It is important to switch between micro- and macro-levels • Have students do more practicals
Assessment	7	Fay, Gerard, Oscar[a], Pete, Raph, Wendy	• Use a pre- and post-test to assess student understanding formatively • Have students present to each other in small groups • Use a table with predefined learning goals

[a]This teacher made two changes in the CoRe for this component. [b]This teacher made three changes in the CoRe for this component.

would not have students work in groups if time was limited. In the interview, Karen, Pete, and Ted indicated that they saw that their students worked together on the assignments, and helped each other. Therefore, they ranked the card about group work higher (blue bar in Figure 3). Regarding students finding out for themselves how to conduct an experiment, Karen, Lily, and Oscar moved this card to "describes me". Karen and Oscar said that they saw that their students could find out how to conduct an experiment, and thus they wanted to do this more often in the future. Raph and David ranked this card higher (blue bar in Figure 3), because they saw the possibilities for teaching students investigation skills in this specific project. Raph also mentioned that he observed that his students were much more actively involved, compared to experiments in regular practice. Oscar and Ted indicated that they want to connect more to the students' world, and moved the corresponding card accordingly. Regarding applets in the classroom, Lily moved the corresponding card to "describes me" and said that they would be fun to use more.

Knowledge of Assessment. As can be seen in Figure 3, students' short presentation in front of the class of the outcome of assignments did not suit most teachers (13). After working with the learning materials, three teachers (Fay, Lily, and Raph) moved the corresponding card. Fay and Lily did not mention this in the postinterview, but Raph said he would have students present the outcomes of experiments or assignments more often. Concerning the card "I check if learning goals are achieved," Pete moved this to "describes me". In the interview, he said that he started using more formative assessment tools. David and Vicky also ranked this card higher (blue bar in Figure 3). David said that he wanted to look for possibilities to check if learning goals are achieved, because he saw a difference between the level of elaboration of student answers during class, and during the summative test.

Development of pPCK

The number of changes to the teachers' CoRes was relatively low. Table 2 identifies the teachers who made changes related to each PCK component. The majority of the teachers (11) made 0, 1, or 2 changes in their CoRe, while five teachers made 4 or 5 changes. Details about each column of Table 2 are presented next.

Knowledge of Curriculum. Six teachers made changes related to curriculum in their post-CoRes. Ian, Lily, and Oscar mentioned the friction between learning to understand chemistry and learning for the test. As Lily put it: "··· the friction between the test and being able to learn chemistry, that has become very clear to me, that I want them to learn chemistry, and not for the test. (...) Hence, I would like to change that." Fay and Ted added that they would like their students to learn more in authentic contexts and see the application of concepts. Ted said: "Also the application, so actually it gives a somewhat broader goal (...) it's something that is used, and that's where I come across it." In addition, Raph clearly emphasized the application of concepts in other topics.

Knowledge of Student Understanding. Six teachers each added one item related to student understanding to their CoRe. Nick, Pete, Raph, and Sean made additions related to alternative conceptions of hydrogen bonding (e.g., which hydrogens can be involved in hydrogen bonding). As Raph mentioned: "Students also found it difficult that not only OH- or NH_2-groups were involved, but that a hydrogen bond could also be formed with an ordinary O-atom in a molecule." An item on the relevance of knowing that students consider Lewis structures as being difficult was added by Wendy, while Gerard added that the cognitive load of a context is important.

Knowledge of Instructional Strategies and Representations. Regarding this PCK component, 15 items were added to the CoRe by eight teachers. First, five teachers (Lily, Nick, Pete, Raph, and Sean) added an item that related to student motivation, for instance, to start engaging students by using the first phase of the 5E model more often, or by connecting with the students' or the teachers' own experience. Pete indicated: "My own experiences. That I started to involve those more, from my life experiences. To make it less abstract for them to understand it a little bit better." Related to this were the additions of Raph and Sean, who said they would both like to use more cutting-edge research contexts in their classroom in the future. Second, Pete, Raph, Ted, and Wendy mentioned the importance of using precise language and definitions. Raph commented about this: "For example, van der Waals. I have now also increasingly used the word "interaction" instead of "bonding" for this. To express more that it is dynamic, not fixed." Third, two teachers added the

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importance of switching between the micro- and macro-levels[38] to their CoRe. Gerard explained that this way of thinking is also important in other science subjects, whereas Nick said that learning about chemical bonding helps students learn to switch between the micro- and macro-levels. Fourth, Pete and Nick also added that they would like to have students do more practicals, for instance, by using a predict-observe-explain structure. Gerard added to his CoRe that teachers need to take into account that not all students have the proper skills to work in groups. Finally, Wendy added to her CoRe that she would like to have her students use applets more often.

Knowledge of Assessment. Teachers made seven additions related to knowledge of assessment to their CoRes. Fay, Gerard, Oscar, and Pete added a formal assessment tool to their CoRe. For instance, Fay wanted to use a pre- and post-test to assess student understanding formatively, and Pete would like to use exit tickets more often. Oscar, Raph, and Wendy added more informal assessment activities. Oscar added the use of a table in which students can assess their understanding of predefined learning goals. Raph added that he would like to have his students present to each other in small groups more often. He said:

> *I would also have more students present to each other. About results and outcomes of assignments. Then, as a teacher, you also get an idea of how things are going. (...) you walk among the groups and listen to what they are saying.*

Wendy added to her CoRe that she would like to look more actively for the extent to which students understand the learning goals: Listen to the conversation in the groups, and answer student questions with questions. In the postinterview, she explained that this was induced by the presentation of the learning goals after each 5E phase.

Encounters with (Context-Based) Teaching and Learning

Data from the teacher logbooks and postinterviews offered insight into the teachers' encounters with the learning materials. In terms of usability, the teachers experienced the learning materials to be complete; most teachers explicitly valued the presence of a clearly understandable teacher guide. For instance, Fay said: "... because the teacher guide was also helpful in indicating the specific minutes where you could stop the video." They also appreciated the 5E structure of the learning materials and the presence of a clear teaching plan. As Lily said: "I really liked this way of working, the students could easily work with it." All teachers indicated in the teacher logbook that their students completed the Engage, Explore, and Evaluate phases of the learning materials within the scheduled time. However, about half of the teachers used more time than suggested in the teacher guide to complete the Explain and/or Elaborate phase. One teacher (Vicky) mentioned that she did not read the teacher guide due to its length. Furthermore, several teachers welcomed the suggestions for adaptations. For example, Raph said: "... also that options were provided: you can do it this way, or try it that way. Depending on how much time you have, or what you like."

Regarding the added value of the context, teachers perceived the context as interesting, increasing student engagement, and doing something different from their regular practice. Ted said:

> *They found it particularly interesting because it was something different from the textbook, and indeed with really good practical examples, with things from practice actually being used. That was the added value. And I also liked it for myself; something different from the standard books, of course.*

Gerard mentioned that the multidisciplinarity of the context (the involvement of a professor, a researcher, and a general practitioner) provided added value. As for congruence with their teaching practice, in the postinterviews all teachers confirmed that the learning materials provided enough possibilities to let them use the materials to suit their teaching practices. Seven teachers (David, Fay, Lily, Oscar, Raph, Sean, and Wendy) used the learning materials as described in the teacher guide. Wendy said: "I mostly did as nearly as possible what was in the teacher guide. (...) I didn't change everything in advance." Six teachers (Karen, Gerard, Ian, Pete, Ted, and Yves) made small adjustments (e.g., skipped only the short student presentations in front of the class). Three teachers (Nick, Udo and Vicky) made larger adjustments (e.g., students did not design an experiment).

From an educative standpoint, the teacher guide must provide support for teachers to understand the underlying rationale of the learning materials. It seemed that most teachers understood the rationale, since they made no or small changes. Gerard said about the changes he made, "... I could shape it myself. I kept the teacher guide in consideration; I made a few changes, but that was fine." However, some teachers seemed not to fully understand the rationale of the learning materials. For example, although the concept-map activity was included to activate prior knowledge and to connect it with concepts from the introductory video, Udo and Vicky skipped this activity. Udo said about this, ".... if you're already not convinced about it [creating concept maps] yourself, you're not going to recommend it to students either." Furthermore, although designing an experiment was considered crucial to promote student thinking, Nick and Udo's students did not have to do this activity. As Nick explained: "Students had to think about how to carry out the experiment, I changed that to an exactly prescribed experiment."

With regard to opportunities to learn, most teachers indicated that they used strategies that they had not used before (Supporting Information). The strategies that were new to many teachers were: using an extended glossary (9/14), showing an engaging introductory video (8/14), DNA as a context to learn hydrogen bonding, and letting students indicate their mastery of the learning goals (7/14). Yves said about the extended glossary: "... normally I would use the book, so normally I say, take a look in your book for a moment. (...) And that's nice that you have an extended glossary where all information is gathered, and not just what you need, you also have to read and search a bit, and that's nice."

The teachers for whom the most strategies were new were Ian (10/13), Pete (9/13), Oscar (8/13), and Yves (8/13). On the other hand, David, Fay, Gerard, Nick, and Wendy rarely used strategies incorporated in the learning materials that were new to them.

■ DISCUSSION

According to the refined consensus model, ePCK is part of the pPCK used in a specific setting,[19] so that changes in ePCK should have been preceded by changes in pPCK. However, the findings of our study show limited evidence of this, because only a few teachers made changes to their CoRe and card-sorting choices that could be attributed to the same PCK component. While most teachers used the learning materials as intended, one (Udo) had a very different stance. He was keen on using the learning materials and expressed general contentment with them, but his teaching approach did not match the rationale. He did not use the teacher guide, and thus the usability-related and educative features, and did not show any changes in ePCK and pPCK. Hence, for some teachers other ways of professional development are necessary to use context-based approaches. The findings also extend existing research[39] by showing that usability-related and educative features in context-based learning materials can lead to ePCK and pPCK development. Furthermore, this study's findings confirm the importance of using relevant contexts for both teachers and students, as others have found.[26,28,40] They are in line with prior research indicating that teachers are more likely to use context-based learning materials after having positive experience with them.[41] More research is needed to find out whether the teachers in this study continued to seek out and use context-based materials in their practice.

■ CONCLUSION

This study set out to answer the research question "In what ways do teachers' encounters with context-based learning materials that contain usability-related and educative features contribute to the development of their ePCK and pPCK?" To answer this question, 16 teachers used newly developed context-based learning materials that contained usability-related and educative features and shared their perceptions before, during, and after implementation through CoRe tasks, card-sorting activities, logbooks, and semistructured interviews.

Changes in teachers' ePCK were investigated through the pre- and post-card-sorting activity as well as the interviews. All except for two teachers showed a change in their ePCK. Most changes were related to group work, practicals, and the use of contexts. Seven teachers changed their ePCK on group work. Namely, they all would like to have their students work in groups more often, because they experienced the possibilities and advantages of students working in groups. The encounter with an assignment in which students had to find out themselves how to perform an experiment led five teachers to recognize the value of such an approach and subsequently commit to implementing it more frequently. After working with these learning materials, five teachers also indicated that they would like to use context-based materials more often. Thus, we conclude that the materials supported teachers' ePCK by facilitating classroom experiences that the teachers perceived as positive. In addition, teachers saw motivated students working together, which appears to have reinforced their (teacher) learning with regard to using contexts.

Changes in teachers' pPCK were investigated using pre- and post-CoRes together with the semistructured interviews. Eleven teachers showed changes in their pPCK. Most changes concerned alternative conceptions, the use of specific language, stimulation of student interest by connecting with their experiences, and formative assessment. Four teachers added relevant aspects that related to alternative conceptions to their pPCK. Four teachers also added the importance of precise language and definitions. Furthermore, strategies to engage students became more important, as five teachers added this to their pPCK. Lastly, four teachers added the use of formal assessment tools to their CoRe, for instance, to check prior knowledge or student learning. Thus, we conclude that the materials contributed directly to teachers' pPCK by expanding their repertoire and indirectly by providing positive experiences that refined and reinforced the recently expanded repertoire.

Concerning the teachers' encounter with the materials, results from the teacher logbooks showed that most teachers used the learning materials as suggested in the teacher guide and that hardly any adaptations were made. This suggests that the materials were perceived as usable by most teachers, a finding that was confirmed by the postinterview data. Similarly, all but one teacher reported that they implemented new strategies as a result of using the materials, and more than half of the participants reported using four or more new strategies because of the materials. This suggests that the materials provided opportunities to learn, and were thus educative. Here, too, the finding was corroborated by the interviews. We therefore conclude that the materials not only included usability-related and educative features, but were also experienced as usable and educative by the participants.

Significance

The findings from this study are relevant for curriculum designers, because they demonstrate that incorporating usability-related and educative features in learning materials (Supporting Information) can contribute to teacher PCK development. These features encompass clear explanations of challenging concepts, guidance on student alternative conceptions, suggestions for instructional strategies, and alignment with learning goals. By integrating these features, curriculum designers can support teachers in enhancing their PCK and facilitating student understanding. The methods and findings are also useful for researchers. The combination of a card-sorting activity, a CoRe task, and a semistructured interview provides rich and useful data on teacher PCK. Therefore, these methods of data collection can be a valuable tool to investigate teacher PCK development. Finally, the use of context-based learning materials with usable and educative features encourages teachers to use specific strategies (e.g., working in groups, and practicals). However, to foster the development of teacher PCK, it is vital to use the materials in ways that align with the underlying rationale of the curriculum materials.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01084.

Characteristics of the participating teachers, detailed research procedure, PCK components in relation to features of the learning materials, cards of the card-sorting activity structured per PCK component, new strategies for the teachers according to their teacher logbooks (PDF, DOCX)

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Notes

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