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studying teachers' pedagogical ideas in the context of a professional learning community

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Bringing design practices to chemistry classrooms: studying teachers' pedagogical ideas in the context of a professional learning community

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ABSTRACT

Bringing design practices to chemistry education is gaining interest with recent science curriculum reforms emphasising design, and calls for integrated STEM education. Design is a central practice in the chemistry discipline, and could foster meaningful chemistry education. Although chemistry teachers are key in bringing design to chemistry classrooms, and in realising design's potential for learning, little is known about their views on teaching and learning regarding design. To reduce this gap in literature, we explored chemistry teachers' pedagogical ideas in the context of a Dutch professional learning community on design in chemistry education. We elicited teachers' ideas through semi-structured interviews and lesson forms which teachers kept while implementing a design project. Multiple patterns emerged through analysing teachers' ideas. We found that the teachers did not see teaching design as a goal of chemistry education. Instead, teachers valued design as a teaching approach to engage students in applying chemistry concepts, in developing soft skills, and in applying or developing research practices. In this paper, we present more patterns in teachers' ideas, and discuss possible explanations of these findings in depth. Finally, we give suggestions for future research, and teacher professional development that may help support a change to bring design into chemistry education.

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Design; chemistry education; teacher views; professional learning community; qualitative research

Introduction

Engaging secondary school science students in design practices is gaining importance around the world with recent reforms of science curricula (e.g. NGSS Lead States [NGSS], 2013; Board of Tests and Examinations [CvTE], 2013), and calls for integrated STEM education (e.g. Education Council, 2015; Fan & Yu, 2017). But, despite design being a central practice in the chemistry discipline, it has received little attention in chemistry education (Talanquer, 2013). Design does, however, offer a much-needed approach

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for meaningful chemistry education (Sevian & Talanquer, 2014; Van Aalsvoort, 2000). In traditional chemistry classrooms, chemistry is often taught as aggregations of isolated facts, and students can experience chemistry to lack relevance (Gilbert, 2006). Even in some context-based chemistry classrooms, teaching content can draw focus from actively engaging students in authentic chemistry ways of thinking and doing (Sevian & Talanquer, 2014). But, engaging students in chemistry talk and tasks helps them understand the meaning of what they are learning (Gilbert, 2006). And, engagement in and learning of both chemistry practices and content are important in preparing students for making chemistry-related decisions as scientifically literate citizens, and for potentially continuing a career in chemistry (Sevian & Talanquer, 2014). Situating learning chemistry in an authentic practice, like design, meaningfully connects chemistry content and practices around a shared practical purpose (Bulte et al., 2005). Researchers have found that design in chemistry education can, for example, promote students' understanding of fundamental ideas in chemistry (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Meijer, Bulte, & Pilot, 2009), and students' real-world problem-solving skills (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005).

Teachers, however, play an essential role in realising the potential of design-based teaching (Kolodner et al., 2003; Schnittka & Bell, 2011). But, although teachers' ideas about teaching and learning are known to influence the implementation of educational reforms (Jones & Carter, 2007; Van Driel, Beijaard, & Verloop, 2001), little is known about chemistry teachers' views on integrating design practices in their school subject. Many studies on design-based science teaching, and teachers in such settings, can be found to zoom in on design in physics contexts (e.g. Dare, Ellis, & Roehrig, 2014; Kolodner et al., 2003). Also, curricula (e.g. CvTE, 2013; NGSS, 2013) and research studies (e.g. Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Guzey, Moore, & Harwell, 2016; Reynolds, Mehalik, Lovell, & Schunn, 2009) offer design-based learning frameworks or examples of chemistry design contexts without discussing what implementing these means for chemistry teachers teaching chemistry. But, taking general teaching and learning principles for design in science education into chemistry classrooms might cause teaching and learning problems and missed opportunities. For example, though design in chemistry has overlap with technology and engineering design (Sevian & Talanquer, 2014), design processes vary per discipline (Berland, Steingut, & Ko, 2014). And, using design activities and terms like 'constructing artefacts' (Fortus et al., 2005), 'building', and 'products' (CvTE, 2013) may increase coherence across science subjects in school, but might not match well with common chemistry design contexts like 'synthesis' (Bensaude-Vincent, 2009), and developing efficient 'processes' (Talanquer, 2013). Additionally, engaging chemistry students in a typical chemistry design setting like making new substances or materials may be challenging for teachers. When students design gluten-free bread (Meijer et al., 2009), for example, students cannot quickly change and retest their design. Design iterations are, however, important as they stimulate students to continuously refine their design, conceptual understanding and practices (Puntambekar & Kolodner, 2005). These examples suggest that chemistry teachers might have or need specific ideas about teaching and learning for bringing design into their school subject.

In this study, we will explore chemistry teachers' ideas about design in chemistry education. Our research focusses on teachers' pedagogical ideas, that is, what design in chemistry education means to them regarding learning goals, student learning, instructional strategies and assessment. Design processes in chemistry have been described as being relevant in different chemistry contexts, such as involving synthesis, analysis and transformation (Sevian & Talanquer, 2014), and chemistry products and processes (e.g. Favre, Falk, Roizard, & Schaer, 2008). Because chemistry teachers may similarly associate design in chemistry education with a variety of chemistry design contexts, we will look at design in chemistry from this broad perspective when exploring teachers' pedagogical ideas.

Our study's participants are Dutch chemistry teachers who, like teachers in several other countries, are encouraged to bring design to their classrooms because of a recent curriculum reform (CvTE, 2013). We study these teachers' pedagogical ideas in the context of a professional learning community on design in chemistry education, which we expected would help elicit teachers' (partly tacit) ideas. As actively engaging students in design does not seem to be a typical teaching approach for chemistry teachers (Boesdorfer & Staude, 2016), a better understanding of teachers' views could support a change to integrate design practices in chemistry education (Talanquer, 2013). Insight in teachers' ideas can inform future research efforts, and the development of lesson materials, teaching strategies and professional development programmes (Levitt, 2001; Van Driel et al., 2001).

Theoretical background

While research practices have held a particular prominent place in chemistry education and research, design practices have received much less attention (Talanquer, 2013). Regarding teachers' ideas in this context, an American survey study, conducted before adoption of the Next Generation Science Standards (2013), did find that chemistry teachers can have naïve conceptions about engineering design (Boesdorfer & Staude, 2016). Also, teachers are often described to have difficulties in connecting science and design to stimulate student learning (e.g. Crismond & Adams, 2012; Guzey, Harwell, Moreno, Peralta, & Moore, 2017). Reviewing examples in literature and curricula on design in chemistry and science education does reveal multiple possibilities for promoting learning chemistry through design, which we could also come across in our exploration of chemistry teachers' pedagogical ideas.

Stimulating learning of chemistry content and practices through design

Design can be implemented as a vehicle for students to *develop chemistry content knowledge* (Fortus et al., 2004). Students construct new knowledge in the context of a design problem (Fortus et al., 2005), and need this knowledge to successfully complete the challenge (Kolodner et al., 2003). When students experience a need-to-know during their design process they are introduced to new concepts, for example, through reading information, watching videos, doing computer simulations, teacher-led demonstrations, asking experts, explicit teaching or conducting experiments (Fortus et al., 2004; Puntambekar & Kolodner, 2005; Van Breukelen, De Vries, & Smeets, 2015). Fortus et al. (2004) found that students can develop understanding of electrochemistry by being embedded in the context of designing environmentally-friendly batteries. Designing a heating or cooling system relying on chemical energy can help students gain knowledge of atomic interactions, reactions and energy (Apedoe et al., 2008). Although Apedoe and her colleagues, like others (Kirschner, Sweller, & Clark, 2006), were concerned that concepts might not be learned as well or as quickly through design, their study's teachers reported they could cover other content more quickly because of students' improved understanding of fundamental ideas in chemistry.

Another option is viewing design primarily as a context for students to *apply chemistry content knowledge*. The Dutch curriculum, for example, requires students to learn to 'use relevant concepts' during a design process (CvTE, 2013). Applying concepts when solving a design problem means students can test and deepen their understanding (Berland et al., 2014; NRC, 2012). This view can take the form of teaching concepts first, and having students complete a design challenge afterwards (as in Schnittka & Bell, 2011).

Improving students' *reasoning in chemistry* is also a possible goal of design in chemistry education. Designing gluten-free bread, for example, was a practice used to develop students' reasoning regarding structure-property relationships (Meijer et al., 2009). Reasoning in design contexts also pops up in science curricula. The NGSS, for example, mention 'engaging in argument from evidence' to 'identify the best solution to a design problem' (NGSS, 2013). Reasoning can also help students learn from design experiences, and transfer their learning to other settings (Kolodner et al., 2003). To encourage students to reason when designing, and to use conceptual understanding in their reasoning, students can be asked to explain design ideas to peers, discuss test outcomes, or justify design decisions (Apedoe et al., 2008; Kolodner et al., 2003; Silk, Schunn, & Cary, 2009). Research on teaching and learning to reason in chemistry through design is still scarce though, as are studies into applying and developing chemistry content knowledge through design.

Design in chemistry education is also seen to take shape as '*designing investigations*' (e.g. Girault & d'Ham, 2014). By designing or optimising experimental procedures, students can learn to solve a scientific problem, such as determining the concentration of dye in grenadine (Girault & d'Ham, 2014). Students can also be asked to design an investigation in the context of a design project. Doing research helps students build knowledge of materials and key design variables so they can make informed design decisions (Crismond & Adams, 2012). Performing research activities in a design context can also stimulate students' learning of scientific practices and new science concepts (Kolodner et al., 2003). Especially before design was emphasised in curricula as a relevant practice in itself, design-based science efforts aimed to improve students' scientific practices and knowledge (e.g. Puntambekar & Kolodner, 2005; Silk et al., 2009). As Fortus et al. (2004): 'Our goal in these [design] units is not to instruct the students about design; we want to engage them in design in order to learn science' (p. 1085).

Currently, the importance of students *developing design practices* such as 'defining problems' and 'designing solutions' (NGSS, 2013) have been gaining attention in science education. A few specific contexts for engaging chemistry students in design (thinking) can also be found in such science curricula. In the NGSS a chemistry-specific design example reads: 'design, build and refine a device that works within given constraints to convert one form of energy into another form of energy' (NGSS, 2013). And, Dutch chemistry students are expected to learn to use their understanding of green chemistry to explain designs of industrial processes (CvTE, 2013). However, unlike for design in higher chemistry education (e.g. Favre et al., 2008; Fung & Ng, 2018), what learning or teaching ‘to design in chemistry’ could mean at the secondary school level is not well described.

In addition to the above mentioned views, design practices in chemistry education may also be found in the form of ‘designing models’ (e.g. Chang, Quintana, & Krajcik, 2010; Justi & Gilbert, 2002), and as an instructional approach to teach analysis, synthesis and transformation practices (Sevian & Talanquer, 2014). Although we do not aim to present an exhaustive overview, these examples indicate that there are multiple (often interrelated) options for stimulating student learning of chemistry content and practices through design. Each focus calls for specific ideas regarding learning goals, student learning, instructional strategies and assessment. Where the examples above primarily express the views of curriculum developers and researchers, this study explores what chemistry teachers think of design in chemistry education.

Teacher pedagogical ideas

Teachers’ ideas about teaching and learning significantly influence their implementation of innovative teaching approaches, and science education reforms (e.g. Jones & Carter, 2007; Roehrig & Kruse, 2005; Van Driel et al., 2001). Although the relation between teacher cognitions and behaviour is complex (Jones & Carter, 2007), teachers’ ideas have been found to influence their teaching of design-based science education. Researchers noticed, for example, that teachers are often unfamiliar with the importance of instructional strategies like iteration, reflection and discussion to stimulate students’ learning of science through design, and instead choose to spend too much time on construction activities (Kolodner et al., 2003). And, science teachers developing their own design projects tend to overlook activities encouraging students to communicate design and science ideas, because such activities are thought of as requiring too much class time (Guzey et al., 2016). Teachers can be stimulated to use such critical teaching strategies by developing instructional frameworks that make connections between science and design explicit for students as well as teachers (Kolodner et al., 2003). Gaining insight in chemistry teachers’ ideas about teaching and learning in the context of design in chemistry education could support developing such frameworks for chemistry education. A better understanding of chemistry teachers’ pedagogical ideas, and potential differences between teachers’ ideas, could also form a starting point for the design of professional development programmes (Van Driel et al., 2001) helping chemistry teachers to bring design practices to their classrooms.

Studying teachers’ ideas about teaching and learning, however, can be challenging. Teachers’ cognitions are often tacit in nature, and difficult to elicit (Verloop, Van Driel, & Meijer, 2001). Teachers can, for instance, lack the vocabulary to articulate their ideas, and an extended period of time may be required to capture ideas influencing teachers’ practice (Loughran, Mulhall, & Berry, 2004). To capture teachers’ ideas, researchers can use more than one elicitation instrument. Examples of such instruments are: semi-structured interviews (e.g. Henze, Van Driel, & Verloop, 2008), stimulated-recall interviews (e.g. Nilsson, 2008), teacher group discussions (e.g. Loughran et al., 2004) and teacher lesson forms (e.g. Henze & Barendsen, 2019). Teachers can also be stimulated to articulate their pedagogical ideas by basing formulations of questions and prompts on well-known pedagogical elements. Four pedagogical elements often used are: learning goals, student learning, instructional strategies and assessment. These interconnected elements also form the foundation of instructional frameworks (e.g. Dochy, Moerkerke, & Martens, 1996; Van Gelder, Peters, Oudkerk Pool, & Sixma, 1973), (chemistry) teacher education programmes (e.g. Aydin-Günbatar & Demirdöğen, 2017; Henze & Barendsen, 2019) and teacher cognition models (e.g. Magnusson, Krajcik, & Borko, 1999). In other studies into teachers' ideas in design-education contexts, using these four pedagogical elements indeed provided insight in teachers' pedagogical ideas (Rahimi, Barendsen, & Henze, 2016; Vossen, Henze, De Vries, & Van Driel, 2019).

Throughout this study, we use the term 'ideas' because, especially in our reform-based context, we expect to elicit a mix of teacher knowledge, beliefs, conceptions and intuitions (Verloop et al., 2001). We expect this study's Dutch teachers to have formed some ideas about design in chemistry education, as they have been teaching a new curriculum emphasising design for three years. However, teachers might not yet have developed a more expert type of pedagogical knowledge and beliefs.

Context of the study: a Dutch professional learning community

The new Dutch science curriculum, introduced in 2013, required all science teachers to address nine so-called 'technical design skills' (incl. 'analysing and describing a technical design problem'; 'drawing up a list of requirements'; 'making a well-argued design proposal'; 'presenting a design process and designed product'; CvTE, 2013). Dutch science students should learn to implement these skills in science contexts while using (science) concepts, and valid arguments. The chemistry-specific part of the Dutch curriculum (grades 9–11 or 12) additionally relates design to contexts like sustainability, industrial processes, materials and health (CvTE, 2013). To help chemistry teachers meet their expressed need for design-based lesson materials for chemistry education, we initiated a two-year-long professional learning community (PLC) for Dutch chemistry teachers (Borko, Jacobs, & Koellner, 2010; Voogt et al., 2015). The PLC activities would be centred around jointly developing, testing and evaluating design projects and teaching strategies for design in chemistry contexts. This PLC set-up also allowed us to research teaching and learning regarding design in chemistry education. The study reported here takes place in the beginning of this PLC as we are interested in exploring what design in chemistry education means to chemistry teachers (without an intensive professional development programme on the topic having influenced their ideas yet).

In the beginning of the PLC, the PLC's chemistry teachers all implemented a 9th grade design project ('Expedition Toothpaste') in one of their own chemistry classes. In the first PLC meeting, shortly before the teachers implemented this project, the teachers and researchers discussed the design project. Teachers were interested in trying out this design project, and improve it later as a PLC. In the project, chemistry students design a toothpaste which survivalists stuck at a deserted island can make (this setting resembles that of popular Dutch television shows). The design project was meant as an introduction for students (and teachers) to design (teaching) practices, and the toothpaste context did not necessarily require addressing chemistry concepts (based on the notion of 'launcher units'; Holbrook, Fasse, Gray, & Kolodner, 2001). Teachers could choose to make connections to curricular chemistry topics, such as structure-property relationships, and acids and bases. The projects' activities were based on the design requirements of the Dutch curriculum, and included Leaning-By-Design elements (incl. moving between design and research, and sharing and discussing ideas and outcomes throughout the project; Kolodner et al., 2003). To improve the toothpaste project in the PLC, teachers kept a record of their teaching and students' learning during project implementation.

Research design

We explored chemistry teachers' pedagogical ideas qualitatively in the context of the PLC. This qualitative design allowed us to investigate chemistry teachers' ideas in depth, and explore what teaching and learning in the context of design in chemistry education means to teachers (Babbie, 2016; Cohen, Manion, & Morrison, 2018). The research question guiding our study was: What pedagogical ideas do the Dutch PLC's chemistry teachers have about design in chemistry education?

Participants

All of the six chemistry teachers of the PLC participated in this study. The teachers had responded to an open invitation (Cohen et al., 2018) for secondary school chemistry teachers to join the PLC. Invitations had been distributed through the regional teacher professionalisation centre, and researchers' personal networks. Teachers were informed about the research aims, and gave their consent (Cohen et al., 2018). The teachers had varying chemistry and design teaching experiences (see Table 1). All teachers had a master's degree in (bio)chemistry, and were qualified for teaching upper secondary school chemistry

Table 1. Participants' reported teaching and professional design experiences.

	Teaching experience secondary school	Design teaching experience		Professional design experience
		in general STEM course	in chemistry course	
T1	Over 20 years	Includes implementing project on biomedical design (10th grade)	Includes developing and implementing project on chemical Rube Goldberg machines (9th grade), and implementing upper secondary school project on drugs	(None)
T2	About 5 years	(None)	Includes developing and implementing project on fireworks (10th grade), and project on soaps and fragrances (11th grade)	Chemical process engineering
T3	First year of teaching	(None)	Includes developing and implementing project on rocket fuels (10th grade), and implementing project on soaps and fragrances (11th grade)	Biotechnological engineering
T4	About 8 years	(None)	(None)	(None)
T5	About 2 years	(None)	(None)	(None)
T6	About 8 years	Includes implementing project on 'dropping an egg' (8th grade), and upper secondary school project on water purification systems	(None)	(None)

education. T1 also had a PhD in chemistry, and T2 and T3 had professional design experience (see Table 1). T2 and T3 were colleagues at the same school.

Data collection

We collected data on teachers' pedagogical ideas about design in chemistry education using two instruments: semi-structured interviews (Brinkmann & Kvale, 2015) and lesson forms accompanying teachers' implementation of the toothpaste design project (similar to Henze & Barendsen, 2019). To elicit what design in chemistry education means to the teachers, we based questions in the interview and forms on the four, general pedagogical elements of goals and objectives, student learning, instructional strategies and assessment. Both data collection methods were employed at the start of the two-year-long PLC (within the first few months, depending on when a teacher timed implementation of the design project), and interviews took place before teachers implemented the project. As researchers have observed that science teachers in a professionalisation setting tend to implement a design-based project in their own way first, after which they can – with help – learn about important components of such projects (Kolodner et al., 2003), we expected that the lesson forms as well as the interview data would give us insight in the pedagogical ideas of this group of teachers beginning to learn about design in chemistry education. We also expected that being an active member of a PLC about design in chemistry education would help bring teachers' (tacit) pedagogical ideas to the surface.

Semi-structured interview

In the interview, conducted first, we asked teachers to talk about their teaching experiences regarding design in chemistry education, and design in other school subjects. Subsequent questions were based on the four pedagogical elements of goals and objectives, student learning, instructional strategies and assessment (as in Loughran et al., 2004 and Henze et al., 2008) tailored for our study's context. Interview questions included: According to you, what are important learning goals of design in chemistry education, and why? Do you think it is important that students design in chemistry, and why (not)? What difficulties for students do you expect? How would you address these difficulties? What other factors influence your teaching regarding design in chemistry? How would you wrap up a design project? How would you assess whether students meet your learning goals? How would you summatively assess student learning? Finally, we asked teachers what topics or settings they thought suitable for designing in chemistry education, as we would be developing chemistry design projects in the PLC (some of which involving teaching chemistry content through design). The semi-structured interview took place at teachers' schools, or their home (for T5). Interviews took 60–75 minutes, and were audiotaped and transcribed.

Lesson forms

Secondly, we collected data through the forms teachers filled out when implementing the toothpaste design project in one of their chemistry classes. Although the teachers implemented the same project, they could formulate their own learning goals throughout the project, and add, remove or adapt activities as they saw fit. In the forms, teachers recorded their ideas about their teaching, their students, and ideas for improving the project. Similar as Henze and Barendsen (2019), we gave them three forms: one for whole-project planning, one for whole-project evaluation, and one for evaluating a single lesson and looking forward to the next. In this study, however, we simplified these forms using the same type of questions in each form. Questions of the interview were adapted for the context of the toothpaste project, for instance: What are your learning goals for this project? (project planning form); Have your students achieved the learning goals, and how do you know that? (lesson evaluation form; project evaluation form). And, questions regarding adapting and improving the project were added: Will/did you adapt elements of the project, why and how? (all forms); How should the project, or the project's teaching materials be adapted, and why? (lesson evaluation form; project evaluation form). Teachers implemented the project in five to six lessons. They were encouraged to fill out the digital forms regularly, and were sent a reminder if necessary.

Data analysis

In analysing chemistry teachers' ideas about design in chemistry education, we stayed close to the teachers' views (Saldaña, 2016). And, to further our theoretical understanding, we looked for patterns in the pedagogical ideas across the six teachers (as suggested by Van Driel et al., 2001). We analysed the data in three cycles. Each cycle had an iterative character, and involved constant comparison, memo writing, and rereading codes, transcripts and lesson forms (Saldaña, 2016). Throughout data analysis, we promoted consensus and consistency by discussing codes, categories and patterns (initially formulated by the first author) intensively between the first and second author, and regularly with all authors. In this description of the data analysis, we use analysis examples of Teacher 2 (who had many pedagogical ideas).

In the first cycle, we coded teachers' pedagogical ideas in the interview transcripts and lesson forms using Atlas.ti. To identify pedagogical ideas in the data, we used the four pedagogical elements (goals and objectives, student learning, instructional strategies and assessment) as a lens. This deductive aspect helped us select ideas relevant to our research focus, as teachers had also shared ideas about, for example, school context and self-efficacy. First cycle codes expressed teachers' ideas in their own words (Saldaña, 2016), and contained a reference to a specific pedagogical element. Examples of first cycle codes are: 'formulating a clear design goal' (goals and objectives), 'some students can immediately [formulate a] good [design problem], others find it very difficult' (student learning), and 'practice formulating design problems using cases' (instructional strategy).

In the second cycle, we condensed the data further, and worked towards finding patterns (Saldaña, 2016). By grouping and regrouping a teacher's first cycle codes, we formulated second cycle codes describing teacher ideas within and across pedagogical elements. For example, the first cycle codes examples mentioned above together describe Teacher 2's idea that design in chemistry education means 'teaching students to formulate a design problem'. Through this process, five categories emerged into which ideas of all the six teachers could be classified. The teachers related design in chemistry to: teaching design (category 1), teaching chemistry content (category 2), teaching research (category 3), and teaching soft skills (category 4). 'Soft skills' were skills teachers viewed as transferable to many other settings (like 'making mistakes' and 'working together'). Using terminology

Table 2. Teacher 2's pedagogical ideas per category (result of the second analysis cycle).

	Design in chemistry education means (to Teacher 2)
Category 1 Relating design in chemistry education to teaching design	Teaching design as a stepwise process
	Teaching the logic of a simplified form of the design cycle
	Teaching most important design skills of the curriculum
	Teaching students to formulate a design problem
	Teaching students to generate partial solutions
	Teaching design throughout secondary school
	Engaging students by making a concrete product
	Using the design cycle as theoretical background
	Using examples and students' practical design experiences
	Having students share final designs
	Having students reflect on the design process
	Assessing intermediate and final design products using criteria
	Not knowing (how to assess) what students learn regarding design
Category 2 Relating design in chemistry education to teaching chemistry content	Teaching to look up chemistry theory to answer a design-related question
	Stimulating students to practice micro-macro thinking when designing
	Possible teaching approach for most chemistry concepts, but time consuming
	Possible teaching approach for all students, but makes senior students nervous
	Difficult to learn chemistry concepts well through design
	Stimulating concept learning early in design project
	Alternating concept- and design-focused lessons and projects
	Choosing design setting related to multiple chemistry topics
	Using a design-based approach from first year chemistry education onwards
	Practicing concept-based final assessment during design project
	Setting content-based criteria for design-based final assessment
Category 3 Relating design in chemistry education to teaching research	Teaching why research is needed when designing
	Using design as a practical approach to teach research
	Teaching most important research skills
	Teaching research throughout secondary school
	Teaching the logic of a simplified form of the research cycle
	Teaching students to design a simple experiment
	Teaching students to formulate a research question
	Stimulating students to control variables
	Teaching students to take lab notes
	Teaching students to analyse data and formulate quantitative and qualitative results and conclusions
	Teaching students to summarise and share research outcomes
Category 4 Relating design in chemistry education to teaching soft skills	Stimulating students' collaborative skills
	Stimulating students' organising skills
	Students need to get used to things going wrong
Category 5 Design in chemistry education as project-based, hands-on learner-centred teaching	Motivating students through hands-on activities
	Stimulating students' feeling of involvement and responsibility
	Basing activities and student workbooks on students' intuitive approach
	Making different agreements on using lab materials
	Giving students extra time to do hands-on activities
	Nudging students when they are stuck by asking questions
	Sharing and clarifying expectations and assessment criteria more regularly
	Using student workbooks, asking questions, observing and having students talk as assessments
	Experiencing difficulties in fairly and summatively assessing group projects
	Assessing students' personal development to understand their learning

from the research field of pedagogical content knowledge, these four categories emerged based on types of large grain size 'content' teachers referred to (Carlson & Daehler, 2019). The fifth category of pedagogical ideas emerged as some of teachers' pedagogical ideas were not related to 'content', but to teachers seeing design in chemistry as a project-based, hands-on and learner-centred way of teaching (category 5). This second analysis cycle led to tables of categorised pedagogical ideas per teacher (see Table 2 for an example).

In the last cycle, to deepen our understanding, we looked for additional patterns (similarities, differences, frequencies, incoherencies, etc.; Saldaña, 2016) in the ideas across the six teachers. We looked for patterns within each category of ideas, and across the categories. Regarding pedagogical ideas in category 1, for example, three patterns emerged: teachers said to teach design as a general process or problem solving approach, teachers were simplifying the curricular design requirements, and teachers preferred to engage students in designing 'something concrete'. In the findings section, we present descriptions of the patterns thus found.

Findings

Through analysing the collected data, we found teachers' pedagogical ideas could be divided into five categories. Teachers related design in chemistry education to: teaching design (category 1), teaching chemistry content (category 2), teaching research (category 3), and teaching soft skills (category 4). Teachers also had pedagogical ideas about design in chemistry education as a project-based, hands-on and learner-centred way of teaching (category 5). Both within and across these five categories, we found patterns in teachers' pedagogical ideas about design in chemistry education. We give thick description of these patterns in this findings section.

Category 1 – relating design in chemistry education to teaching design

To the teachers, teaching students to design meant teaching design as a more general process or problem-solving approach, and simplifying the curriculum standards regarding design. A third pattern emerged as teachers preferred to engage chemistry students in designing 'something concrete', which did pose challenges.

Teachers took a more general perspective on teaching design by teaching the practice as a universally-applicable, step-wise process or problem-solving approach. Teacher 4, for instance, taught students to design by teaching them to: 'work stepwise to solve a problem'. Teacher 1 said to teach students to 'go through a certain process', and that this process was 'much more important to assess' than the quality of students' final design.

Teachers were also simplifying the Dutch curriculum standards which prescribed nine technical design skills (based on the steps of a design cycle) for science students to learn in secondary school. Teachers reduced the variety of design skills to be learned. For example, Teacher 2: 'Students need to […] be able to implement the most important design steps'. Teacher 2 focussed especially on teaching students to formulate a design problem, and to generate 'partial solutions' (thinking of several design ideas per function of a design). Simplifying the curricular design standards would help students learn to design, and motivate students.

In teaching design, teachers preferred to engage students in designing something concrete (as opposed to, for instance, drawing a process design). This would motivate students more, and allow them to judge the quality of their design more easily. However, a preference for concrete products did pose challenges. Teacher 4:

> You'd like to give students the freedom to build something, which I think is very difficult in chemistry. In physics you can say 'Here's some wood and a fretsaw, go build a car' […]. But in chemistry I can't picture that, because there's not that much space for experimenting, as you need to be careful.

Category 2 – relating design in chemistry education to teaching chemistry content

In the second category of pedagogical ideas, relating design in chemistry education to teaching chemistry content, teachers viewed design as a way for students to apply 'existing' chemistry content knowledge, and were apprehensive about teaching new chemistry concepts through design.

Teacher 1: 'Design is another way for students to apply their [chemistry] knowledge, […] another context you could say'. Such a context could have benefits for student learning. Teacher 5: 'Students will remember everything better […]. They will realise that topics from previous chapters can come back when designing'. Recalling experiences from a physics-design project, Teacher 6 shared a strategy for helping students connect chemistry concepts to their design:

> For example, [by saying] 'You just tested [the design], you saw it didn't work, now think about how you can improve it; we just talked about forces, use that'. That was about physics, not chemistry, but you can involve concepts this way.

However, for some teachers, finding a suitable design context for this approach was challenging. Teacher 1: 'I think that's quite hard […], because I'm thinking of linking it to a concept … '.

Teachers were apprehensive about students developing new content knowledge through design. Teacher 4: 'The anxious part of such a fun teaching approach is, will addressing content go as quickly as through whole-classroom teaching?'. Teacher 2 preferred to address most concepts at the start of a design project, as it was difficult to teach chemistry concepts well through design. A design-based teaching approach to teach new chemistry concepts (one of the PLC's topics) was deemed most suitable for students who already knew 'the basics' of chemistry, and were not in their final year of school in which passing the national exams was the primary focus.

In their implementation of the toothpaste design project, teachers did not focus on making connections between design and chemistry content. Teacher 1, for example, wrote to have 'left acids and bases out of it, because of time and because groups didn't ask me about it'.

Category 3 – relating design in chemistry education to teaching research

In the category of pedagogical ideas relating design in chemistry education to teaching research, we found two different perspectives. Teachers either considered students doing research in a design context mainly as a way for students to improve their research skills, or as a way for students to improve their design by applying research skills.

Teachers 2, 4 and 5 held the first view. Teacher 2 considered design ‘a practical approach to help students develop research skills in chemistry’, and addressed many different research skills when implementing the toothpaste project. Teacher 5 wrote in the project preparation form to have only research-related learning goals for the toothpaste design project: wanting students to learn to ‘conduct research themselves, and say whether something meets the design requirements’ and ‘conduct research in a group context’. This would help prepare students for doing their big, open-ended science study at the end of secondary school.

Teachers 1, 3 and 6 held the other perspective: seeing research activities primarily as a way for students to improve their designs. Teacher 1: ‘Students learn that research is necessary to decide which solution is best for a certain design requirement’ and ‘that [research] can lead to conflicting results for the different design requirements, so you need to make decisions’. These teachers addressed research activities ‘as part of the design process’ during the toothpaste design project. Teacher 3: ‘Students learn to explain why designing a product also requires doing research’.

Category 4 – relating design in chemistry education to teaching soft skills

In the fourth category of ideas, teachers saw design in chemistry education as a way to address important soft skills which they could not in ‘normal’ chemistry lessons. Teachers also realised engaging students in design meant teaching soft skills they did not personally see as being important in chemistry education, but which students needed when designing.

Teachers saw design in chemistry education as an opportunity for helping students apply or develop soft skills they deemed important, but could not easily address in typical chemistry lessons. Teacher 1: ‘[Design] gives students the opportunity to use their creativity. They can give it their own spin, more than when they are working on a theoretic topic and making exercises’. Teacher 3 valued design primarily as a way to teach students to think for themselves, and make their own decisions because chemistry students would often simply follow cookbook recipes when doing lab work.

A design-based approach also meant to teachers addressing soft skills they did not necessarily value, but which students needed when designing (mostly involving collaboration, independent-working and planning skills). Teacher 2: ‘Planning is also a skill you want them to learn, but I don’t know if I would do that straight away’. However, during the toothpaste project, Teacher 2 noticed students ‘had difficulties in organising their own work’, and he decided to help them by teaching them how to make a ‘good action plan’.

Category 5 – design in chemistry education as project-based, hands-on and learner-centred teaching

To the teachers, design was a ‘different’ teaching approach for chemistry education which meant weighing off contrasting ideas regarding student learning, instructional strategies and assessment.

Designing's hands-on, learner-centred and project-based aspects made it a different way of teaching according to the teachers. Teacher 4: 'I kind of see it as […] just something different'. This teaching approach provided teachers with interesting opportunities for teaching and learning. However, it also came with big challenges. For example, such a teaching approach was seen as both motivating students (especially the hands-on activities), and causing potential motivation problems. Teacher 1: 'students sometimes see such projects merely as a way to improve their grade average'. Also, on one hand, teachers felt this type of teaching meant not answering students' questions directly, letting students work in their own tempo, not giving grades, and allowing students to follow their own intuition. On the other hand, key activating and motivating strategies for most teachers were telling students what to do, and giving students a grade. Teacher 3: 'I [end up] continuously telling them what needs to be done, because otherwise, generally, not much is happening'. As another example, whole-classroom discussions and presentations were valued as an opportunity for students to learn from each other, and for the teacher to gain insight in students' learning. Contrastingly, such activities were also seen as 'time eaters' and disrupters of students' team-work process. Teachers were all balancing such ideas, but seemed to make different decisions for their teaching.

Across the five categories

Looking at teachers' pedagogical ideas across the categories showed teachers valued design not as a goal, but as a teaching approach for chemistry education. Also, teachers had a personal focus in using design as a teaching approach.

Although teachers had pedagogical ideas about teaching design, they did not see design in chemistry education to be important in itself. For example, Teacher 5: 'I don't think design is particularly important in chemistry education. But, I think students develop so much skills through design which are useful for their future studies or jobs'. To Teacher 5, these more relevant skills were working independently, not being afraid of making mistakes, and doing research. Teachers had a personal focus in implementing design as a teaching approach. Teacher 1, for instance, saw design mostly as a context for applying chemistry concepts, and a way to motivate students for her lessons: '[…] I've noticed design can get students excited, especially those who are normally waiting till the lesson is over'. Teacher 6 wanted students to develop skills like creativity and problem solving through design, and continued with: 'So that's not tied to chemistry, but well, if we're designing in chemistry education, then let it be a chemistry design'. Some teachers did refer to 'ties' between chemistry and design. Teacher 2 wrote to teach students design skills during the toothpaste project because of the curriculum, and because 'design skills play a role in many chemistry jobs'. Teacher 3 addressed design skills because 'students don't realise that products they use daily didn't just come into existence'. However, these teachers also valued design in chemistry education as a teaching approach, not as a goal.

Discussion of findings

Bringing design practices to secondary school chemistry classrooms could foster meaningful chemistry education. Although chemistry teachers are key in realising design's potential for student learning, little is known about their views on this topic. To reduce this gap in literature, we explored what pedagogical ideas chemistry teachers have about design in chemistry education. We studied teachers' ideas in depth in the context of a newly-initiated Dutch professional learning community. As in other countries, a recent curriculum reform in the Netherlands was encouraging chemistry teachers to engage their students in design.

The categories and patterns found in teachers' pedagogical ideas indicate that, even in a context where design is the central theme, chemistry teachers can adhere to somewhat traditional views on chemistry education by valuing design as a way to address *chemistry content knowledge* and *research practices*. Teaching of chemistry content and 'scientific' practices are long-established emphases in chemistry curricula and classrooms (Gilbert, 2006), which may cause teachers to believe these are more important than teaching design. Teachers' ideas may also have been influenced by their familiarity with teaching research and chemistry content as opposed to teaching design. A focus on science content and practices was found as well in our review of literature on design-based chemistry and science education. Fortus et al. (2005) explain their choice of teaching science over teaching design by stating that teaching and learning design is a 'very useful activity' but that design was not included in the science standards. In the context of this study, design practices were part of the curriculum, but, as with many curriculum reforms (e.g. Jones & Carter, 2007), this did not lead the chemistry teachers to believe teaching *design* to be a relevant goal of chemistry education. Indeed, design is sometimes described as a possible pedagogy for chemistry education, rather than as a practice to learn in itself (Sevian & Talanquer, 2014). And, although researchers may suggest using design to help students develop understanding of *new chemistry concepts* (e.g. Fortus et al., 2004; Meijer et al., 2009), which has led to efforts in the Netherlands aiming to stimulate context-based science education, the teachers preferred teaching chemistry content before engaging students in design activities (which is more common among science teachers; Guzey et al., 2016). The *research* activities embedded in the toothpaste design project could have also contributed to teachers relating design to teaching research. Still, this category of pedagogical ideas (like the other categories) appeared in both the interview and lesson form data. Perhaps teachers recognised that boundaries which are often perceived to exist in science education between design and research are especially fuzzy in the context of chemistry (Talanquer, 2013).

Although the teachers remained close to more traditional views of chemistry education concerning students' chemistry content knowledge and research practices, they were taking a more contemporary perspective by valuing design as an approach to address *soft skills* (like creativity and meta-cognition). Teachers felt teaching approaches they commonly used in chemistry education did not allow them to stimulate students' use and development of these important skills. Teachers' notion of design being a *project-based, hands-on and learner-centred teaching approach* seems to have promoted this association. Increasing attention in Dutch schools on teaching 'twenty-first century skills' may have also influenced this idea. Indeed, design-based science education has been described as lending itself to help develop students' complex cognitive and social skills (Kolodner et al., 2003). We saw the teachers felt very strongly about the importance of certain soft skills (skills which varied per teacher). To them, design seemed to mean having a rare opportunity to address such skills in chemistry education which highly motivated them to include design practices in their teaching.

Teachers' pedagogical ideas about design in chemistry education also seem to have been influenced by a lack of collective pedagogical ideas, and lesson materials for design in chemistry education. Teachers regularly referred to experiences with or knowledge of design in physics educational contexts while having few chemistry-specific pedagogical ideas (for example, regarding connecting chemistry contexts or content to design activities to stimulate learning). Information available to Dutch teachers, including the design practices described in the science curriculum, are largely based on experiences with students designing in physics contexts. An absence of well-founded teaching resources hinders teachers from gaining chemistry design teaching experience, and from developing effective design lessons themselves.

Additionally, like Boesdorfer and Staude (2016) found, we saw indications of each teacher having a naïve understanding of design. And, only the teachers in the PLC with a professional background in (bio)chemical engineering (Teachers 2 and 3) made some references in their pedagogical ideas to design as an authentic chemistry practice. Teachers' seemingly limited knowledge of design processes, and of the role of design in chemistry might complicate translating general science, or physics-based frameworks and curriculum standards for design-based teaching to chemistry education.

Conclusions and implications

With this study, set in the context of a Dutch professional learning community, we gained new insight in chemistry teachers' views on bringing design practices to chemistry classrooms. We conclude that, contrary to what one might expect based on design's central role in chemistry, and the Dutch curriculum reform emphasising design practices, this study's chemistry teachers did not see learning to design (in chemistry) as an important goal of chemistry education. Instead, teachers valued design as an approach to engage students in applying chemistry concepts, in developing soft skills, and in applying or developing research practices. As a teaching approach, teachers did consider design to offer benefits regarding student learning, student motivation, and preparing students for future school projects, studies and careers. But, using a design-based teaching approach in chemistry education also posed challenges for teachers, including selecting suitable design contexts that would engage students in making 'something concrete', and in applying chemistry concepts. To make teaching design in itself more relevant, teachers said to teach design as a more generally-applicable process or problem-solving approach. Although the PLC's teachers thus had multiple pedagogical ideas in common, we found ideas also varied per teacher.

Whereas bringing design to physical science classrooms is sometimes seen as a 'natural fit' (as mentioned in Roehrig, Moore, Wang, & Park, 2012), our findings show this connection is not necessarily explicit for chemistry teachers teaching chemistry. To develop their understanding of the role of design in chemistry, the chemistry teachers of this study, and chemistry teachers in other contexts, may benefit from professional development opportunities addressing the practical (Freire, Talanquer, & Amaral, 2019), technological sides (Bensaude-Vincent, 2009; De Vos, Bulte, & Pilot, 2002) of chemistry. Additionally, our findings show the PLC teachers' need for support in learning to recognise (and perhaps use) opportunities to stimulate student learning in the context of design, as well as in developing practical skills to guide student learning in 'hands-on, learner-centred and project-based' contexts (as also noted by others, incl. Kolodner et al., 2003). Although some teachers had more experience regarding design (see Table 1), which might have influenced the extent and coherence of their pedagogical ideas, data analysis of both sources and comparisons with literature showed all teachers were at a beginning stage in their thinking about design in chemistry education, and could benefit from such support to develop pedagogical ideas about design in chemistry education. Since we found that chemistry teachers' primary goals for integrating a design-based teaching approach can vary, more chemistry teachers might be motivated to bring design practices to their classrooms by developing professional development programmes, and lesson materials which accommodate for a variety of perspectives.

The design and effect of teacher professionalisation initiatives on chemistry teachers' pedagogical ideas and their teaching are interesting topics for future research. Follow-up studies could also investigate whether the categories and patterns we found are more common among chemistry teachers, and whether chemistry teachers can hold views we did not come across in our sample (such as stimulating students' chemistry reasoning or daily-life decision making through design, or seeing teaching design as a relevant goal in chemistry education). Developing chemistry-specific principles for teaching and learning to and through design is also an important research direction. As our literature review showed, research on design in secondary school chemistry education is still scarce. And, the chemistry teachers in this study also expressed a clear need for design-based teaching strategies and lesson examples they felt they could take into their classrooms.

Studying chemistry teachers' pedagogical ideas in the context of a PLC provided us with in-depth insight in their views. Basing our data collection and analysis on the four general pedagogical elements of learning goals, student learning, instructional strategies and assessment, and collecting data through interviews as well as lesson forms allowed us to investigate the (tacit) pedagogical ideas of a group of teachers who, despite having had different experiences, were all beginning to explore the field of design in chemistry education. Other researchers aiming to explore the pedagogical ideas of teachers in an innovative educational context may also be interested in using this approach (although filling out logbook-type forms can be demanding for some teachers). Moreover, the five categories of pedagogical ideas that emerged in this study can be adopted as an initial analytic framework for future research studies.

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