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Teachers Noticing Chemical Thinking While Students Plan And Draw Designs

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Introduction

Researchers have been emphasising the importance of teachers paying attention to student thinking as it unfolds in class (Levin, Hammer, & Coffey, 2009; Coffey, Hammer, Levin, & Grant, 2011; Cowie, Harrison, & Willis, 2018). Students come to class with a range of ideas about the world around them, ideas which may not have been anticipated by teachers and lesson plans (Hammer, Goldberg, & Fargason, 2012). Noticing student thinking in class can enable teachers to adapt or build instruction based on students' ideas and reasoning, and tailor their actions to students' learning needs (Hammer, et al., 2012; Cowie, et al., 2018). These notions are also relevant in design-based science classrooms, where students are engaged in designing solutions for real-world problems.

Actively engaging students in design has been gaining traction in science education with the consolidation of (engineering) design practices in science curricular reforms (e.g. NGSS Lead States [NGSS], 2013; Board of Tests and Examinations [CvTE], 2013). In frameworks for design-based science education (incl. Kolodner et al., 2003; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Chusinkunawut, Henderson, Nugultham, Wannagatesiri, & Fakcharoenphol, 2020), we find various ways for students to share their thinking with teachers. When students share their thinking with teachers, student thinking can become observable meaning that teachers have an opportunity to notice it (Luna, Selmer, & Rye, 2018). In 'whiteboarding sessions', for example, students are encouraged to discuss design discoveries and questions with the class, during which teachers can "identify student misunderstanding and misconceptions" (Kolodner, et al., 2003). But, while researchers may be able to identify students' disciplinary thinking while students design (e.g. English, King, & Smeed, 2017; Siverling, Suazo-Flores, Mathis, & Moore, 2019; Chusinkunawut, et al., 2020), there exists little empirical research on science teachers' noticing of student thinking during design-based activities. There have, however, been calls for investigating teachers' attention to student thinking in design-based science classrooms (Watkins et al., 2018). Design projects for science education typically target several disciplinary goals, such as goals concerning students' design practices, scientific practices and understanding of science concepts (e.g. Kolodner, et al., 2003; Fortus, et al., 2004; Berland, Steingut, & Ko, 2014; Guzey, Harwell, Moreno, Peralta, & Moore, 2017). Studying teachers' noticing of and responding to student thinking during design-based science activities may provide insight in teachers' navigation of these goals while student thinking unfolds in class (Watkins, et al., 2018).

In this exploratory study, we draw on the construct of teacher noticing (M. Sherin, Jacobs, & Philipp, 2011) to begin to unpack teachers' attention to student thinking during design-based science activities. We will focus our study specifically on teachers' in-the-moment noticing of students' chemical thinking during conversations with student teams who are engaged in design planning and drawing. While designing in chemistry classrooms can serve multiple purposes, it is often highlighted as a meaningful context for students to develop their ideas and reasoning about chemistry concepts (Fortus, et al., 2004; Apedoe, Reynolds, Ellefson, & Schunn, 2008; Meijer, Bulte, & Pilot, 2009; Sevian and Talanquer, 2014). Research suggests that students' thinking about science concepts may become observable during conversations between teachers and students surrounding students' design plans and drawings (e.g. Roth, 1994; Guzey and Aranda, 2017). As we explore teachers' noticing of students' chemical thinking in this setting, we will also investigate teachers' use of sources of evidence. Although using evidence of student thinking is often seen as an important, or even crucial aspect of teacher noticing (e.g. Santagata, 2011; Barnhart and van Es, 2015; Lam and Chan, 2020), this remains to be explored in design-based classrooms. Design activities can, however, offer science teachers access to a particularly varied and perhaps unusual collection of potential sources of evidence, as physical artefacts like prototypes and design drawings play a key role in design processes. And, annotated design drawings, for instance, may provide insight in students' thinking about science concepts (e.g. English, et al., 2017; Kelley and Sung, 2017). With the insights from this exploratory study, we aim to contribute to the growing knowledge base on teacher noticing in science education. We will additionally provide suggestions for future research and analytical instruments.

Background

Noticing student thinking

During instruction, teachers are faced with a "blooming, buzzing confusion of sensory data" (M. Sherin, Jacobs, et al., 2011). Teacher noticing refers to the processes through which teachers manage this information overload. Teachers choose where to focus their attention on and where their attention is not needed, and interpret what they pay attention to (M. Sherin, Jacobs, et al., 2011). Teachers tend to have diverse objects of interest in what they see and hear students doing, such as those having to do with students' subject matter learning, effort, and emotional well-being (Erickson, 2011). While teachers may notice a range of things in a classroom, these can differ in type for different instructional activities (Russ and Luna, 2013). Researchers found, for example, that a biology teacher's noticing centred more on the substance of students' biology thinking (e.g. understanding of protein structure) during whole-classroom discussion, and on students' task management (e.g. following of standard procedures) during lab work (Russ and Luna, 2013).

While design activities are also making their way into science classrooms due to curricular reforms (incl. NGSS, 2013; CvTE, 2013), we know little about science teachers' noticing in this instructional context. Researchers have noted, however, that open-ended and multi-faceted design challenges may make noticing as well as responding to student thinking more complex, as such challenges can result in an increased variety of student ideas (Watkins, et al., 2018). For instance, when generating and justifying design ideas it is likely that students consider the properties of materials even when that concept is not an explicit part of a design project's learning goals (Siverling, et al., 2019). The findings of a video-based study, conducted in an elementary engineering design context, indicated that some teachers may notice student thinking about a greater variety of science concepts than others. Dalvi and Wendell (2017) asked teachers what science ideas two fourth-grade students expressed who were discussing their design for a device that could lift a giant peach out of the ocean. They found that more of the study's teachers addressed students' ideas about the concept of levers than about more abstract concepts such as weight and gravity (Dalvi and Wendell, 2017).

In this study, we explore teachers' noticing of students' chemical thinking during design activities in the authenticity of teachers' own, secondary school classrooms. Noticing students' ideas and reasoning as it unfolds in science classrooms can enable teachers to make in-the-moment decisions that help students progress towards disciplinary practices and understandings (Hammer, et al., 2012). As teachers may thus be faced with diverse thinking in design contexts, we are particularly interested in characterising teachers' noticing of students' chemical thinking (i.e. ideas and reasoning about chemistry concepts) in terms of the range of involved chemistry concepts.

Although teacher noticing has been gaining research interest across educational contexts in the last decade, it is still an emerging construct which researchers conceptualise in different ways (Jacobs, 2017). For instance, whereas some researchers have investigated teacher noticing processes separately, others have studied teacher noticing holistically (Thomas, 2017; Walkoe, Sherin, & Elby, 2019). Teacher noticing is often taken to involve at least the two main processes of attending and interpreting, but the relationship between these processes is dynamic and complex (M. Sherin, Jacobs, et al., 2011; M. Sherin, 2017). Researchers have raised both theoretical (e.g. perception being both a top-down and bottom-up process) and practical questions (e.g. unclear where attention stops and interpretation begins) regarding disaggregation of these processes (B. Sherin and Star, 2011; M. Sherin, 2017; Superfine, Fisher, Bragelman, & Amador, 2017). In this exploratory study, we will take a holistic view on teacher noticing, without trying to tease apart teachers' attention to and interpretation of student thinking. This approach, which tends to place relatively more emphasis on the interpretation aspect of teacher noticing, has already shown to be fruitful in other studies with a similar research interest in teachers becoming aware of students' disciplinary thinking in science and engineering classrooms (incl. Johnson, Wendell, & Watkins, 2017; Dini, Sevian, Caushi, & Orduña Picón, 2020).

Using evidence in noticing student thinking

In classroom situations, teachers may simultaneously hear students talk, see things written on the blackboard, and more (B. Sherin and Star, 2011). The information which regards 'observable student behaviours' can provide evidence of a student's thinking (Griffin, Murray, Care, Thomas, & Perri, 2010). This evidence can come from a variety of sources, such as from what students say, write, draw and make (Griffin, et al., 2010; Ruiz-Primo, 2011) . Research suggests that what teachers, and novices especially, use as evidence may not actually allow them to make meaningful inferences about student thinking (Erickson, 2011; Barnhart and van Es, 2015). Teachers can, for example, see students' enthusiasm in raising their hands and on-task behaviour as evidence of students having achieved a lesson's learning goals (Barnhart and van Es, 2015). Or, see teacher behaviour as evidence of student thinking (Morris, 2006).

Using evidence of student thinking is commonly seen as an important, or even crucial aspect of teacher noticing (incl. Santagata, 2011; van Es, 2011; Talanquer, Bolger, & Tomanek, 2015; Lam and Chan, 2020), which researchers have been studying from several perspectives. They have, for example, looked at the extent to which teachers consistently refer to evidence when making claims about student thinking (e.g. Talanquer, et al., 2015; Barnhart and van Es, 2015). Others have studied whether teachers refer to specific events or interactions as evidence to support their claims about student thinking (e.g. van Es, 2011; Taylan, 2017). More recently, researchers have additionally argued the need for investigating what sources (or forms) of evidence teachers use (Lam and Chan, 2020).

Teacher noticing is often investigated in professional development or teacher education settings. In such settings, teachers tend to have some time to review a premade selection of potential evidence of student thinking (e.g. Talanquer, et al., 2015; Barnhart and van Es, 2015; Dalvi and Wendell, 2017). In real classroom situations, however, teachers get bombarded with potential, and often fleeting evidence of student thinking (B. Sherin and Star, 2011). Moreover, teachers are facing the pressure of having to make instant instructional decisions (Jacobs, Lamb, Philipp, & Schappelle, 2011). Lam and Chan (2020) suggested that these characteristics of in-the-moment noticing emphasise the need for teachers to home in on sources of evidence which are more revealing of the content of student thinking. Students' nodding heads in response to a teacher question, for instance, are typically less revealing of student thinking than verbal or written replies (Hiebert, Morris, Berk, & Jansen, 2007). In studying preservice science teachers' noticing in response to video clips, Lam and Chan (2020) found that these teachers were not particularly sensitive to some of the more revealing sources of evidence that were available to them (e.g. students' verbal explanations and artefacts).

We are also interested in science teachers' use of sources of evidence in noticing student thinking, as this remains to be explored in design-based classrooms. Design contexts can offer teachers access to a particularly varied and perhaps unusual collection of potential sources of evidence, since physical artefacts like prototypes and design drawings play an important role in design processes.

Design planning and drawing as a noticing opportunity

For teachers to notice student thinking, this thinking needs to be observable (Luna, et al., 2018). Our exploration of teachers' noticing during design-based science activities is set against the back-drop of design planning and drawing activities. Planning and drawing (elements of) potential design solutions are essential aspects of design processes, which we find embedded in many frameworks for design in (science) education (incl. Kolodner, et al., 2003; Fortus, et al., 2004; Crismond and Adams, 2012; National Research Council, 2012; English, et al., 2017; Chusinkunawut, et al., 2020). The learning-by-design approach, for instance, engages science students in a design planning phase in each design iteration during which student teams are prompted to generate and refine their ideas for a design solution, sketch and describe what they plan to construct, and justify design decisions based on experimental results (Kolodner, et al., 2003). Such activities can stimulate students to share their thinking with others. For example, productive planning of design solutions in a team requires students to explain and justify design ideas to others for which they may make of use their thinking in various disciplines (English, et al., 2017). Also, designs drawings have been described as providing teachers and students with a material basis for discussing design and science ideas (Roth, 1994).

Research suggests that evidence of students' thinking about science concepts may be found in a variety of sources during design planning and drawing activities. For instance, researchers have gained insight in student thinking by studying students' talk during interactions with other students and/or with teachers (e.g. Valtorta and Berland, 2015; Siverling, et al., 2019; English, et al., 2017; Guzey and Aranda, 2017). Researchers have also consulted students' design drawings, often in conjunction with annotations such as labels, descriptions and arrows (e.g. Fortus, et al., 2004; English, et al., 2017; Kelley and Sung, 2017). Fortus and colleagues (2004), for example, studied a team's drawing as well as written justification document of their design for an electrochemical cell which demonstrated that the students understood that the difference between the electrode's electrochemical potentials determined the cell's voltage. Whereas student drawings can be difficult to make sense of in themselves (e.g. what does that squiggly line stand for?), student writings or verbal explanations can help clarify what students mean (Neumann and Hopf, 2017). Researchers have also noted that students can express the meaning of design drawings by using gestures (English, et al., 2017). For example, Roth (1994) found that a student indicated a force and its direction by animating a design drawing of a pulley system with a sweeping gesture.

In exploring teachers' in-the-moment noticing, we will zoom in on teachers' conversations with students while student teams are engaged in planning and drawing designs. Researchers have highlighted that whole-classroom conversations can provide opportunities for teachers to gain insight in and support students' thinking about science concepts during design projects (e.g. Roth, 1994; Kolodner, et al., 2003). However, students typically spend a large part of a design project working within their team (e.g. more than half of a unit; Valtorta and Berland, 2015). Teacher-student conversations during small-group design activities may offer similar opportunities for teachers to notice student thinking. And, because teachers have the change to "provide help as needed" as they travel from group to group (Kolodner, et al., 2003), these may be important opportunities too.

Accessing and analysing teacher noticing

To study teacher noticing, which is situated in and integrally tied to instructional settings, researchers need to collect data in a contextualised way (Jacobs, 2017). Researchers have gained access to teachers' in-the-moment noticing by consulting video data on teachers' practice in conjunction with teachers' retrospective reports on their thinking in class (M. Sherin, Russ, & Colestock, 2011; Nickerson, Lamb, & LaRochelle, 2017). Teachers' actions can provide insight into their noticing, as teachers' noticing can influence their observable responses (Levin, et al., 2009; Mason, 2011). But, only studying a teachers' practice may mean that instances are missed where teachers noticed something, and decided not to act on it (M. Sherin, Russ, et al., 2011). By asking for teachers' reflections on their practice, and showing teachers video clips of classroom situations to stimulate their recall, researchers can obtain such information and triangulate their data (Nickerson, et al., 2017; Furtak, 2012). Although teachers have been asked to reflect on video clips of their practice in writing (e.g. Barnhart and van Es, 2015), interviewing teachers can provide particularly rich data as researchers have the possibility to ask follow-up questions (Jacobs, 2017). Still, teacher noticing is notoriously difficult to study as its tacit, transient and situated nature poses various methodological challenges (e.g. Thomas, 2017; Chan, Xu, Cooper, Berry, & van Driel, 2020). For instance, while retrospective interviews can present valuable insights, revisiting videos of classroom situations creates a new noticing opportunity for teachers outside of classroom constraints (M. Sherin, Russ, et al., 2011).

Chemical thinking framework

The use of frameworks describing student thinking in a certain content area helps researchers to determine what counts as evidence of a teacher noticing student thinking in that area (Nickerson, et al., 2017). Rather than using a framework describing student thinking about a specific concept (e.g. Furtak, 2012), our study's open-ended design context and research interest called for a framework covering student thinking about a range of chemistry concepts. We found this in the chemical thinking framework (Sevian and Talanquer, 2014). The chemical thinking framework defines a set of crosscutting chemistry concepts which can be used to analyse students' ideas and reasoning in chemistry as they engage in authentic chemistry practices (Sevian and Talanquer, 2014). These six crosscutting chemistry concepts are chemical identity, structure-property relationships, chemical causality, chemical mechanism, chemical control and benefits-costs-risks. They relate to eleven 'progress variables' along which students' chemical thinking has been hypothesised to develop (Sevian and Talanquer, 2014; see Figure 1). Elements of this framework have been used to characterise student thinking in a variety of chemistry contexts (incl. Banks et al., 2015; Yan and Talanquer, 2015; Cullipher, Sevian, & Talanquer, 2015; Weinrich and Talanquer, 2015).

Using this framework allows us to capture the possibly wide scope of teachers' noticing of students' chemical thinking during the design activities, and to characterise this in terms of associated crosscutting chemistry concepts. But, while researchers have been identifying, for instance, students' underlying assumptions, conceptual modes, and modes of reasoning (Sevian and Talanquer, 2014; Yan and Talanquer, 2015), teachers' noticing of students' chemical thinking will likely manifest itself differently. Noticing student thinking in a science discipline has, for example, been found to take the form of teachers identifying a student's knowledge gap, (in)correct terminology, misconception, confusion or reasoning inconsistency (Coffey, et al., 2011; Talanquer, et al., 2015; Dini, et al., 2020).

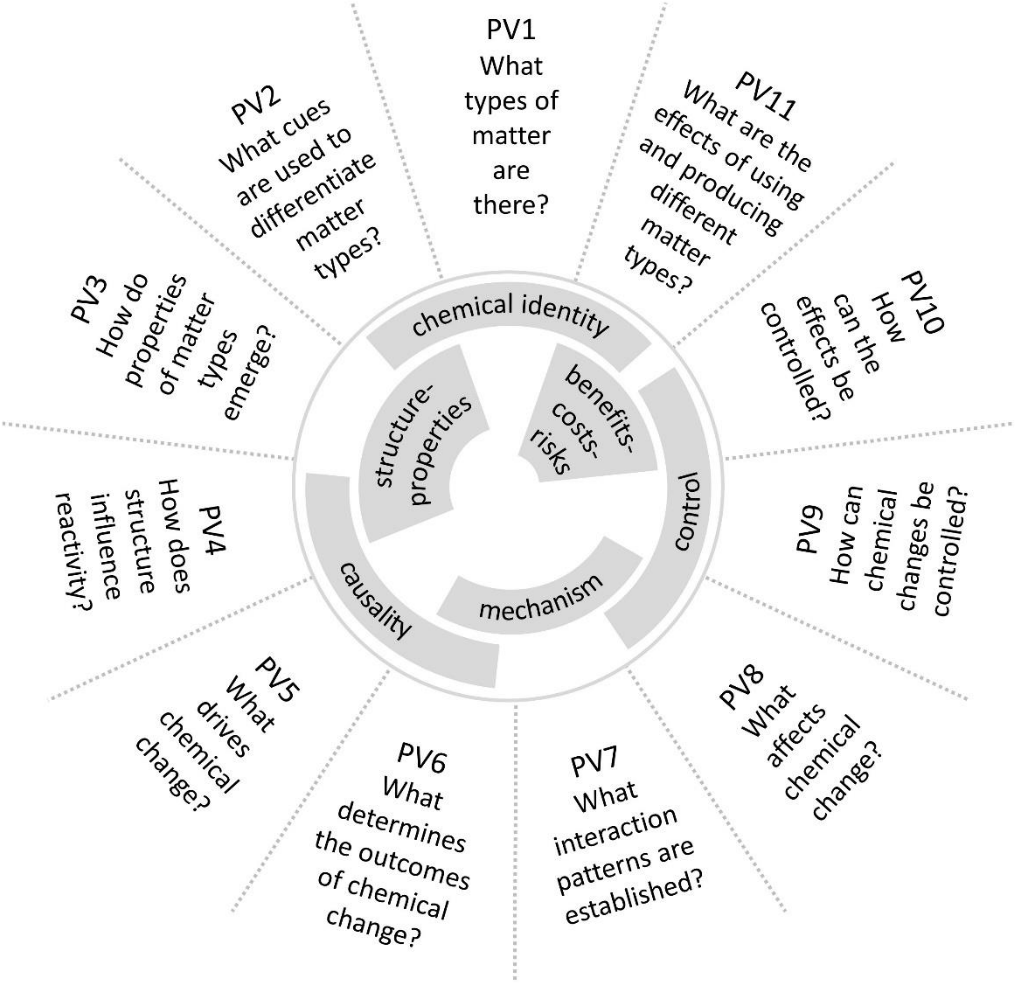

Figure 1. The crosscutting chemistry concepts and progress variables (PVs) of the chemical thinking framework (visually adapted from Sevian & Talanquer, 2014; with permission from the Royal Society of Chemistry).

Research questions

We formulated the following research questions to guide our explorative study, and gain insight into teachers' noticing in a design-based science classroom context:

RQ1. What chemical thinking do teachers notice during conversations with students who are engaged in design planning and drawing?

RQ2. What sources of evidence do teachers use in noticing students' chemical thinking during conversations with students who are engaged in design planning and drawing?

Methods

We used qualitative research methods to explore two chemistry teachers' noticing of students' chemical thinking, and use of sources of evidence during conversations with student teams engaged in design planning and drawing. We collected data on these teachers' noticing in the context of a design project for 10th-grade chemistry.

The design project

In the Dutch design project 'The thermo challenge', teams of 10th-grade chemistry students iteratively design a product that uses an exothermic or endothermic chemical reaction to change the temperature of a drink or food. The project was being developed by a professional learning community of secondary school chemistry teachers and researchers with the aim to stimulate students to apply and develop their understanding of chemistry concepts through engagement in design. The project specifically targets students' understanding of reaction energy, reaction heat and reaction rate. These concepts relate to progress variables 5, 8, 9, 10 and 11 of the chemical thinking framework (Sevian and Talanquer, 2014; see Figure 1). We present an overview of the design activities of each of the project's nine lessons in Table 1. The activities of lessons 3 and 7 centre on design planning and drawing. In addition to these activities, teachers also engage students in classroom rituals such as whiteboarding and relating a lesson's activities to a design cycle (as in, for example, Kolodner, et al., 2003). Per lesson, one or two design canvasses were developed to support teams in the small-group design activities, and offer teachers potential evidence of student thinking. Canvasses contain prompts and empty spaces for students to respond to these prompts (e.g. "sketch three different design ideas", lesson 3; "How did you incorporate your understanding about reaction rate, colliding particles and activation energy in the design?", lesson 7). Teacher materials include presentation drafts, information on proposed classroom and lab activities, and examples of student work.

Table 1. Descriptions of the student design activities per lesson of the design project. Data was collected during the small-group design planning and drawing activities in lessons 3 and 7 (shown in *italics*).

	Student design activities
Lesson 1	Watching an introductory product video, formulating project questions based on the product's user instructions, participating in class session on role of design in chemistry and design processes, playing and reflecting on an drawing game with the class, setting team's design challenge and requirements, drawing first ideas for design solutions
Lesson 2	Participating in classroom session on reaction energy and heat, investigating endothermic or exothermic reactions in the lab, experimenting with amounts of reactants, recording observations, comparing results, justifying selection of reaction for the design
Lesson 3	Participating in classroom session on estimating required amounts of reactants, comparing examples of design drawings and formulating success criteria with the class, *generating and drawing multiple design ideas, considering different materials and design functions, formulating pros and cons of ideas, deciding on a design, estimating required amounts of reactants*
Lesson 4	Constructing prototype, testing prototype, and recording observations and ideas for improving the design
Lesson 5	Constructing prototype, testing prototype, and recording observations and ideas for improving the design
Lesson 6	Participating in classroom session on reaction rate surrounding a demonstration experiment, investigating influence of different factors on reaction rate in the lab, recording and explaining observations
Lesson 7	Participating in classroom session on observations reaction rate experiments, sharing design problems and solutions with other teams, *evaluating team's prototype performance, generating ideas for improving the design, incorporating time aspect in design requirements,*

	incorporating understanding of reaction rate in design, drawing design ideas and making design decisions, estimating required amounts of reactants
Lesson 8	Constructing prototype, testing prototype, and recording observations and ideas for improving the design
Lesson 9	Creating the team's 'instructable', reflecting on design process, sharing end products

Participants

The two chemistry teachers participating in this study were voluntary members of a professional learning community on design in chemistry education and formative assessment. The PLC was facilitated by this study's researchers. Two of the six teachers of the PLC participated in this study. A year earlier, these teachers had implemented a previous version of the design project (with a smaller role for design drawing activities). These teachers were interested in participating. Teacher 1 had about 7 years of experience in teaching secondary school chemistry, and Teacher 2 had about 3 years of experience. Both held a master's degree in (bio)chemistry, were qualified for teaching upper-secondary school chemistry, and had work experience as (bio)chemical engineers. The teachers were colleagues at the same urban school. During the PLC meetings leading up to this study, they had been engaged in analysing annotated design drawings collected in a pilot study, constructing content representations for the thermo challenge design project (CoRe; Loughran, Mulhall, & Berry, 2004), discussing good practices for informal assessment conversations (referring to Ruiz-Primo, 2011), and formulating questions to help elicit students' understanding of chemistry concepts during the design planning and drawing activities (included in the teacher guide).

Each teacher selected one of their 10-grade chemistry classes for data collection. Teachers formed teams of about three students with the aim to promote learning. We asked teachers to choose two student teams to be the centre of our data collection, teams who would want to participate in the design activities and the research. Focussing on teachers' interactions with two design teams allowed for an in-depth analysis, while limiting close-up recording of students in class as this creates somewhat intrusive conditions. All students were informed about our overarching research aim (understanding how teachers can gain insight in student learning unobtrusively), and research process (incl. approach to data collection). Teachers and students gave us their consent. We will refer to the focus teams in the class of Teacher 1 as teams A and B, and those in Teacher 2's class as teams C and D. During lesson 3 only one of team B's students had been present.

Data collection

We collected two types of data to gain access to teachers' noticing: classroom and interview data. We collected classroom data during project lessons 3 and 7. These were the lessons in which students were planning and drawing designs in their teams, in preparation of constructing and testing prototypes the next lessons (see Table 1). Collecting data over two lessons rather than one meant that there were more opportunities for conversations between a teacher and focus team, potentially providing us with more revealing data. We conducted the retrospective interviews as soon as possible after each data collection lesson. These interviews required an additional research intervention between lessons 3 and 7.

Classroom data

We positioned a camera and an audio recorder (providing better audio quality) at each focus teams' tables. To obtain high quality video data (e.g. showing teacher and student expressions and gestures, and elements of teams' canvasses) we used cameras with a wide angle set to record in high resolution. An additional camera was positioned in the back of the classroom to capture what happened behind a team camera, and in the class as a whole. We aimed to limit the intrusiveness of the equipment itself by using small-size action cameras. The teacher had a personal audio recorder. We tested the whole setup during lesson 1 in each class, also as a way for the teachers and students to get acquainted with this approach to data collection. The first author and a research assistant were present during each lesson as equipment managers and to take field notes (in the back of the class, focus teams were positioned in the front). Photos of design canvasses were taken at the end of each lesson as secondary data.

Interview data

We conducted a retrospective interview after each of these lessons, for which we prepared the collected video data by selecting conversations of interest. In selecting the video clips, we looked for conversations between a teacher and a focus team during the lesson's small-group activities (excluding interactions without student talk). Because of our focus on teachers' noticing of students' chemical thinking we also excluded conversations which concerned classroom logistics only (e.g. the time that was left; why a student of a team was absent; which design team would give which other team feedback). The selected conversations were cut from the lesson video, and separately recorded audio was added if necessary (the researcher also had a transcript available). We arranged the order of the clips in such a way that richer conversations (in terms of apparent instances of a teacher noticing students' chemical thinking) would be presented to the teacher first. The first and second author discussed the selection and order of clips before the interview took place.

In the retrospective interview, the researcher showed the teacher a clip and first asked broadly: Do you remember what you were thinking during this conversation? Can you tell me something about that? We then probed further for the teacher's noticing of student thinking, and use of evidence while revisiting the clip in parts (divided by a teacher's verbal responses). Our questions were: What did you infer here about student thinking? Why did you think students were thinking that? This approach was repeated for each clip. The semi-structured interview set up also allowed for asking follow-up questions (e.g. What do you mean by that? Did you realise that at the time, or is this standing out to you now?). We also asked teachers about their responses to students during the conversations, but those teacher interview comments are not the focus of this present study. At the end of each interview, the teacher was asked what had stood out to them in conversations with other teams in the class. All interviews were audio recorded and transcribed.

Data analysis

We qualitatively analysed the data to gain in-depth insight in each teacher's noticing of students' chemical thinking, and use of sources of evidence. We consulted videos and transcripts of the conversations between a teacher and focus teams in class in conjunction with transcripts of the retrospective interviews conducted after the design lesson. Throughout the iterative analysis procedures we relied on memo writing to document our analytic reflections (Saldaña, 2016), and table displays to compare and categorise the data (Miles, Huberman, & Saldaña, 2013). While we kept revisiting the video data, we also wrote detailed descriptions of video observations allowing us to zoom in on and record aspects of the videotaped conversations relevant to our research questions (Saldaña, 2016). We occasionally referred to secondary data sources, such as teams' design canvasses, to help us interpret the data. The first author did the bulk of the analyses, while the first and second author met up during the iterative processes to study video and interview data, and discuss observations, coded excerpts and emerging patterns until reaching consensus.

In addition to these general data analysis processes, we also employed the following specific procedures to answer our two research questions.

Analysing teachers' noticing of students' chemical thinking

We focussed our analysis on those conversations between teacher and student teams which had been selected when preparing the retrospective interviews (see the data collection for the selection criteria). Four conversations between Teacher 1 and focus teams were retrospectively discussed by the teacher in the interviews (one per team per lesson; 60 to 90 s in duration). Two other conversations had not been discussed due to time constraints, and were not included in this analysis (team A, lesson 3; team B, lesson 7). In Teacher 2's case, five conversations had been selected and retrospectively discussed (one per team per lesson, and a second conversation with team C in lesson 7; 25 to 80 s in duration).

We first studied the classroom and retrospective interview data for each conversation for indications of a teacher noticing student thinking. In the classroom data, we inferred a teacher's noticing by studying the teacher's verbal and non-verbal responses for influence of the teacher having noticed student thinking (Mason, 2011; Levin, et al., 2009; Haug and Ødegaard, 2015). Such responses included a teacher rephrasing observed student thinking, and giving an explanation or suggesting a student activity that addressed a certain idea. For example, Teacher 1's responses to a student question concerning the reusability of ammonium chloride included giving a short verbal explanation "no, because it reacted so it's become another substance", which was identified as an instance of the teacher noticing student thinking. We also examined a teacher's interview comments for references to student thinking, taking into account that this may appear in a variety of forms, such as a teacher describing a gap in a student's understanding, a failure to remember or an inconsistency in a student's reasoning (Talanquer, et al., 2015; Dini, et al., 2020). For instance, Teacher 1's statement "so, then I thought, she apparently thinks that the substance does not get used up, or only got dirty or something" was identified as the teacher noticing student thinking (teacher describing an underlying assumption driving student thinking; Dini, et al., 2020). Using the table displays, we constantly compared our analysis of the classroom and interview data to verify our interpretation of the data. During this process, we found instances where a teacher seemed to notice 'new' student thinking in the retrospective interview. These typically coincided with teacher statements like "What I realise now […]" and "No, I don't think I noticed that before..". As we were interested in teachers' noticing of student thinking in class, we excluded these instances.

We then sought to characterise each teacher's noticing of students' chemical thinking. To this end, we used the chemical thinking framework (Sevian and Talanquer, 2014) to identify whether instances of a teacher noticing student thinking, as identified in the previous analysis phase, involved students' chemical thinking. And, if so, to classify to which progress variable (see Figure 1) the teacher's noticing of chemical thinking related. During this coding process, we constantly compared our data (incl. student contributions) to the findings of previous studies in which researchers used elements of the chemical thinking framework to characterise student thinking (incl. Banks, et al., 2015; Yan and Talanquer, 2015; Cullipher, et al., 2015; Weinrich and Talanquer, 2015). For instance, Teacher 1's recognition that a student did not have knowledge about the melting points of plastics was identified as noticing chemical thinking, and coded as relating to progress variable 2 (melting points can be thought of as a cue to differentiate matter types; Ngai and Sevian, 2017). In the findings section, we provide thick descriptions of each teacher's noticing of students' chemical thinking per progress variable.

Analysing teachers' use of sources of evidence

We iteratively developed codes distinguishing sources of evidence which teachers used in noticing student thinking during the conversations, and we applied these codes to the classroom and interview data. We based our coding on sources of evidence as differentiated by others (incl. Cowie and Bell, 1999; Roth, 1994; Ruiz-Primo, 2011; Lam and Chan, 2020; Luna, et al., 2018), and adapted and created new codes to account for what we observed in our study's data (Miles, et al., 2013). Following our holistic perspective on teacher noticing, we included instances of teachers attending to evidence of student thinking, as well as teachers supporting their interpretations with evidence when coding the data (Superfine, et al., 2017). In the video data, we inferred teachers' use of evidence from its influence on teachers' responses rather than examining, for instance, only the direction of teachers' gaze (Mason, 2011). For example, observing Teacher 1 to use the same type of hand gestures as a student had just used when talking about the team's prototype and its materials, indicated that the teacher had paid attention to the student's gestures. We also examined teachers' interview comments for references to evidence of student thinking. For instance, Teacher 2 commenting (in response to the interview question "And, why did you think he thought that?") with "Because he says 'do we need to know that precisely or not'…" indicated that the teacher used evidence from the source of student talk. In Table 2, we present the developed codes (incl. examples from data).

Table 2. Codes distinguishing sources of evidence used by teachers in noticing student thinking during conversations surrounding design planning and drawing activities.

Code	Description	Examples from data (interview comments; video observations)
Talk	Teacher using student talk as a source of evidence	"Because he says 'do we need to know that precisely or not'…" (T2, team C, lesson 7); Observing the teacher to listen and reply to a student asking a question (T2, team D, lesson 3).
Design drawings	Teacher using students' (annotated) design drawings on design canvasses as a source of evidence	"[…] you look at the drawing and she hadn't drawn much" (T1, team B, lesson 3); Observing the teacher to lean over and look in the direction of a team's design drawing while a student points at and explains one of its elements and responding by smiling, nodding and saying "fun" (T1, team A, lesson 3).
Notes and graphs	Teacher using students' notes or graphs on design canvasses (not a direct part of students' annotated design drawings) as a source of evidence	"[…] because she has experimental observations standing next to it with a smaller amount of substances, and there the temperature is lower" (T1, team B, lesson 3); Observing the teacher to read out loud a team's canvas notes (T2, team D, lesson 7).
Prototypes and materials	Teacher using students' physical prototypes or construction materials as a source of evidence	"I didn't understand well why he was gonna stop with that bottle […] just that they were saying goodbye to that thing" (T1, team A, lesson 7); Observing the teacher to simultaneously look at, tap on and comment on a team's prototype (T1, team B, lesson 7).
Gestures	Teacher using student gestures as a source of evidence	"She's pointing to the canvas of the lab lesson" (T1, team B, lesson 7); Observing the teacher to use similar gestures as a student just used representing a prototype and its materials (T1, team A, lesson 7).
Practical actions	Teacher using students' practical actions as a source of evidence	"He was kind of playing with those cans" (T2, team D, lesson 7); Observing the teacher to comment on a student who is determining the volume of a container by saying "o, you are checking how much it holds" (T1, team A, lesson 7).
Eyes, faces, heads and posture	Teacher using students' (moving) eyes, faces,	"[…], and then you do see her smile a little" (T2, team C, lesson 3);

	heads or posture as a source of evidence	Observing the teacher to look in the direction of students' nodding heads when having given an explanation and asked "Yes?", and then to continue talking about something else (T2, team D, lesson 3).

We then focussed on what sources of evidence teachers used in noticing students' chemical thinking specifically. We compared our coding of each teacher's use of sources of evidence to our earlier analysis of the teacher's noticing of students' chemical thinking (as determined in the previous analysis phase). As others have noted, trying to establish direct links between teachers' use of evidence and noticing of student thinking was difficult (Superfine, et al., 2017). For instance, a teacher could refer to a certain source of evidence after having made several claims about students' chemical thinking without specifying which of those claim(s) had been informed by evidence from that source. We thus decided to look for patterns in teachers' use of sources of evidence per and across conversations, rather than per instance of a teacher noticing chemical thinking. We looked for patterns including those based on frequency, similarity, differences and sequences (Saldaña, 2016), and were informed by prior research on teachers' use of evidence (incl. Lam and Chan, 2020; Barnhart and van Es, 2015). As in the previous analyses, we constantly compared our observations in the classroom and interview data to verify our interpretations. In the findings section, we present our characterisation of each teacher's use of sources of evidence in noticing students' chemical thinking.

Findings

Teachers' noticing of students' chemical thinking

Both teachers noticed chemical thinking while in conversation with focus design teams during the design planning and drawing activities. Teacher 1 noticed chemical thinking in all of the conversations we studied (one per team per lesson). Teacher 2 noticed chemical thinking in two of the five conversations (team D, lesson 3; team C, lesson 7). Teacher 1's noticing concerned progress variables 1, 2, 6, 7, 8, 9, 10 and 11 of the chemical thinking framework (see Figure 1 for the framework). Teacher 2's noticing of chemical thinking involved progress variable 11. We present thick descriptions of each teacher's noticing of students' chemical thinking in the following paragraphs.

Teacher 1

PV1 – what types of matter are there? We found that multiple of Teacher 1's noticing instances related to progress variable 1. In a conversation with students of team A (lesson 7), Teacher 1 recognised that a student "knew which materials insulate heat and conduct heat" but "did not use some words". Halfway into a conversation, this student had used the words metal and plastic while asking Teacher 1: "Is it smart to, kind of, have the outside one made of plastic, and the inside one of metal? So that you don't pass on heat quickly with your hand to the bottle, but that… the substance can pass it on to the metal.". As a response, the teacher rephrased the student's statement referring to conducting and insulating materials rather than metal and plastic. In the same conversation, Teacher 1 also noticed student thinking regarding diversity in a matter class. The teacher identified that students were considering plastic as their only option for insulating material, whereas styrofoam, for example, could also be potentially useful. Teacher 1: "They had been converging, […] it was time to diverge.". Regarding another conversation with team A (lesson 3), Teacher 1 commented in the interview that he had noticed something he had never before. He had found that a student thought that "the substance does not get used up, or only got dirty or something". A student of the team asked the teacher whether ammonium chloride, which the team wanted to use for the design they had drawn, could be reused. After having stimulated the student to rephrase her question, the teacher replied that it could not as the substance had reacted and become another substance. The student's thought was perhaps not so strange, the teacher said retrospectively, as people can also perform actions repeatedly without getting used up.

PV2 – what cues are used to differentiate matter types? The teacher's noticing of student thinking also related to PV2, specifically to seeing matter's response to certain conditions as differentiating cues. In a conversation with team A, Teacher 1 identified that a student was distinguishing heat conducting and insulating materials (lesson 7; also see the description under PV1). And, that another student of team A was still confused about metal as a heat conductor after this had been discussed. Teacher 1: "He had talked about it, I had repeated it, and then she says 'OK, conducting material, metal right?'. […] I was thinking 'Eeeh but that's clear now right, why are you still doubting that?'". Teacher 1 also noticed that a student of team B was thinking about the "heat resistance" of materials, and did not know the melting points of plastics (lesson 3). The student of team B had asked the teacher whether she could use plastic for her design, considering that there would be very high temperatures involved. Teacher 1 replied that she could as "most plastics can withstand a hundred degrees". Retrospectively the teacher commented: "She thinks that the materials that they use won't withstand those temperatures. That she will have a problem. I can tell her that, that's not knowledge that she possesses, the melting points of plastics. […] That 'hundred degrees' was a little bit vague, I wanted to reassure her that the materials she uses can handle those temperatures.".

PV6 – what determines outcomes of chemical change? Teacher 1's noticing of student thinking which related to this progress variable specifically concerned seeing amounts of reactants as determining the outcome of a reaction (outcome in terms of a temperature change, not chemical products). During a conversation with team A (lesson 7), the teacher approvingly recognised that these students were indeed considering this aspect in their design. In a conversation with a student of team B (lesson 3), however, Teacher 1 identified that a student was not considering this, and he explained it to her. In the interview, Teacher 1 commented:

> She had tried it out already, but apparently it didn't stuck. Sometimes that seems so explicit, that they do an experiment […], and that you can sort of assume that they understand that you get a higher temperature with more of the substances, and a lower temperature with less of the substances. But, that is not at all so straightforward, that it retains as knowledge when they have done such an experiment. That you actually need to discuss it explicitly or do something with it. When designing, you do something with that knowledge.

PV7 – what interaction patterns are established? In the conversation initiated by a student of team A asking whether ammonium chloride could be reused (lesson 3; also see the description under PV1), Teacher 1 also noticed thinking related to progress variable 7 (crosscutting concept mechanism). The teacher commented that the students of the team seemed to think that "reactants were not really necessary to make new substances". In the interview, Teacher 1 expressed his surprise as students had learned the definition of chemical reactions, had done a lot of lab work with reactions, and had written and discussed many reaction equations. After having told the team that ammonium chloride had become another substance, the teacher additionally responded with saying: "Then you would need to turn it back into ammonium chloride first, but that's complicated.". In the moment of the conversation, the teacher retrospectively commented, he had decided to address it no further as "students were mainly interested in the consequences for their design, not in the concept of reactions".

PV8/9 – what affects chemical change and how can chemical change be controlled? In a conversation with students of team B (lesson 7), Teacher 1 noticed student thinking related to progress variables 8 and 9. We take these together here, as they were very entangled in the data. A student of team B had asked, referring and pointing to a prompt on lesson 7's design canvas: "Just it's, 'How is your understanding about reaction rate'… What do we do with that?". The teacher replied: "Well, we know that reaction rate can be influenced by a higher temperature, by a higher concentration, by the type of substance, and by a few other things. And you could use that knowledge to.. improve your design.". Teacher 1 retrospectively commented to have noticed that the students of the team "have the knowledge, but they can't really apply it". As the conversation continued, the teacher also noticed that one of the students showed "a good beginning of understanding" how to use the factors to increase the rate of their chosen reaction.

PV10 – how can the effects be controlled? Teacher 1's noticing of student thinking also related to progress variable 10 (controlling benefits, costs and risks of using and producing different matter types). The teacher noticed that students of team A (lesson 7) "drew good conclusions" for optimising their product based on understanding of different types of materials, heat transfer, the volume of their drink and amounts of starting substances required to reach a certain temperature. The teacher's responses during the conversation included saying "that's a good idea" when a student had verbally explained an element of their new design solution while drawing it in the air. In a conversation with a student of team B, concerning potentially melting plastic (lesson 3), Teacher 1 noticed that the student "had recognised herself that material properties play a role in the design". However, the student did not realise that she could "regulate the temperature herself", which teacher 1 explained to her. Teacher 1 also said to have noticed that students of team A were "considering the consequences" of what they had just learned about ammonium chloride, concerning its non-reusability, for their design. Towards the end of a conversation with team A (lesson 3), students explained their drawn design idea of using a tea filter containing ammonium chloride to change the temperature of the drink (while also ensuring that users would not ingest ammonium chloride, according to the students). Teacher 1 retrospectively commented: "I thought, they are doing well. They are thinking about how their design works. They are justifying decisions for materials and for filters and stuff. Keep up the good work!". In the conversation, Teacher 1 responded to the students' explanations by nodding, smiling and saying "fun" and "OK".

PV11 – what are the effects of using and producing matter types? Teacher 1 also noticed student thinking regarding progress variable 11. In a conversation with a student of team B (lesson 3), Teacher 1 noticed that the student was having difficulties in choosing a reaction for the team's design. Teacher 1's retrospective comments included: "She was doubting which substances to choose, and that doubt has a relation with the temperature that they… that they saw during the experiment.". The teacher also recognised that the student was "worrying about" the risks that materials could melt, and that the food in their designed product could become too hot. In a conversation with team A (lesson 7), Teacher 1 noticed that a student was considering and calculating the amount of heat required to meet their design's requirements. The team had come up with a new design solution, which was not based on the tea-filter idea anymore. In the interview, the teacher commented: "I remember thinking for a moment, oh that's a pity, they want to abandon an original idea for a standard solution. […] But, as they are calculating, they are doing a good job.". During another conversation with team A (lesson 3), Teacher 1 noticed that students wanted to make their product reusable. As reusing ammonium chloride was not an option anymore, the teacher told the team they could sell it in separate packages which was "good for revenue". Teacher 1 later commented: "I thought, instead of reuse being a problem, I see it as an opportunity.".

Teacher 2

PV11 – what are the effects of using and producing matter types? Related to effects of using matter, Teacher 2 identified that students of team C "had forgotten what Q represented" (lesson 7). One of the students had asked her, referring to a prompt on the design canvas: "Mam, what do you mean exactly with 'required Q'? Because I don't know what to fill in.". The teacher was not surprised at the student's forgetfulness as the topic had been addressed in a previous lesson, and the particular student had missed parts of some lessons. In the conversation, the teacher told the team's students what Q stood for ("the reaction heat that needs to be released or gets used"). When the student subsequently asked whether that had to be calculated precisely, Teacher 2 said to have noticed that "he thinks it needs to be precise". She told the student that they could make an estimation based on what they already knew. Teacher 2 also noticed a confusion among the students of team D regarding selecting a reaction for the design (lesson 3). A student had asked the teacher whether they needed to choose from the ones proposed in the project or whether they could choose their own "material". Teacher 2 retrospectively commented to have thought: "That he was in doubt about that. That he thought 'maybe I can also just cool it with ice cubes' or something.". Teacher 2 verbally responded in class with: "No, you need to, like make a choice between experiment one or experiment two. Euh, so reaction one and reaction two of the exothermic or endothermic reaction that you have chosen.".

Teachers' use of sources of evidence

In studying what sources of evidence each teacher used in noticing students' chemical thinking, we found that student talk was both teachers' main source of evidence. We additionally found that the other sources of evidence as distinguished in Table 2 could play a supporting role in Teacher 1's noticing of chemical thinking. We did not find this pattern for Teacher 2. We describe this characterisation in more detail in the following paragraphs.

Teacher 1

Student talk. Student talk was Teacher 1's main source of evidence in noticing student's chemical thinking during the conversations. The teacher's noticing of student thinking as described in the previous findings section was largely based on what students said. Throughout the retrospective interviews, Teacher 1 referred to student talk as providing evidence of chemical thinking. For instance, concerning a conversation with a student of team B (lesson 3) Teacher 1 commented: "My attempts at uncovering what's confronting her are suddenly verified by a clear quote. I thought, OK she's indeed concerned about the heat resistance of materials.". The quote Teacher 1 referred to was the student asking "So, then you can use plastic, for instance?". In the video data, we would often observe Teacher 1 to listen to talking students without interrupting, and to respond to (some of) the content of students' talk. For example, when a student of team A was asking a question ("so, metal right?"; lesson 7), the teacher turned to face her, and nodded while replying "metal conducts heat well". That student talk was Teacher 1's main source of evidence was furthermore highlighted by finding that the teacher's noticing of students' chemical thinking concentrated on those students of focus teams who talked relatively extensively (two of the students of team A, and one of team B). The teacher also commented in interviews that it was difficult for him to grasp what those students were thinking who were not very talkative (e.g. a team B who "always says 'Yes, I understand', and then gets nothing at test time").

Other sources. While student talk was Teacher 1's main source of evidence, we found this teacher to use multiple sources of evidence in noticing students' chemical thinking. For instance, in a conversation with a student of team B (lesson 3), Teacher 1's noticing had been informed by evidence from the sources of student talk and annotated design drawing. Teacher 1 commented in the retrospective interview:

> That’s a combination of what she says in the moment, what had happened in the previous lesson when they had also been talking about temperature. Then I’d also thought that she was concerned about that high temperature. You look at the drawing, and she hadn’t drawn much. She clearly hadn’t made a decision for a substance. That was apparently what was holding her back. You always try to relate the question they ask to where they are in the design process. That quickly provides you with a lot of information.

Our video observations of this conversation included observing Teacher 1 to respond to the student’s verbal questions, and to look in the direction of her design canvas. We saw that all sources of evidence as defined in Table 2 had played a role in Teacher 1’s noticing in at least one of the studied conversations.

Teacher 1 appeared to rely more heavily on evidence from non-talk sources when students were not very talkative. The teacher learned, for example, about a team B student’s chemical thinking because the student was “pointing” at a certain design canvas element when “asking half a question” (gesture and talk; lesson 7). Using evidence from multiple sources also helped the teacher to weigh the trustworthiness of identified evidence on student thinking. For instance, the teacher commented retrospectively that a student of team B “confirms with her mouth” (talk; lesson 7) that she knew how to increase the reaction rate. The student had shortly stated in the conversation: “We are figuring it out”. On the other hand, the teacher commented, “she demonstrates that she doesn’t know what to do”. This was demonstrated, the teacher said, by the student first resting her head on her hands (posture), and then being engaged in drawing the team’s design (practical action; design drawing) instead of discussing ideas for influencing the reaction rate with the teacher and other team mates (talk). In the video of the conversation, we observed Teacher 1 to nod in response to the student’s short statement, and then to look in her direction multiple times as the conversation with the team continued. This example also illustrates our finding that non-talk sources provided Teacher 1 with evidence of student thinking, but that the teacher could not conclusively determine what students were thinking if he had little access to student talk.

Teacher 2

Student talk. Student talk was also Teacher 2’s main source of evidence in noticing student’s chemical thinking. The teacher’s noticing of student thinking as described in the previous findings section was informed by what students had said. Teacher 2’s interview comments specifically referred to student questions as requiring the teacher’s attention, and suggesting some sort of issue in students’ thinking. For instance, regarding the conversation with team C (lesson 7) Teacher 2 retrospectively commented: “I think I was busy collecting prototypes, so I was actually not expecting this kind of question anymore. But, they clearly didn’t understand something”. The question Teacher 2 referred to was: “Mam, what do you mean exactly with ‘required Q’? Because I don’t know what to fill in.”. In the videos of the conversations, we observed the teacher to prompt a student to repeat a question, listen to talking students (while also repeatedly cutting students off by starting to talk herself), and to respond to (some of) the content of student talk. For example, when a student of team B started asking a question (“Do you need to, like, make one of those two choices bet-”; lesson 3), Teacher 2 came closer, gave an initial reply (“Yes, you need to make a choice”), and then gave a longer reply when the student had extended his question a bit further.

In analysing the data we found no interview references to other, non-talk sources of evidence for those conversations during which Teacher 2 noticed chemical thinking. With the exception of a general statement that a raised student hand indicated to Teacher 2 that a student had a question (team D, lesson 3).

Discussion

The purpose of this study was to explore teachers' noticing of student thinking in a design-based science classroom context. We qualitatively analysed two chemistry teachers' in-the-moment noticing of students' chemical thinking, and use of sources of evidence as the teachers engaged in conversations with 10th-grade chemistry students who were planning and drawing designs. Our exploratory study's findings add to the growing knowledge base on teacher noticing in science and engineering design education, and provide suggestions for analytical instruments and future research.

Our findings regarding research question 1 demonstrate that the teachers noticed chemical thinking during conversations with students who were planning and drawing designs in their teams. This outcome is encouraging as researchers have noted that open-ended design challenges can result in an increased variety of student ideas, which may make attending to student thinking more complicated for teachers (Watkins, et al., 2018). Noticing student thinking as it unfolds in class could, however, enable teachers to adapt their instruction and actions based on that thinking in order to support student learning (Hammer, et al., 2012; Cowie, et al., 2018). Previous research suggested that students' science thinking could become observable during conversations between teachers and students surrounding students' design plans and drawings (e.g. Roth, 1994; Guzey and Aranda, 2017). This study's findings reveal that teachers may use such conversations, at a small-group level, to become aware of students' thinking about chemistry concepts.

This study's use of the chemical thinking framework (Sevian and Talanquer, 2014), also yielded the unique finding that a chemistry teacher may notice student thinking concerning a variety of progress variables and crosscutting chemistry concepts in a design-based classroom context. Even within single conversations we could find Teacher 1 to notice student thinking related to various crosscutting chemistry concepts (e.g. chemical identity, chemical mechanism and benefits-costs-risks). Conversely, Teacher 2's case illustrates that a teacher's noticing scope may be quite narrow in terms of involved crosscutting chemistry concepts. Teacher 2's noticing instances centred on progress variable 11, which is associated with the crosscutting concepts of chemical identity and benefits-costs-risks. While design projects typically target certain science concepts, research has shown that design activities can give rise to student thinking about a greater variety of science concepts (Siverling, et al., 2019). We also observed this phenomenon in our study's data, and across teachers' focus design teams. Teacher 1's noticing reflected the range of crosscutting chemistry concepts which appeared to be relevant in students' thinking to a greater extent than Teacher 2's noticing. We also found more instances of Teacher 1 noticing chemical thinking during conversations with the design teams than in Teacher 2's case. While the focus teams' students were planning and drawing designs, Teacher 1 thus had more opportunities than Teacher 2 to tailor his actions in support of the students' thinking about a variety of chemistry concepts.

Our findings regarding research question 2 show that a teacher may draw on evidence from multiple sources in noticing chemical thinking during conversations in the context of design activities (e.g. student talk and gestures; Teacher 1). This is a promising finding, as blending evidence from multiple observable student behaviours can allow teachers to draw more accurate inferences about student thinking (Griffin, et al., 2010). The analysis of Teacher 2's use of sources of evidence suggests that a teacher may, on the other hand, use a less extensive variety of sources of evidence when noticing chemical thinking (a similar observation can be found in Lam and Chan, 2020). The findings additionally demonstrate that both teachers in this study used student talk as an important source of evidence in noticing students' chemical thinking. Researchers have similarly been turning to verbal student data to gain in-depth insight in students' chemical thinking (e.g. Yan and Talanquer, 2015; Banks, et al., 2015). And, this finding was to be expected as we had purposefully focussed our study's design on teachers' conversations with students. However, contrary to our own expectations and recommendations in literature (incl. Roth, 1994; English, et al., 2017; Kelley and Sung, 2017), we found no indications of either teacher using what students of focus teams had drawn or annotated as evidence. We did see that Teacher 1 used whether students had been drawing or were in the action of drawing as evidence. As researchers we observed that there had, however, been conversations where teams' emerging design drawings and annotations contained supporting and even supplementary evidence of chemical thinking. But, in the information buzzing and high-pressure environment of teacher-student conversations, students' chemical thinking had also been observable to teachers in other, perhaps more transparent and revealing sources of evidence.

Teacher noticing appears to be influenced by multiple factors, like teachers' epistemological framing (Russ and Luna, 2013; Wendell, Swenson, & Dalvi, 2019), pedagogical content knowledge (Meschede, Fiebranz, Möller, & Steffensky, 2017), teaching experience (Erickson, 2011), and beliefs about teaching, learning and students (van Es, 2011). Indeed, such factors may also have been at play in our study. For instance, Teacher 1 had said to believe that teams' annotated design drawings "contained no visible chemistry knowledge", which offers one possible explanation as to why we found no indications of the teacher using what student's had drawn or annotated as evidence. We also noted throughout the study that, while both teachers seemed to have multiple objects of interest during the conversations with designing students (as in Erickson, 2011), Teacher 1 appeared to have a more substantial interest in students' (chemical) thinking. For example, Teacher 1 stated in interviews that he valued that students were "sharing their thinking" with him, and that he saw conversations with design teams as an opportunity to "build bridges between chemistry and design". Teacher 2's interests during the conversations seemed to lie more with students' effort and task progress. And, with students' realisation that they were "supposed to" design a product with separate containers for reactants, and a mechanism for bringing these together ("that's the critical point of the design which actually always goes wrong"). This could be another example of what we had found in an earlier study, namely that these teachers had a different focus in their goals for designing in chemistry education (Stammes, Henze, Barendsen, & de Vries, 2020).

A teacher's noticing in classroom contexts is additionally impacted by factors such as the extent to which students disclose their thinking, either voluntarily or prompted (Cowie and Bell, 1999). We observed, for example, that Teacher 1 was asked more student questions, and a greater variety of questions in the course of the studied conversations than Teacher 2. Moreover, how teachers respond in class based on their noticing shapes subsequent classroom events, and the new information which teachers can make sense of (M. Sherin, Jacobs, et al., 2011). Also, characterisations of teacher noticing like the one in this study are framed by the research conditions (e.g. influenced by the extent to which stimulated-recall interviews tapped into teachers' noticing; M. Sherin, Russ, et al., 2011).

Implications for future research

Teacher noticing is highly situated in nature, complicating the creation of teacher noticing measures that may be enacted across contexts (Thomas, 2017). Our study suggests, though, that the chemical thinking framework (Sevian and Talanquer, 2014) could offer one such measure for investigations into teachers' content-specific noticing in chemistry educational contexts. Characterisations of student thinking in a content area can support researchers in robustly identifying and describing instances of teacher noticing (Nickerson, et al., 2017). Researchers' characterisations of students' chemical thinking based on elements of the framework proved to be useful for characterising teachers' noticing in our study's open-ended design context. In future work, researchers could also use descriptions of productive intermediate student understandings (Sevian and Talanquer, 2014), to evaluate and possibly stimulate the development of chemistry teachers' noticing. Learning to notice productive beginnings in students' thinking may help teachers to discriminate among a range of observable student ideas, and leverage those which have a high potential for supporting student learning (Stockero, Leatham, Van Zoest, & Peterson, 2017). Such studies could also explore the value of combining the chemical thinking framework with content-independent frameworks to characterise the nature and quality of teachers' developing noticing (e.g. Van Es and Sherin, 2008; Talanquer, et al., 2015).

Our exploratory study points to more directions for future research. Researchers can use our codes distinguishing sources of evidence as a provisional analysis framework in other studies set in design-based science contexts. Follow-up studies could investigate teachers' use of sources of evidence among a bigger group of science teachers, and across different design activities. And, compare how teachers use various sources as they identify and perhaps connect different disciplinary aspects of students' thinking (e.g. design and chemical thinking). This may help us understand how teachers negotiate multiple foci of interest in design-based science classrooms. Such studies could also explore the benefits of asking teachers to point to elements of videoclips and student artefacts while talking about their noticing, and of videotaping teachers' interview responses as a way of gaining deeper insight in teachers' use of evidence. Future research efforts could additionally build on this study by exploring how science teachers can (learn to) use various sources of evidence in class, including design-based ones, to draw in-the-moment and high-quality inferences about students' thinking while students design.

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References

Apedoe, X. S., Reynolds, B., Ellefson, M. R., & Schunn, C. D. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology, 17*(5), pp. 454-465.

Banks, G., Clinchot, M., Cullipher, S., Huie, R., Lambertz, J., Lewis, R., . . . Talanquer, V. (2015). Uncovering chemical thinking in students' decision making: A fuel-choice scenario. *Journal of Chemical Education, 92*(10), pp. 1610-1618.

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: Examining the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education, 45*, pp. 83-93.

Berland, L., Steingut, R., & Ko, P. (2014). High school student perceptions of the utility of the engineering design process: Creating opportunities to engage in engineering practices and apply math and science content. *Journal of Science Education and Technology, 23*(6), pp. 705-720.

Board of Tests and Examinations [CvTE]. (2013). *Scheikunde VWO: Syllabus central examen 2013. [Chemistry VWO: Syllabus central exam 2013]* Utrecht: College voor Toetsen en Examens.

Chan, K. K. H., Xu, L., Cooper, R., Berry, A., & van Driel, J. H. (2020). Teacher noticing in science education: do you see what I see? *Studies in Science Education*, pp. 1-44.

Chusinkunawut, K., Henderson, C., Nugultham, K., Wannagatesiri, T., & Fakcharoenphol, W. (2020). Design-Based Science with Communication Scaffolding Results in Productive Conversations and Improved Learning for Secondary Students. *Research in Science Education*, pp. 1-18.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching, 48*(10), pp. 1109-1136.

Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice, 6*(1), pp. 101-116.

Cowie, B., Harrison, C., & Willis, J. (2018). Supporting teacher responsiveness in assessment for learning through disciplined noticing. *The Curriculum Journal, 29*(4), pp. 464-478.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), p 738.

Cullipher, S., Sevian, H., & Talanquer, V. (2015). Reasoning about benefits, costs, and risks of chemical substances: mapping different levels of sophistication. *Chemistry Education Research and Practice, 16*(2), pp. 377-392.

Dalvi, T., & Wendell, K. (2017). Using student video cases to assess pre-service elementary teachers' engineering teaching responsiveness. *Research in Science Education, 47*(5), pp. 1101-1125.

Dini, V., Sevian, H., Caushi, K., & Orduña Picón, R. (2020). Characterizing the formative assessment enactment of experienced science teachers. *Science Education, 104*(2), pp. 290-325.

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake resistant buildings. *The Journal of Educational Research, 110*(3), pp. 255-271.

Erickson, F. (2011). On noticing teacher noticing. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (1st ed., pp. 17-34). Abingdon, Oxon: Routledge.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), pp. 1081-1110.

Furtak, E. M. (2012). Linking a learning progression for natural selection to teachers' enactment of formative assessment. *Journal of Research in Science Teaching, 49*(9), pp. 1181-1210.

Griffin, P., Murray, L., Care, E., Thomas, A., & Perri, P. (2010). Developmental assessment: Lifting literacy through professional learning teams. *Assessment in Education: Principles, Policy & Practice, 17*(4), pp. 383-397.

Guzey, S. S., & Aranda, M. (2017). Student participation in engineering practices and discourse: An exploratory case study. *Journal of Engineering Education, 106*(4), pp. 585-606.

Guzey, S. S., Harwell, M., Moreno, M., Peralta, Y., & Moore, T. J. (2017). The impact of design-based STEM integration curricula on student achievement in engineering, science, and mathematics. *Journal of Science Education and Technology, 26*(2), pp. 207-222.

Hammer, D., Goldberg, F., & Fargason, S. (2012). Responsive teaching and the beginnings of energy in a third grade classroom. *Review of Science, Mathematics and ICT Education, 6*(1), pp. 51-72.

Haug, B. S., & Ødegaard, M. (2015). Formative assessment and teachers' sensitivity to student responses. *International Journal of Science Education, 37*(4), pp. 629-654.

Hiebert, J., Morris, A. K., Berk, D., & Jansen, A. (2007). Preparing teachers to learn from teaching. *Journal of Teacher Education, 58*(1), pp. 47-61.

Jacobs, V. R. (2017). Complexities in measuring teacher noticing: Commentary. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 273-279). Cham: Springer.

Jacobs, V. R., Lamb, L. L., Philipp, R. A., & Schappelle, B. P. (2011). Deciding how to respond on the basis of children's understandings. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (1st ed., pp. 97-116). Abingdon, Oxon: Routledge.

Johnson, A. W., Wendell, K. B., & Watkins, J. (2017). Examining experienced teachers' noticing of and responses to students' engineering. *Journal of Pre-College Engineering Education Research, 7*(1), p 2.

Kelley, T. R., & Sung, E. (2017). Sketching by design: teaching sketching to young learners. *International Journal of Technology and Design Education, 27*(3), pp. 363-386.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., . . . Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design (tm) into practice. *The Journal of the Learning Sciences, 12*(4), pp. 495-547.

Lam, D. S. H., & Chan, K. K. H. (2020). Characterising pre-service secondary science teachers' noticing of different forms of evidence of student thinking. *International Journal of Science Education, 42*(4), pp. 576-597.

Levin, D. M., Hammer, D., & Coffey, J. E. (2009). Novice teachers' attention to student thinking. *Journal of Teacher Education, 60*(2), pp. 142-154.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), pp. 370-391.

Luna, M. J., Selmer, S. J., & Rye, J. A. (2018). Teachers' noticing of students' thinking in science through classroom artifacts: In what ways are science and engineering practices evident? *Journal of Science Teacher Education, 29*(2), pp. 148-172.

Mason, J. (2011). Noticing: Roots and branches. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (1st ed., pp. 65-80). Abingdon, Oxon: Routledge.

Meijer, M. R., Bulte, A. M., & Pilot, A. (2009). Structure–property relations between macro and micro representations: Relevant meso-levels in authentic tasks. In J. Gilbert & D. Treagust (Eds.), *Models and modelling in science education: Multiple representations in chemical education* (pp. 195-213). Dordrecht: Springer.

Meschede, N., Fiebranz, A., Möller, K., & Steffensky, M. (2017). Teachers' professional vision, pedagogical content knowledge and beliefs: On its relation and differences between pre-service and in-service teachers. *Teaching and Teacher Education, 66*, pp. 158-170.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2013). *Qualitative data analysis: A methods sourcebook.* Los Angeles, CA: Sage Publications.

Morris, A. K. (2006). Assessing pre-service teachers' skills for analyzing teaching. *Journal of Mathematics Teacher Education, 9*(5), pp. 471-505.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.

Neumann, S., & Hopf, M. (2017). Discovering Children's Science Associations Utilizing Drawings. In P. Katz (Ed.), *Drawing for Science Education* (pp. 111-121). Rotterdam: Sense Publishers.

Ngai, C., & Sevian, H. (2017). Capturing chemical identity thinking. *Journal of Chemical Education, 94*(2), pp. 137-148.

NGSS Lead States [NGSS]. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.

Nickerson, S. D., Lamb, L., & LaRochelle, R. (2017). Challenges in measuring secondary mathematics teachers' professional noticing of students' mathematical thinking. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 381-398). Cham: Springer.

Roth, W. M. (1994). Thinking with hands, eyes, and signs: Multimodal science talk in a grade 6/7 unit on simple machines. *Interactive Learning Environments, 4*(2), pp. 170-187.

Ruiz-Primo, M. A. (2011). Informal formative assessment: The role of instructional dialogues in assessing students’ learning. *Studies in Educational Evaluation, 37*(1), pp. 15-24.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching, 50*(3), pp. 284-314.

Saldaña, J. (2016). *The coding manual for qualitative researchers.* Los Angeles, CA: Sage Publications.

Santagata, R. (2011). From teacher noticing to a framework for analyzing and improving classroom lessons. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers’ eyes* (1st ed., Vol. 152, pp. 168). Abingdon, Oxon: Routledge.

Sevian, H., & Talanquer, V. (2014). Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research Practice, 15*(1), pp. 10-23.

Sherin, B., & Star, J. R. (2011). Reflections on the study of teacher noticing. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers’ eyes* (1st ed., pp. 66-78). Abingdon, Oxon: Routledge.

Sherin, M. (2017). Exploring the boundaries of teacher noticing: Commentary. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 401-408). Cham: Springer.

Sherin, M., Jacobs, V., & Philipp, R. (2011). Situating the study of teacher noticing. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (1st ed., pp. 3-13). Abingdon, Oxon: Routledge.

Sherin, M., Russ, R. S., & Colestock, A. A. (2011). Accessing mathematics teachers’ in-the-moment noticing. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers’ eyes* (1st ed., pp. 79-94). Abingdon, Oxon: Routledge.

Siverling, E. A., Suazo-Flores, E., Mathis, C. A., & Moore, T. J. (2019). Students' use of STEM content in design justifications during engineering design-based STEM integration. *School Science and Mathematics, 119*(8), pp. 457-474.

Stammes, H., Henze, I., Barendsen, E., & de Vries, M. (2020). Bringing design practices to chemistry classrooms: studying teachers’ pedagogical ideas in the context of a professional learning community. *International Journal of Science Education, 42*(4), pp. 526-546.

Stockero, S. L., Leatham, K. R., Van Zoest, L. R., & Peterson, B. E. (2017). Noticing distinctions among and within instances of student mathematical thinking. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 467-480). Cham: Springer.

Superfine, A. C., Fisher, A., Bragelman, J., & Amador, J. M. (2017). Shifting perspectives on preservice teachers’ noticing of children’s mathematical thinking. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 409-426). Cham: Springer.

Talanquer, V., Bolger, M., & Tomanek, D. (2015). Exploring prospective teachers' assessment practices: Noticing and interpreting student understanding in the assessment of written work. *Journal of Research in Science Teaching, 52*(5), pp. 585-609.

Taylan, R. D. (2017). Characterizing a highly accomplished teacher’s noticing of third-grade students’ mathematical thinking. *Journal of Mathematics Teacher Education, 20*(3), pp. 259-280.

Thomas, J. N. (2017). The ascendance of noticing: Connections, challenges, and questions. In E. Schack, M. Fisher & J. Wilhelm (Eds.), *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 507-514). Cham: Springer.

Valtorta, C. G., & Berland, L. K. (2015). Math, science, and engineering integration in a high school engineering course: A qualitative study. *Journal of Pre-College Engineering Education Research, 5*(1), p 3.

van Es, E. A. (2011). A framework for learning to notice student thinking. In M. Sherin, V. Jacobs & R. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (1st ed., pp. 134-151). Abingdon, Oxon: Routledge.

Van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers'"learning to notice" in the context of a video club. *Teaching and Teacher Education, 24*(2), pp. 244-276.

Walkoe, J., Sherin, M., & Elby, A. (2019). Video tagging as a window into teacher noticing. *Journal of Mathematics Teacher Education*, pp. 1-21.

Watkins, J., McCormick, M., Wendell, K. B., Spencer, K., Milto, E., Portsmore, M., & Hammer, D. (2018). Data-based conjectures for supporting responsive teaching in engineering design with elementary teachers. *Science Education, 102*(3), pp. 548-570.

Weinrich, M., & Talanquer, V. (2015). Mapping students' conceptual modes when thinking about chemical reactions used to make a desired product. *Chemistry Education Research and Practice, 16*(3), pp. 561-577.

Wendell, K. B., Swenson, J. E., & Dalvi, T. S. (2019). Epistemological framing and novice elementary teachers' approaches to learning and teaching engineering design. *Journal of Research in Science Teaching, 56*(7), pp. 956-982.

Yan, F., & Talanquer, V. (2015). Students' ideas about how and why chemical reactions happen: mapping the conceptual landscape. *International Journal of Science Education, 37*(18), pp. 3066-3092.