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Drawing meaning from student-generated drawings: exploring chemistry teachers' noticing†

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This study explored experienced chemistry teachers' noticing when using student-generated drawings as evidence. While drawings of chemical entities and processes may offer valuable information on student thinking, little is known about how teachers draw meaning from student drawings. To explore this area, we investigated three experienced chemistry teachers' noticing. Teacher noticing refers to the processes through which teachers pay attention to certain observable information, and interpret what they attend to. In this study, we examined what types of drawing features stood out to teachers, and what analytic approaches (or stances) they used. We collected data on teachers' in-the-moment noticing (within their active classrooms), and on their delayed noticing (when teachers reviewed drawings after class). The findings demonstrate teachers' ability to attend to chemistry-specific details in students' drawings in both noticing settings. Teachers recognised several visual forms in student drawings, depictions of quantities, chemical entities at different length scales, and various chemical properties and behaviours. Findings furthermore showcase how two common analytic approaches (*i.e.* evaluation and sense making) can manifest in a drawing context. The study's results, tied to real classroom settings, yield ways of looking at student drawings that may help (beginning) chemistry teachers to leverage drawing activities as a window into student thinking. The study's analytic framework and detailed characterisations could furthermore be used by teacher educators and researchers who are seeking to support or examine teacher noticing as a key aspect of (chemistry) teacher expertise.

Introduction

Student-generated drawings can offer a unique window into students' developing thinking in chemistry (Cooper *et al.*, 2017). Drawings in chemistry are used to connect the tangible, macroscopic world to the theoretical models developed to understand and control observed chemical phenomena, and to support reasoning and discussion (Kozma *et al.*, 2000; Cooper *et al.*, 2017). Through analyses of student drawings, researchers have gained valuable insights into secondary school students' thinking about chemistry concepts such as chemical reactions and structure and properties of matter (*e.g.* Nyachwaya *et al.*, 2011; Zhang and Linn, 2013; Cooper *et al.*, 2015; Cheng, 2018; Ryan and Stieff, 2019; Stammes *et al.*, 2023). *Teachers*' analyses of student-generated drawings have, however, received little research attention so far. Some explorative studies do suggest that student-generated drawings of chemical entities and processes may be relevant to teachers' classroom practice (Stammes *et al.*, 2021; Jazby *et al.*, 2022). But, previous work has mainly investigated how chemistry teachers use their own drawings or drawings provided by curriculum materials (see, *e.g.*, Eilam and Gilbert, 2014).

The present study uses the construct of teacher noticing to explore how chemistry teachers approach the analysis of student-generated drawings. We thereby take teacher noticing to concern the intertwined processes of paying selective attention to certain observable information, and interpreting what is attended to (Sherin *et al.*, 2011a). Some of the information that is available to a teacher may be more meaningful to them, or may better support their noticing of student thinking (Jazby *et al.*, 2022). A better understanding of teacher noticing in drawing contexts can yield insights into how students can make their thinking noticeable in drawings, and how teachers can interpret student drawings. This is of particular importance as teacher noticing is increasingly considered a core aspect of science teachers' expertise (Chan *et al.*, 2021), while we know little about how chemistry teachers draw meaning from student drawings.

Our study specifically examines what features of student drawings are of interest to three experienced chemistry teachers, and what analytic approaches (or stances) they adopt when asked to notice students' chemical thinking

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(*i.e.* students' ideas and/or reasoning regarding chemistry concepts). We collected and analysed data on teachers' 'in-the-moment' as well as 'delayed' noticing, since drawings offer a source of information that a teacher may access both during and after class (*cf.* Lam and Chan, 2020). Studying teacher noticing so closely tied to teachers' actual classroom practice is not yet common in chemistry education research, which means that this study's findings provide a rather unique window into this important aspect of chemistry teacher expertise.

Theoretical framework

Student-generated drawings in chemistry

Drawing activities can serve multiple purposes in education (*cf.* Ainsworth *et al.*, 2011), of which research often stresses that student-generated drawings can offer a unique window into student thinking. Chemists use drawings to connect the physical, macroscopic world to the theoretical models of invisible chemical entities and processes which seek to describe, explain or predict chemists' macroscopic experiences (Kozma *et al.*, 2000). Like other types of visualisations (*e.g.*, animations, 3D artefacts), drawings represent core components of theoretic models, and facilitate thinking and communication (Talanquer, 2011).

Analyses of student-generated drawings (also known as sketches) have revealed students' ways of thinking about concepts such as chemical reactions and the structure and properties of matter (incl. Nyachwaya *et al.*, 2011; Zhang and Linn, 2013; Cooper *et al.*, 2015; Cheng, 2018; Ryan and Stieff, 2019; Stammes *et al.*, 2023). Researchers found, for instance, that students may consider matter like calcium carbonate to behave as molecular compounds upon dissolution, by observing students to draw such matter as a single unit rather than as polyatomic ions (Nyachwaya *et al.*, 2011). Consultation of student drawings can even unveil aspects of thinking in chemistry that may not be as evident in, for instance, students' talk or writing (Ryan and Stieff, 2019; Stammes *et al.*, 2023).

Various features of student-generated drawings may be of interest to those seeking to infer student thinking. For instance, examining students' use of circles of different sizes, colours and patterns, and how these circles were arranged into groups helped infer researchers student thinking about molecule composition (Ryan and Stieff, 2019). Distinguishable features of student-generated drawings, such as the way visual objects (*e.g.* circles, lines) or clusters of objects (*e.g.* a group of circles) are joined together or positioned in space, are seen as reflecting choices made by students when producing the drawings (Tang *et al.*, 2019). Carefully analysing such features can then reveal how a student thinks about a certain concept. For instance, analysing drawings of water molecules showed that some students drew oxygen and hydrogen atoms as intersecting circles while others drew these in a separate or adjoining manner. These different types of drawn associations between atoms implied different ways of thinking about intra-molecular bonds (Tang *et al.*, 2019).

A recent perspective on the nature of visual representations in chemistry also stresses the importance of paying attention to visualisations' distinctive features (Talanquer, 2022). Recognition of major visual aspects, such as the depicted length scale(s) and use of chemical symbols and/or icons, is considered necessary to be able to interpret their meaning. For instance, inferring chemical composition from an iconic, ball-and-stick visualisation of water requires paying attention to the colour of the balls. Inferring composition from a depiction of water as "H_2O" would call for recognition of chemical symbols. Both conceptual and perceptual processes are seen as playing a role in such analyses (*e.g.* knowledge of disciplinary conventions; fluency in processing visual information; Talanquer, 2022).

While previous research has thus brought forward approaches for analysing student drawings, little is known yet about chemistry teachers' analyses of student-generated drawings. In this study, we explore this understudied area from the perspective of teacher noticing.

Teacher noticing

Teacher noticing concerns the interrelated cognitive and perceptual processes though which teachers make sense of and manage the burst of sensory information they are faced with in classrooms or other instructional settings (Sherin *et al.*, 2011a). Teachers actively pay attention to some of what they see and hear, and interpret what they attend to (Sherin *et al.*, 2011a). Teacher noticing has been gaining traction in science education research as it is seen as a perspective that highlights the dynamic and situational nature of teachers' expertise (Chan *et al.*, 2021), as well as the more covert aspects of teachers' formative assessment enactment (Dini *et al.*, 2020).

Use of evidence. While there exist multiple conceptualisations of teacher noticing, teachers' interaction with evidence of student thinking tends to be emphasised throughout (incl. Goldsmith and Seago, 2011; Barnhart and Van Es, 2015; Talanquer *et al.*, 2015; Luna *et al.*, 2018; Murray *et al.*, 2020). Barnhart and Van Es (2015), for instance, targeted pre-service science teachers' ability to use evidence when making claims about student thinking, considering the rather superficial forms of student information novice teachers tend to focus on (*e.g.* seeing students staying on task as evidence of conceptual understanding). Teachers' ability to ground their inferences on student thinking in evidence is seen as a characteristic of more sophisticated noticing (Van Es, 2011). Researchers have also studied teacher noticing in relation to specific forms of student information, such as written work of students (Talanquer *et al.*, 2015; Murray *et al.*, 2020), or ephemeral evidence like verbal explanations and gestures (Lam and Chan, 2020). Different types of evidence hold different affordances for revealing student thinking (Hiebert *et al.*, 2007), and may also be used differently by teachers. Some information may, for instance, be more meaningful or easily recognised by teachers (Lam and Chan, 2020; Jazby *et al.*, 2022), or may be more or less associated with teachers focussing on students' correctness rather than underlying student thinking (Goldsmith and Seago, 2011).

Despite the opportunities that student-generated drawings can offer for revealing student thinking in chemistry, teacher noticing has not yet been investigated in detail in regards to this type of evidence. Previous research does present some examples of elementary science teachers using student artifacts including drawings when noticing (Luna *et al.*, 2018; Jazby *et al.*, 2022). This suggests that student drawings may indeed offer teachers noticing opportunities. Another study found, however, that a teacher working amidst the pressures of a design-based learning classroom may look more at *whether* students are drawing rather than *what* students are drawing, thus limiting noticing opportunities (Stammes *et al.*, 2021). Whether secondary school, chemistry teachers are able to recognise specific features of their student drawings in a more typical chemistry lesson still remains to be investigated. It is also not clear how two well-known noticing approaches may be used by teachers in a drawing context.

Analytic stances. Previous noticing research has demonstrated that teachers tend to use different analytic approaches, also referred to as 'stances', when asked to notice student thinking (Van Es and Sherin, 2008). For example, in a study on chemistry teachers' noticing regarding written work, some teachers predominantly evaluated student answers by focussing on their canonical correctness (Murray *et al.*, 2020). Other teachers took a sense-making approach more frequently, such as through speculating about student reasoning possibly underlying student writings (Murray *et al.*, 2020). These *evaluative* (*i.e.* focus on canonical correctness) and *sense-making* stances (*i.e.* focus on sensibility of student responses) can both be of value to teachers (Dini *et al.*, 2020; Murray *et al.*, 2020). Yet, researchers emphasise that a sense-making approach offers better possibilities for acknowledging and building on students' ideas and experiences (Van Es and Sherin, 2008; Dini *et al.*, 2020). While a certain form of evidence may be more associated with teachers adoption of one of these stances (Goldsmith and Seago, 2011), their manifestation has not yet been examined in regards to student drawings. To gain a better understanding of teacher noticing when using drawings as evidence, this study will therefore also examine teachers' analytic approaches.

Delayed and in-the-moment noticing. Student drawings provide a potential source of evidence that is accessible to teachers in class, so while students are engaged in drawing activities, as well as out of class if drawings are collected for post-active examination. Both of these situations provide noticing opportunities for teachers, referred to respectively as involving 'in-the-moment' and 'delayed' noticing. Delayed noticing occurs in contexts where teachers have some time to review collected student data (*cf.* Lam and Chan, 2020). While this type of noticing is regularly the focus of noticing research (*e.g.*, Talanquer *et al.*, 2015; Luna *et al.*, 2018; Murray *et al.*, 2020), there also exists work that has sought to probe teachers' in-the-moment noticing, amidst an active classroom. Jazby and colleagues (2022), for example, used data from classroom cameras and a recall interview to study the type of student artefacts that informed an elementary teacher's noticing. By examining the teacher's in-class gaze, and interview statements and gestures, they found that the teacher had noticed student thinking about gas production and solid dissolution through recognising details of students' playdough models, drawings and talk (Jazby *et al.*, 2022). Others have equipped teachers with head-mounted camera's to help access their in-the-moment noticing (Sherin *et al.*, 2011b). Since student drawings may be used as evidence in both noticing situations, we collect data on teachers' in-the-moment 'and' delayed noticing in this study.

Research aim and questions

Informed by our literature review, this study seeks to explore chemistry teachers' noticing of student thinking when using student drawings as evidence. We will specifically examine teachers' recognition of drawing features, and teachers' adoption of analytic stances. Both these noticing aspects are considered to involve intertwined perceptive and interpretative processes (Sherin and Star, 2011; Talanquer, 2022), which we will examine as a whole (following, *e.g.*, Dini *et al.*, 2020). We will probe the in-the-moment and delayed noticing of three chemistry teachers, in the context of their own chemistry classrooms and self-chosen drawing activity. This enables teachers to use what they know about their students, and the classroom activities as resources to support their noticing (Hiebert *et al.*, 2007; Van Es and Sherin, 2008), and yields insight into teacher noticing as occurring in school contexts.

To guide the study, we posed the following research questions:

(1) What features of student-generated drawings do three experienced chemistry teachers recognise when asked to notice student thinking in chemistry during and after class using student-generated drawings as evidence?

(2) What analytic stance(s) do three experienced chemistry teachers adopt when asked to notice student thinking in chemistry during and after class using student-generated drawings as evidence?

Research design

This case study used qualitative research methods to explore teacher noticing surrounding student-generated drawings in secondary school chemistry education. Three experienced chemistry teachers participated, who each implemented a drawing activity. We collected data on teachers' in-the-moment and delayed noticing using point-of-view cameras and (recall) interviews. We then analysed the data for teachers' recognition of drawing features and adoption of analytic stances. We describe the details of this research design in the following sections.

Participants and study context

The study took place in upper secondary chemistry education in the Netherlands. Three teachers, contacted through local networks on professional development and pre-service teacher supervision, were interested in and available to participate in the study. The teachers were included in the study because they offered access to the phenomenon of interest (*i.e.* teacher noticing surrounding student drawings), and were experienced chemistry teachers (13–15 years of teaching experience). The teachers also already occasionally engaged students in making drawings, such as drawings of electrochemical cells. All three teachers had had careers in chemical industry or academia previous to becoming a teacher.

We asked each participating teacher to plan a lesson for an upper secondary chemistry class with a drawing activity they personally deemed meaningful for making visible students' chemical thinking (*i.e.* ideas and/or reasoning concerning chemistry concepts). The drawing activity had to target thinking at (at least) a sub-microscopic scale, given the value of drawing activities for making visible student thinking at invisible scales (Cooper *et al.*, 2017), and the Dutch curricular emphasis on the chemical triplet. We also asked teachers to include icons (*i.e.* objects that resemble the nature of a chemical entity/process) as an aspect of their drawing activity in order to set these apart from drawing activities only involving chemical symbols (*e.g.* structural formula; chemical equations). Lastly, we asked teachers to consider how to gather information besides student drawings (*e.g.*, through including a written assignment, conducting one-on-one and/or whole class conversations) to help them infer meaning from drawings (also see, *e.g.*, Tang *et al.*, 2019). Lesson plans were discussed with the first author to come to activities that teachers saw as meaningful for uncovering student thinking, and that fit the requirements of the study.

Teachers 1 and 2 selected a 12th-grade chemistry class (resp. 24 and 10 students) for their activity, and Teacher 3 an 11th-grade class (16 students). All teachers independently chose electrochemistry as a topic. Teachers' drawing activities asked students to draw one or more electrochemical reactions which were just demonstrated in an experiment (Teacher 1), which students conducted themselves (Teacher 2), or that were described as taking place in a paper-based battery (Teacher 3). Details of these drawing activities are presented as Supplementary Materials 1 (ESI†).

Ethics statement. We obtained ethical approval for this study at the first author's institution (reference number REC22142). Formal procedures followed included obtaining informed consent from the teachers and their students (with the option to decline or withdraw participation).

Data collection

We collected data on chemistry teachers' noticing in two ways. The first probed teachers' in-the-moment noticing (amidst the active classroom), and the second teachers' delayed noticing (with more time to review and revisit students' drawings).

Teachers' in-the-moment noticing was accessed through tagged videos recorded from the teacher's point-of-view (POV), discussed during a stimulated-recall interview (following Sherin *et al.*, 2011b). We equipped each teacher with a head-mounted action camera and a hand-held clicker before the lesson. Teachers were asked to press the clicker whenever they "noticed something interesting regarding students' chemical thinking surrounding the drawing (activity)". The teacher's clicker and camera were synched so that each click resulted in a tag on the videotape. An additional camera was positioned at the back of the class to capture the lesson as a whole. The video from the POV camera was used for a recall interview immediately after the lesson. During this interview (*cf.* Sherin *et al.*, 2011b), a video still of each tagged instance was shown. The teacher was asked to explain why the moment had been tagged as interesting regarding students' chemical thinking, and – if that had not already become clear – in what (drawing) information the teacher had observed that. If the teacher did not recall the moment, the video was played back from about 15 seconds before the tag up to the tag, until the teacher recalled the moment. After all tags were discussed, we asked teachers to describe if there were any other, un-tagged outstanding moments, and whether they had used any criteria for tagging interesting moments (*cf.* Sherin *et al.*, 2011b).

In the second part of the interview, teachers were asked to look at the collected student work more calmly and extensively, while talking aloud about what they noticed regarding students' chemical thinking. We mentioned that some drawings might stand out more to them than others (*i.e.* noticing among drawings; *cf.* Stockero *et al.*, 2017). To elicit their noticing further, we occasionally asked why something was interesting to them (*e.g.* when a teacher quietly studied one drawing in particular), or in what drawing information a teacher had observed something (if the teacher had not communicated this already). When the teacher had reviewed students' drawings, we again asked whether they had used any criteria for determining interesting aspects. The two interview parts took a total of 52 to 59 minutes, after which we closed off with a few general questions about teachers' perceived value of student-generated drawings.

Interviews were videotaped to capture not only teachers' talk, but also, for example, their gestures (*e.g.* teacher pointing at a drawing). We additionally provided teachers with pens and paper to help them in explaining their thinking. Before the study's data collection, we tested the in-class camera setup during a regular lesson. This provided an opportunity for students to get acquainted with the setup, and for teachers to try out the head-mounted camera and tagging process. Collected student work (incl. drawings) was photographed.

Data analysis

We analysed the collected data on chemistry teachers' noticing from two dimensions, that of teachers' recognition of drawing features (RQ1), and teachers' adopted stances (RQ2). First, however, we organised the data, and selected relevant noticing units. We describe our approach in more detail next.

Organising and selecting data. First, we transcribed the video data and aligned the different data sources. The alignment regarding teachers' in-the-moment noticing entailed linking tagged classroom moments (in-class videos and transcript) to teachers' explanations of their in-the-moment noticing (first part interview video, transcript, any teacher notes), and the complete student work involved (photographs). We also linked teachers' delayed noticing (second part interview video, transcript, any teacher notes) to the student work discussed (photographs). We then selected those data sets that concerned teachers using student-generated drawings as evidence. For instance, when explaining one of the tags, Teacher 1 talked about having observed a student in class to have drawn two magnesium atoms relatively far apart. The linked POV video also showed such a drawing, with the teacher even pointing at the students' drawn atoms with a pencil while asking: *"But, do you really see magnesium like this, as two separate…?"*. We selected this unit for noticing involving student drawings as a form of evidence. We excluded data where we *only* observed teachers using evidence such as student talk or answers to non-drawing assignments.

We selected a total of 96 units of analysis (30–34 per teacher), with a unit consisting of the aligned data set regarding a teacher's full discussion of an in-class, drawing-related moment or after-class, analysed student drawing. Selected units were typically linked to one (developing) student drawing (see Supplementary Materials 1 for example drawings, ESI†), and on some occasions to more than one drawing (*e.g.* when a tag cued the teacher's recall of a more frequently observed pattern). In Teacher 1's and 3's cases, selected noticing units were (almost) evenly distributed among the two parts of the interview. In Teacher 2's case, the majority of units concerned the delayed noticing part of the interview. This teacher had tagged fewer moments in class (6 tags as opposed to 33 for Teacher 1 and 22 for Teacher 3), and relatively more time had been spend on the after-class analysis of drawings.

Coding recognition of drawing features. To answer research question 1, we examined the selected noticing units for teachers' identification of distinctive features of students' drawings. As an initial coding scheme, we used the framework presented in Talanquer (2022) which describes major distinctive features of visualisations in chemistry such as the use of symbols (*e.g.* chemical symbols depicting chemical elements) and icons (*e.g.* balls depicting atoms). We observed the teachers in our study to also highlight such features in their students' drawings. For example, one unit included Teacher 1 recalling *"[…] I also saw that they, well magnesium they drew onwards like this, and then oxygen they drew like this. Very close together […]"* while the teacher drew two sets of large circles (see Fig. 1a and b). Examining the linked POV video, and photographed student drawing showed that such circles had indeed been observable in class (see Fig. 1c). We thus coded the unit as the teacher having recognised *icons* in student drawings.

In addition to such deductive coding, we used inductive coding when coming across data that involved teachers recognising features not explicitly mentioned in the initial coding framework. For instance, in a unit concerning the analysis of the drawing shown in Fig. 1d, Teacher 2 comments included: *"[…] well it says 'precipitation' here at the [blue] circle, but I see two spheres. But, we know that M–N–O-two is the precipitation […]"*. Here, the teacher identified not only use of icons (*"two spheres"*), but also pointed out students' use of text (*"it says 'precipitation' here"*). Others have also noted that students' use of written words can play a role in making sense of drawings (incl. Tang *et al.*, 2019), and we included recognition of *text* as a drawing feature in our code book.

Through this iterative process of deductive and inductive coding, and carefully examining the different types of data, we developed a codebook describing four categories of drawing features recognised by teachers (see Supplementary Materials 2, ESI†). In a total of 14 out of 96 units, we could not identify recognition of any specific drawing feature. This occurred, for instance, when teachers very shortly evaluated a drawing's general (in)completeness (*e.g.* teacher saying *"well, here I am missing some things"*, and quickly turning to another drawing to discuss).

This first noticing dimension was initially coded by one author, and discussed with a research assistant in several iterations till consensus was reached. The second author checked the coherence of codes, and their application throughout this process. Disagreements were resolved through discussion and consensus. In the Results section, we describe the four categories of drawing features recognised by teachers, and present code occurrences.

Coding adoption of stances. Regarding the second research question, we studied selected noticing units for teachers' employed stance(s). Building on previous research (incl. Dini *et al.*, 2020; Murray *et al.*, 2020; Van Es and Sherin, 2021), we specifically looked for evidence of teachers adopting an evaluative and/or sense-making stance (*i.e.* focussing on canonical correctness and/or sensibility of student responses). In one unit, for instance, Teacher 3 recalled having seen a student drawing a single set of ions, and thinking: *"[…] draw at least two*

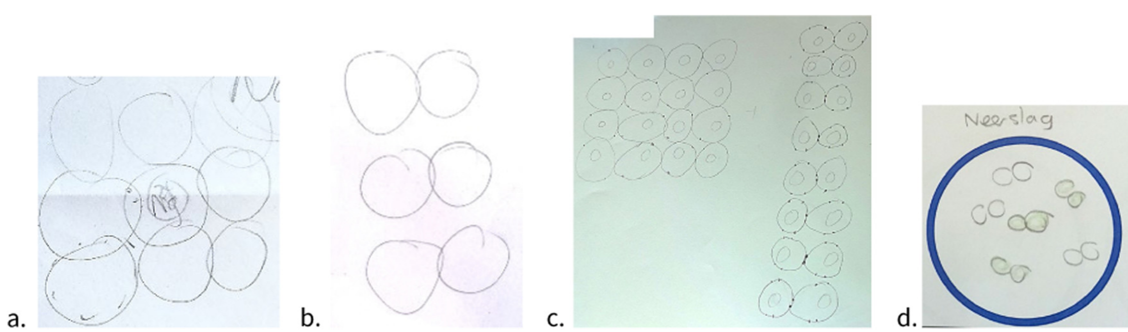

Fig. 1 (a) and (b) Teacher 1's drawings made while explaining an in-class noticing instance regarding student drawings of magnesium (a) and oxygen (b). During this interview moment Teacher 1 only drew the large circles in (a), other details were added later in the interview. (c) Student drawing in which Teacher 1 recognised use of icons. (d) Student drawing in which Teacher 2 recognised use of text (the Dutch word "neerslag" translates to "precipitation").

or three sets, you know, don't write this [teacher points at own notation of "LiPF6"] down just once, to me that's insufficient understanding of what an electrolyte is. You need multiple moving ions, and when you write this down once, well, than you haven't understood well what an electrolyte is. [...]". Here, the teacher evaluated the correctness of student thinking (understanding of electrolyte is insufficient/not well understood), and of the drawing's features (depicted quantity of ions is too little), and we coded the unit as 'evaluative'.

One unit could receive two stance codes. 19 units could not be coded as concerning evaluation and/or sense making. These units tended to involve teachers only describing a drawing's features and/or teachers reflecting on their own thinking or practice rather than on students. One author initially coded the data for this research question, and the other author recoded the data. Through discussion of disagreements and closer consultation of teachers' comments and gestures consensus was reached. We describe the two stances with examples and occurrences in the Results section.

Results

Recognised drawing features

The three teachers recognised a range of drawing features when asked to notice student thinking in chemistry using student-generated drawings. Features identified by teachers fell into four categories: *visual form, quantities, scale*, and *properties and behaviours*. Below, we first describe each category of drawing features, and then present code occurrences. Detailed descriptions and examples for all codes are also provided as ESI.†

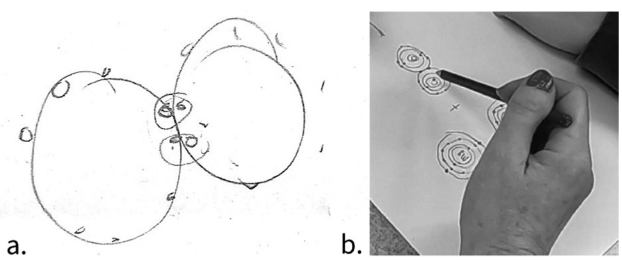

Fig. 2 (a) Drawing made by Teacher 1 concerning students' drawings of oxygen molecules during the stimulated-recall interview (the teacher drew the circles around the electron pairs at a later moment in the interview). (b) Video still of corresponding in-class moment with Teacher 1 using a pencil to tap and count depicted electrons.

Visual forms. The first category of drawing features concerned teachers recognising one or more visual forms in students' drawings. We discerned attention to the visual forms of *icons, chemical symbols, mathematical symbols*, and *text*. Teacher 1, for instance, showed to have identified icons in drawings of oxygen molecules when the teacher recalled: "*[...] Some had simply drawn eight electrons in the outermost shell. So like this [teacher starts making drawing of Fig. 2a], and then two, and then, so that's 1, 2, 3, 4, 5, 6, 7, 8. And in here, too. So just two electrons [extra] on both sides [...]*".

In this example, Teacher 1 had taken icons in the shape of circles and dots to resemble electron shells and electrons. Fig. 2b shows a video still of the corresponding in-class moment, with the teacher using a pencil to point at and count depicted electrons in a student drawing.

Teachers' noticing instances could involve more than one visual form, such as when Teacher 2 analysed the drawing of Fig. 3. In his analysis, Teacher 2 talked about the level of detail of the depicted chemical entities while pointing at, encircling and underlining with a finger the drawing's chemical symbols (K^+ and MnO_4^-) and icons (circles and groups of circles).

Quantities. The second category concerned teachers recognising quantities depicted in students' drawings. We discerned attention to two types of quantities in the teachers' noticing: *(relative) amounts* and *relative distances/sizes*. Teachers were regularly engaged in identifying amounts, either specific or relative amounts. Recognising specific amounts occurred, for instance, when Teacher 1 expressed counting the exact number of electrons depicted in drawings of oxygen molecules (see first example of previous section). Identifying amounts in relative or more general ways occurred, for example, when Teacher 3 observed "*here he has started to count more [ions]*". Teachers regularly compared amounts, such as when Teacher 3 counted and compared the exact number of depicted negatively and positively charged species in the electrolyte (Fig. 4a).

Teachers also highlighted relative distances between and sizes of drawn objects or object clusters. When analysing the drawing in Fig. 4b, for instance, Teacher 2 commented that "*the difference in size is probably depicting a difference in type of ions*". Teachers could identify both amounts and distance or size in a drawing. For example, Teacher 1's explanation for tagging a moment regarding a depiction of magnesium (see Fig. 4c) as being interesting included saying: "*That they think that you can depict a metal lattice with two atoms [...], and that he has drawn them so far apart.*".

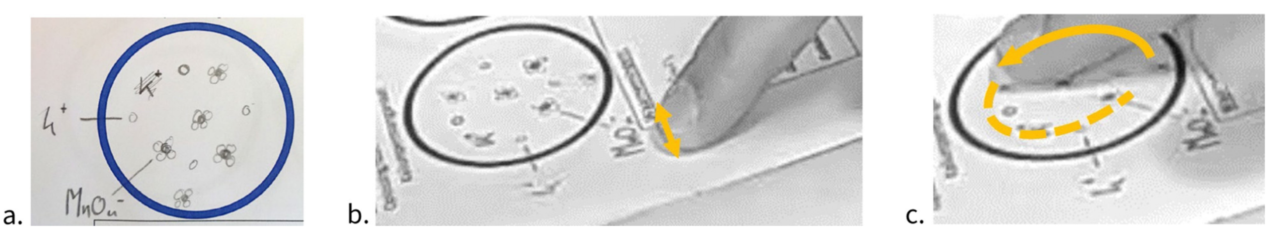

Fig. 3 (a) Student drawing from Teacher 2's class. (b) and (c) Video stills of Teacher 2 using a finger to underline and encircle the chemical symbols and icons in the drawing.

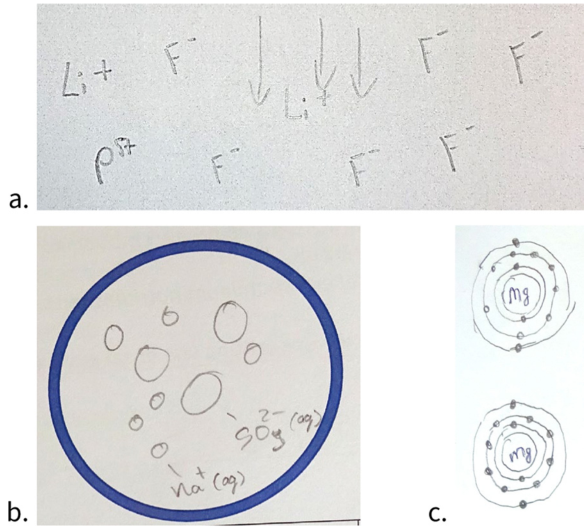

Fig. 4 (a) Drawing of electrolyte from Teacher 3's class in which the teacher counted the number of positively and negatively charged species. (b) Drawing from Teacher 2's class regarding which the teacher commented on the relative sizes of the different circles. (c) Drawing from Teacher 1's class regarding which the teacher commented on the relative distance between the two magnesium atoms.

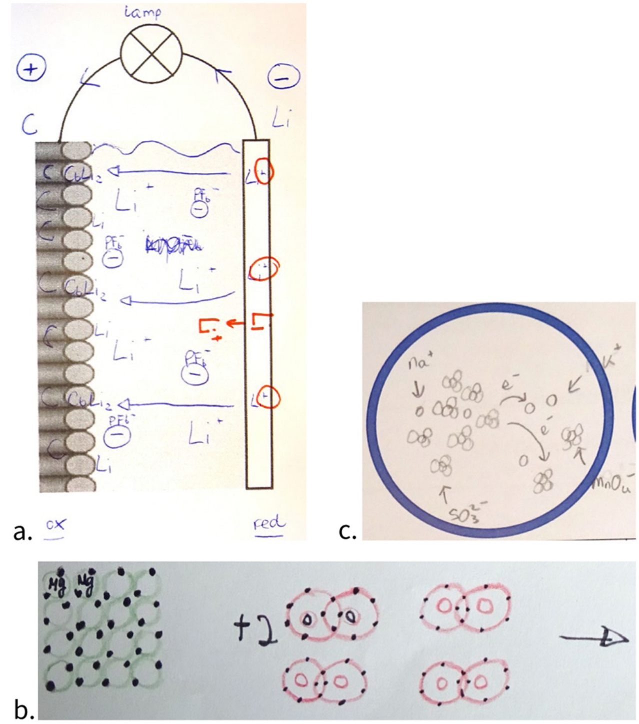

Fig. 5 (a) Student drawing from Teacher 3's class in which the teacher recognised a different macroscopic perspective on the arrangement of paper battery, lamp and wires (the student had turned the page 90 degrees). (b) Student drawing from Teacher 1's class in which the teacher highlighted object depicting the molecular-atomic scale. (c) Student drawing from Teacher 2's class in which the teacher recognised entities drawn at molecular-atomic and electronic scales.

Scale. The third category of drawing features concerned teachers recognising objects drawn at a certain length scale. We distinguished five codes in this category: *macroscopic, mesoscopic, particulate, molecular-atomic* and *electronic*. Each scale entailed teachers attending to different types of depicted chemical entities. At the macroscopic scale we found, for instance, Teacher 3 highlighting a differently drawn perspective on the order of a paper battery, light bulb and wires (see Fig. 5a), and depictions of lithium as "Li (s)". The mesoscopic scale encompassed attention to structures within a paper battery, and the particulate scale to a teacher identifying matter depicted as sub microscopic specks. At the molecular-atomic scale teachers recognised, for instance, drawings of molecules, metal lattices and salt structures, or of atoms within polyatomic ions. Attention to depictions of electrons, electron shells, nuclei and electronic components of ions characterised the electronic scale.

Noticing instances could revolve around one length scale in particular. When explaining a tagged moment concerning the drawing shown in Fig. 5b, for instance, Teacher 1 focused on drawn objects at the molecular-atomic scale as the teacher recalled having observed a mismatch in the stoichiometry of the depicted magnesium atoms and oxygen molecules (the mathematical symbol "2" was subsequently added by students). Teachers' noticing instances could also encompass multiple length scales. For example, while pointing at the various icons and symbols of the drawing in Fig. 5c, Teacher 2 commented: *"[...] This is the S–O-three. We also have potassium. Yes, and does this electron go to the potassium? Is the electron going to this one? This is Mn–O-four. [...]"*.

Here, Teacher 2 identified objects depicted at the molecular-atomic scale (the single and grouped circles; the symbols "SO_3", "K", "MnO_4"), and the electronic scale (the "e^-"s). Recognising drawn objects at multiple length scales essentially meant zooming in and out on students' drawings.

Properties and behaviours. The fourth and final category of drawing features concerned teachers identifying properties and behaviours of drawn objects. We discerned attention to *composition, structure, movement, state of matter, electrical aspects*, and *sequences of events*.

Composition entailed teachers highlighting the type or number of entities that a cluster of drawn objects consisted of. Structure involved teachers attending to their connectivity or spatial arrangement of objects. Teacher 1, for example, commented on both composition and structure when analysing a drawing of magnesium (see Fig. 6a). Teacher 1: *"[...] It is a rather elongated metal lattice. But, scanning this quickly, I do get the idea that the number of electrons is correct."*.

Identifying movement typically involved attention to arrows, such as when Teacher 2 traced the arrows with "e^-" signs of Fig. 5c with a finger, while wondering where these electrons were going to exactly. Teachers also identified states of matter in students' drawings. Teacher 1, for instance, remarked how oxygen molecules were drawn so close together by a duo of students, that the oxygen appeared to exist in an *"even more solid phase"* than the magnesium they had drawn (see Fig. 6b).

The teachers furthermore recognised various electrical aspects depicted in students' drawings. These included formal

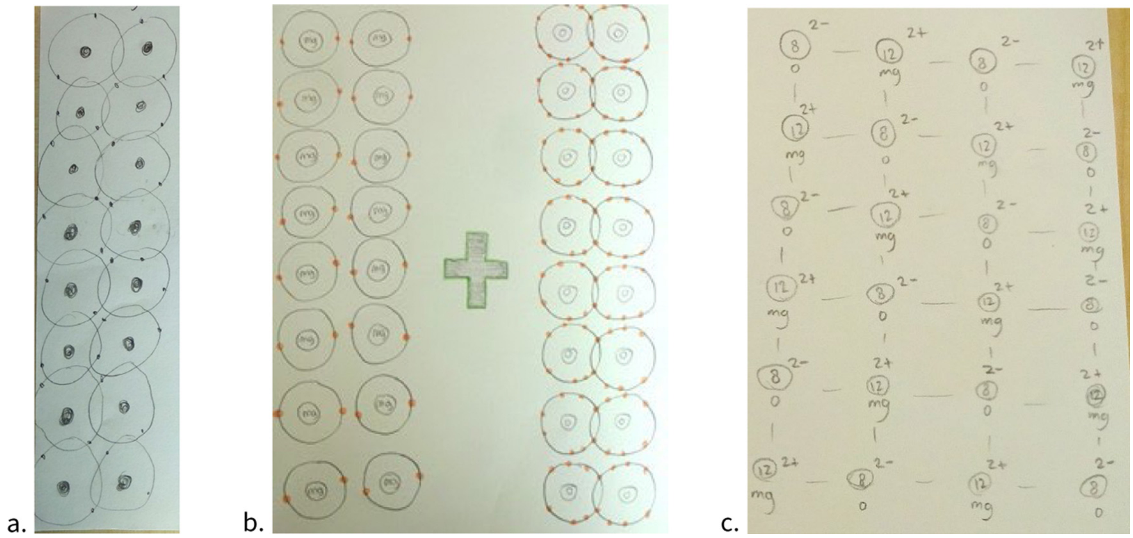

Fig. 6 (a) Student drawing from Teacher 1's class in which the teacher recognised chemical composition and structure. (b) Student drawing from Teacher 1's class in which the teacher recognised states of matter. (c) Student drawing from Teacher 1's class in which the teacher recognised electrical aspects.

charges and oxidation states; the role of electrons in ionic, metallic and covalent bonding; the loss, gain and transfer of electrons; and mechanisms of an electrochemical cell. Teacher 1 identified, for example, that students had drawn a salt lattice *"with formal charges"*, and *"with dashes"* as if perhaps indicating something tangible like a shared electron pair rather than electrostatic interactions (also see Fig. 6c).

The last feature within this category concerned teachers identifying sequences of events. Teacher 2, for example, compared two drawings made by a student, each depicting another moment of a redox reaction, while commenting: *"[...] Here you see the S–O-three-two-minus euhm, gaining electrons. And, that S–O-four-two-minus is then formed [...]"*.

Feature occurrences. We also examined how often teachers recognised certain drawing features. Across the in-the-moment and delayed noticing units, teachers recognised an average of six different drawing features per unit. In the delayed noticing data, teachers identified, on average, more types of features per unit than in the in-the-moment data (*e.g.*, 6.4 *vs.* 4.3 features per unit for Teacher 3). Recognition of two features was only found among teachers' delayed noticing data (*use of text* and *particulate scale*). Comparing feature occurrences also showed that each teacher recognised certain drawing aspects in particular (Fig. 7). We describe these patterns per case next.

Teacher 1 had asked students to draw the electrochemical reaction between magnesium and oxygen at a (sub) microscopic level by using an adapted Bohr model (see Supplementary Materials 1, ESI†). Within this drawing context, Teacher 1's noticing units often involved identifying *icons* in student drawings (*e.g.* dots representing electrons), and *(relative) amounts* and *distances/sizes* (*e.g.* number of atoms; distance between molecules). Teacher 1's noticing furthermore centred on chemical entities at the *molecular-atomic* and *electronic scales* (*e.g.* atoms in a metal lattice; electron shells). The teacher additionally recognised all six types of chemical properties and behaviours in her students' drawings. Identification of chemical *composition* and *structure* (*e.g.* of a magnesium atom) occurred most often, followed by highlighting of *electrical aspects* (*e.g.* role of electrons in ionic, metallic or covalent bonding).

Teacher 2's students had been asked to draw the progress of a few electrochemical reactions at three moments in time. For this teacher, identification of *icons* and *chemical symbols* was prevalent (*e.g.* circles representing atoms; use of chemical formula). Teacher 2 also identified *(relative) amounts* several times (*e.g.* number of depicted atoms), and entities at multiple length scales. Of these, the *molecular-atomic* scale was most prevalent (*e.g.* the atomic part of polyatomic ions), followed by the *electronic, particulate* and *macroscopic* scales. We did not observe identifications of chemical structure, but did find Teacher 2 identifying the other five types of chemical properties and behaviours in student drawings. Most often this concerned chemical *composition* (*e.g.* of ions), followed by *sequences of events*, *electrical aspects*, *movement* and *state of matter* (*e.g.* step-wise changes in matter composition; electron gain; electrons moving).

Teacher 3 had asked students to draw the components and mechanism of a paper battery. In this teacher's case, identification of *chemical symbols* (*e.g.*, chemical formula; charge signs) prevailed over the other visual forms. Teacher 3 also repeatedly identified *(relative) amounts* in her students' drawings (*e.g.* number of negatively charged ions). We furthermore observed attention to entities at all five length scales among this teacher's noticing instances, of which the *molecular-atomic* and *electronic scale* appeared most often (*e.g.* atoms in electrode; electron aspect of ions). Lastly, the teacher recognised all six types of properties and behaviours among students' drawings. She attended most frequently to chemical *composition* and *electrical aspects* (*e.g.* paper battery components; charges).

Adopted analytic stances

In addition to teachers' recognition of drawing features, we examined the data for teachers' adoption of two analytic stances: evaluation and sense making. The results show that

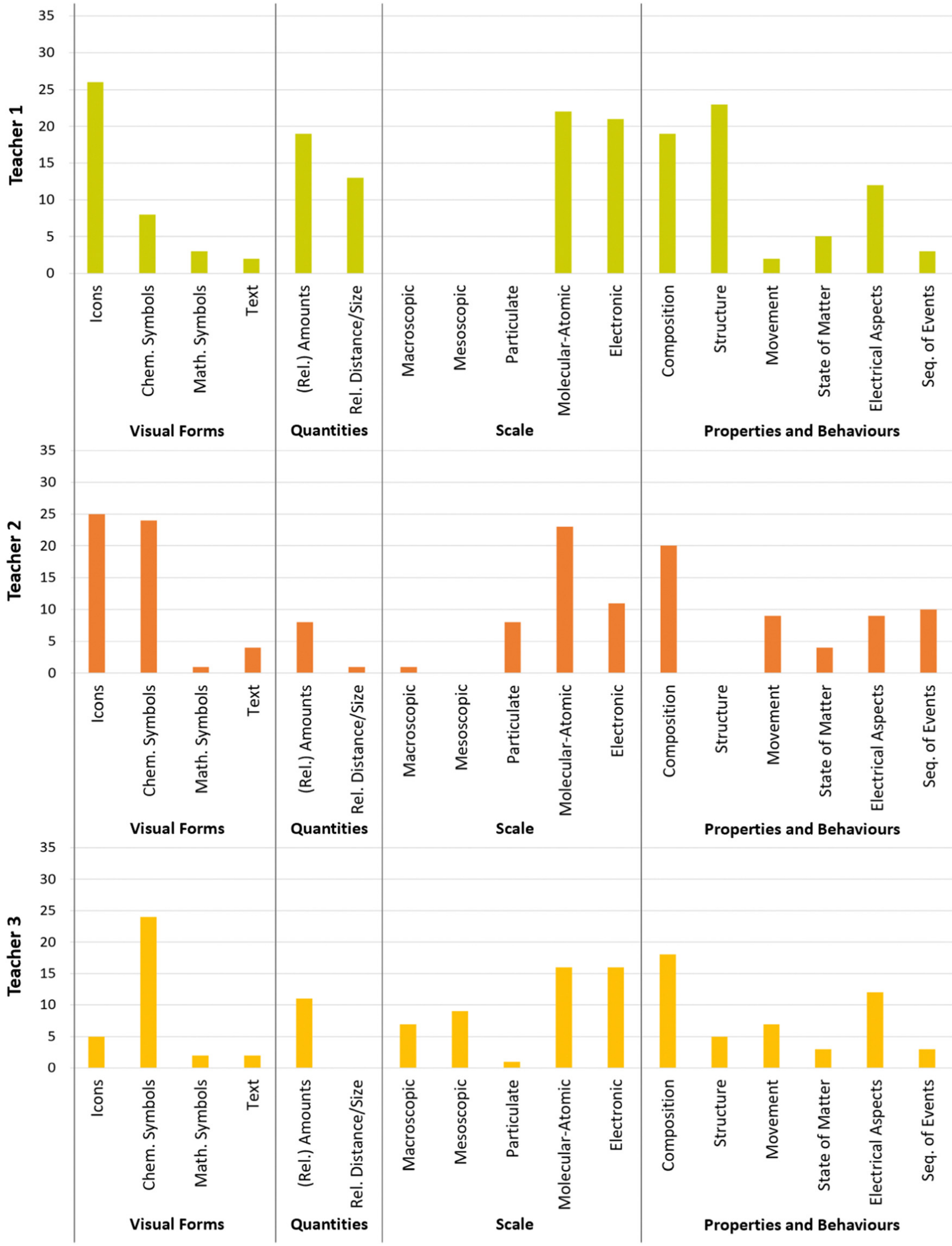

Fig. 7 Occurrances of recognised drawing features per teacher across the teacher's noticing units.

teachers used both these stances when asked to notice student thinking using drawings as evidence. Adoption of an evaluative stance took shape as teachers assessing the correctness or completeness of students' drawing and/or thinking against a canonical reference (*e.g.* canonical chemistry knowledge; how the teacher would have drawn a certain feature). Adoption of a sense-making stance placed more emphasis on finding the sensibility in students' drawing and/or thinking, and involved teachers trying to take a student's perspective to help them make sense of why a student may have drawn or thought something.

In the following paragraphs, we present descriptions and examples of how the two stances manifested in the data, and illustrate how this could coincide with teachers' recognition of drawing features. We then present stance occurrences.

Evaluative stance. The chemistry teachers often adopted an evaluative stance towards students' drawings. This approach entailed teachers assessing the correctness or completeness of students' drawing and/or thinking against some canonical reference. Specifically, teachers used students' drawings to evaluate the correctness or completeness of drawings (*e.g.* students having drawn certain features correctly or missing a feature), and/or of aspects of student thinking (*e.g.* students knowing something or lacking certain understanding).

For example, Teacher 3 evaluated both a student drawing's features and aspect of student thinking while reviewing the drawing of Fig. 5a. Teacher 3: *"[...] So, she dóes have a lot of lithium ions [teacher points at ions in electrolyte with a pen], but also did not draw [icons] here in the electrode [teacher points at lithium electrode]. Yes, it says, what does it say here? Oh, there's a plus here, that is also all wrong [teacher encircles a '+' with red pen], do you see it? So she, did she get it right here? I think so [teacher turns to the student's chemical equation on another sheet]. There she does, but she draws, do you see? What she does is, she should have, this one chánges into a lithium plus [teacher draws 'Li', arrow and 'Li +' in red], and she draws plusses here [teacher encircles more '+' signs]. Well, that's of course, then she hasn't understood it. [...]."*

In this example, the teacher first evaluated the correctness of several identified drawing features, including the quantity of lithium ions (*"dóes have a lot"*), and the use of the chemical symbol "+" suggesting a charge at the electrode (*"that is also all wrong"*; also see the teacher's notes in red ink in Fig. 5a). The teacher also highlights to be missing certain features, including the use of icons in addition to symbols (specifically circles representing atoms; *"did not draw"*). Teacher 3 then used her evaluation of drawn and not-drawn features to evaluate the student's understanding (*"then she hasn't understood it"*). We saw that teachers also used drawings to evaluate chemical ideas students did grasp. Teacher 2, for instance, pointed out in a drawing (see Fig. 8a) that the *"[student] knows very well what [substances] are formed"*. The teacher explained this assessment by highlighting the drawing's chemical symbols depicting specific compositions at the molecular-atomic and electronic scale. As another example, Teacher 3 concluded that *"[student] understands that [ions] fall apart"* upon dissolution when examining the drawing presented in Fig. 8b.

There were also noticing instances in which teachers evaluated drawings only, without explicitly inferring an aspect of student thinking. For instance, regarding a drawing of potassium and permanganate ions (Fig. 3a), Teacher 2 positively evaluated its depicted length scale and composition (*"much more in detail"*; *"the separate potassium and the four little oxygens and the manganese"*), but did not comment on an aspect of student thinking. Teacher 2: *"And the same thing is what you see here too. Much more in detail. The separate potassium and then the four little oxygens and the manganese. [...] I think that's beautiful. And I find it, appreciate it, or well how shall I put it? I find this coming closer to the truth, insofar as the truth is the truth [teacher laughs], than what I see here [teacher gestures towards another student's drawing of a polyatomic ion as a single sphere]."*

This example also illustrates how employing an evaluative stance involved teachers using a reference of 'correctness' towards students' drawings and/or thinking. Teacher 2, for instance, referred to some canonical *"truth"* in the excerpt above. Occasionally, teachers did come to question their exemplary reference when faced with student drawings. Teacher 1, for example, explained having seen a drawing of a metal structure depicted at an electronic scale with students *"intentionally"* having drawn overlapping circles representing electron shells, *"as if they had a shared electron pair"* (see Fig. 6a for such a drawing). The teacher subsequently recalled: *"[...] And then I thought, well I don't really know how I should respond to this, because those orbitals they, yeah they do overlap a little bit I think. But, then you get into those quantum mechanical things that you have such a band in which they exist, those electrons. And then I thought, well leave it be since it is not that wrong I think. But it is certainly not how we taught them, that [shells] are just touching each other, and, at least that is how I visualise it, maybe that's my misconception, but that [electrons] can cycle from the one to the other through the lattice [teacher draws an arrow in her own drawing of a metal lattice with touching circles; see Fig. 8c]."*

Sense-making stance. Teachers also occasionally adopted a sense-making stance when asked to notice student thinking using drawings. This stance entailed teachers trying to see the

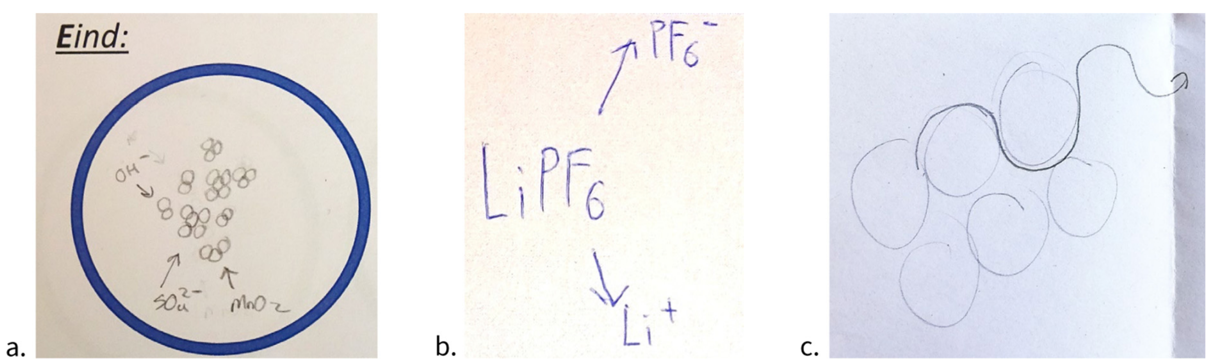

Fig. 8 (a) Student drawing from which Teacher 2 inferred knowledge about substance formation (the Dutch text reads "End"). (b) Student drawing from which Teacher 3 inferred understanding about the behaviour of ions in a solvent. (c) Drawing of Teacher 1 made when explaining how she herself visualises electron movement in a metal lattice.

sensibility in students' drawing and/or thinking by taking a student's perspective. Teachers would, for example, enquire into or speculate about underlying thinking, drawing construction actions, personal motivations or (classroom) experiences that could explain their observations.

For instance, when explaining a tagged moment regarding the drawing of Fig. 5a, Teacher 3 recalled: *"I liked this, because she had turned the drawing. She was the only one who started to draw it from the other side, and that's because the first [electrochemical] cells that I build [teacher starts to draw such a cell], they have like a beaker like this and a beaker like this and then here's your salt bridge, and here are your electrodes, and here is whatever. And, that's how we started with those cells. So, then she told me, 'yes because then it looks like what we did at the beginning'. So, she could understand it better by turning it."* Interviewer: *"Oh, yes, very interesting."* Teacher 3: *"Yes, so the others all did it like this [teacher turns her drawing]. Yes, that's a flat cell of course. But, she could understand it better because then the whole drawing looked like this one [teacher turns the drawing again], and so she knew 'Hey, they start here, this is the minus pole, through the lamp to the plus pole' [teacher traces a flow of electrons]. So, yes, she turned it in order to understand it."*

In this example, Teacher 3 recognised that a student had drawn a different macroscopic perspective on the arrangement of a paper battery, light bulb and wires. Given the student's previous experiences with electrochemical cells, the teacher considered this choice to make sense and to have even supported the student's understanding of the system's electrical properties.

When adopting a sense-making stance, teachers were sometimes careful in drawing inferences about student thinking from drawings. For instance, when reviewing the drawing of a salt structure, Teacher 1 highlighted students having drawn dashes between ions (Fig. 6c). The teacher contemplated how this could indicate the idea of there being some sort of tangible bond between ions, perhaps due to students having seen three-dimensional salt structures with physical links between spheres. But, Teacher 1 concluded: *"I don't know if the people who drew this did or did not think about that."*

Teachers' adoption of a sense-making stance regularly appeared together with the evaluative stance. For example, when recalling a certain tagged moment, Teacher 1 first evaluated a drawing of an oxygen molecule as having contained *"too many"* electrons. Then, while still using her own thinking as a reference, the teacher tried to see the sense in students' underlying thinking by speculating that students may have invented electrons in order to comply with their grasp of the octet rule. Teacher 1: *"[...] Yeah, apparently it is much more unclear to them than I think. I think, you only have a few elements that form molecules. And, carbon, oxygen, nitrogen are no strange, unfamiliar elements. So, then with oxygen, if you know that it has six [electrons] in its outer shell, than you should realise: so two too little, two overlap, that works out together with that, you know with that double bond. But, I think that they, that the octet rule is not yet clear, that they just invent two electrons extra to get to eight in the outer shell."*

Stance occurrences. We found the two stances, evaluation and sense making, to be adopted across the three teachers, and to occur in both types of noticing settings (*i.e.* in-the-moment and delayed). The majority of noticing instances involved teachers taking an evaluative stance towards students' thinking and drawings (24–28 units per teacher). The sense-making stance appeared less often in the data, namely in a total of thirteen units (2–7 units per teacher). Eleven of these thirteen units involved teachers taking both an evaluative and sense-making approach when using drawings as evidence. For example, a teacher evaluating the correctness of drawing features, ánd trying to see the sense in students' thinking.

Lastly, comparing teachers' stances against their recognition of drawing features showed that the majority of units contained evidence of teachers recognising features ánd taking an evaluative and/or sense-making stance (71 out of 96 selected units). The results presented above regarding teachers' analytic stances show examples of how teachers' identification of drawing features coincided with the stances. In the other units, we saw evidence of teachers either recognising drawing features or adopting a stance. These instances involved, for instance, teachers only describing the drawing features that stood out to them, or teachers evaluating a drawing's general (in)completeness without highlighting specific features. Yet, the majority of noticing instances thus concerned teachers identifying several drawing features in student-generated drawings, and using identified features for evaluation and/or sense making.

Discussion and conclusion

This study sought to explore chemistry teachers' noticing of student thinking when using student-generated drawings as evidence. We probed three experienced teachers' in-the-moment and delayed noticing, and examined the data from two perspectives: teachers' recognition of drawing features, and adoption of analytic stances.

Results regarding research question 1 reveal chemistry teachers' ability to identify chemistry-specific details in student-generated drawings. Previous research found that attending to the specifics of what students draw, say or write can be challenging for teachers (Barnhart and Van Es, 2015). For instance, teachers may focus on *whether* students are drawing in class rather than *what* students are drawing exactly (Stammes *et al.*, 2021). Conversely, our present study now showcases three experienced chemistry teachers who were able to identify chemistry-specific features in their students' drawings. The teachers recognised several *visual forms* in drawings, as well as depictions of *quantities*, entities at different *length scales* and chemical *properties and behaviours*. These features have elsewhere been posited as important for learners to recognise in order to grasp the meaning of a chemical visualisation (Talanquer, 2022). Our empirical findings now demonstrate that attending to these four categories of visual features can also help chemistry teachers to interpret student drawings. As such, this study's distinguished drawing features offer an analytic perspective that chemistry teachers and researchers could use and build on when interpreting student-generated drawings (*e.g.*, At what length scales have students portrayed chemical entities, and using which visual forms? What are differences in students' depictions of a certain chemical property or behaviour?). This study furthermore demonstrates that teachers may not only be able to attend to specific drawing features in the relative calmness of after-class drawing analysis, but even within the bustle of their active classrooms (particularly Teachers 1 and 3). Investigations into chemistry teachers' (in-the-moment) noticing of their own students' learning are still rare, so this study has yielded unique illustrations of how teacher noticing can occur both within and outside of authentic chemistry classrooms.

Findings regarding research question 2 demonstrate that two common teacher noticing approaches, namely evaluation and sense making, can also be found in a drawing context. While the prominence of these two noticing stances for chemistry teachers has been noted in relation to other types of student artefacts (see, *e.g.*, Murray *et al.*, 2020), this had not yet been investigated in regards to drawings. Our findings, which are tied to teachers' actual classroom practice, thus reemphasise the relevance of these stances for teachers in practice. While sense making tends to be considered more sophisticated as it better allows for acknowledging and building on students' ideas (Dini *et al.*, 2020; Murray *et al.*, 2020; Van Es and Sherin, 2021), use of an evaluative stance can help teachers meet school demands (*e.g.*, Teacher 3 also had to prepare students for an upcoming summative assessment). The present study's findings do appear to point to teachers' reflections on 'truth' as a possible way of nuancing a focus on students' (in)correctness. While teachers often evaluated students' drawings and thinking against a 'correct' canonical reference, they occasionally came to question this reference when confronted with students' take on the drawing assignment. Indeed, chemical visualisations like drawings reflect only certain core components of a theoretical model; a model that is based on assumptions (Talanquer, 2011). There can thus be multiple, chemically-acceptable outcomes when visually portraying entities or processes (Talanquer, 2022). We saw teachers to occasionally consider such aspects related to the nature of chemical visualisations. Perhaps this type of reflection could help chemistry teachers to come to complement an evaluative stance with one that focussing on trying to see the sensibility of students' drawing choices and their underlying thinking.

Lastly, while uncovering what students think requires room for students to make their own drawing choices (Tang *et al.*, 2019), teachers may also need students to depict certain drawing features to be able to draw meaningful inferences from drawings. We observed this when teachers expressed to be in want of a drawing feature they said would have helped them to speculate about students' thinking, such as a chemical symbol to help clarify the meaning of an icon. To aid chemistry teachers in enriching and shaping their information environment, this study's characterisation of drawing features might again be helpful. It provides terminology and drawing examples that teachers could use and expand on when designing a drawing activity or when interacting with students in class. Teachers could, for instance, instruct students to use certain 'icons' as well as 'chemical symbols' when drawing chemical entities. Or, based on a teacher's in-class observation, they could ask a student to add a depiction at the 'electronic scale' or to draw how the student thinks an entity would 'move'. Such shaping of contexts and interactions to gain access to additional student information supports teacher noticing (Van Es and Sherin, 2021).

Limitations and future research

This study's description of recognised drawing features and noticing stances offer new avenues for educational practice and research, while also having its limitations. The three teachers of this study each developed their own drawing activity, and we observed that each case could be characterised by teachers recognising certain drawing features in particular. Yet, all teachers connected their activity to the topic of electrochemistry which suggests that follow-up research involving different drawing contexts could be expected to expand the range of possibly meaningful drawing features (consider, *e.g.*, depictions of interactive forces as in Talanquer, 2022). Future work could also investigate teacher noticing in drawing contexts from additional perspectives, such as examining how teachers shape their information environment and how they combine information from various forms of evidence (*e.g.* verbal expressions or gestures; see Stammes *et al.*, 2021, for an example). This type of research would further increase our understanding of how chemistry teachers can leverage drawing activities for noticing student thinking.

We took care in this study to align teacher and student data in our analysis. Yet, the extent to which teachers' drawing inferences corresponded to students' drawing intentions, and how teachers' noticing influenced student thinking and representational practice remain to be investigated. It is also not yet clear to what extent teachers using evaluative and sense-making stances in conjunction, as we observed in this study, reflects a drawing-specific characteristic or perhaps an example of an emerging rather than sophisticated noticing expertise (as in, *e.g.*, Barnhart and Van Es, 2015). Supporting and examining the development of (novice) chemistry teachers' noticing regarding student-generated drawings is a topic for future research. Such efforts could make use of this study's analytic framework of drawing features, and suggestion regarding teachers reflecting on the nature of drawings in chemistry to potentially support teacher noticing.

Finally, to accurately characterise teacher noticing, we took care to collect and analyse multi-modal data (incl. teachers' point-of-view-data, talk, gestures and drawings). Our findings remain, nevertheless, limited by what teachers could share with us through these modes. Progress is being made with using eye-tracking to examine teacher noticing (Jarodzka *et al.*, 2021). Such methods might be able to shed further light onto the intricate relations between how teachers perceive and interpret student drawings.

Conclusion

While student-generated drawings can offer a unique window into student thinking (Ainsworth *et al.*, 2011; Cooper *et al.*, 2017), little was known about chemistry teachers' use of this potential source of information. The present study illuminated this phenomenon through the construct of teacher noticing. Our study's findings, originating from real classroom contexts, showcase experienced teachers' ability to recognise chemistry-specific features in student drawings, both during and after class. The results additionally unveil how two well-known analytic approaches, evaluation and sense making, can manifest in a drawing context. This study's findings and analytic framework yield affordances for chemistry teachers and teacher educators who seek to leverage drawing activities to gain insight into and possibly support student thinking. Moreover, the results suggest directions for future research into teacher noticing as a key aspect of (chemistry) teacher expertise.

Data availability

This paper's text, figures and ESI,† present supporting data which have been collected as described in the Data Collection section. Other data from this study's participants are not available due to ethical requirements.

Conflicts of interest

There are no conflicts to declare.

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