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Teacher practices of verbal support during a design project in the chemistry classroom

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Abstract
Design activities are gaining interest as rich contexts for learning science, technology, engineering, and mathematics (STEM) subjects. STEM teachers may find this challenging however, as designing requires support that they are not used to providing. In a subject like chemistry, teachers would have to balance creativity and responsibility for the students with concept learning and safety in the classroom. In a case study, we analyzed the verbal interactions of three teachers with their students during design activities in the classroom, with the aim of understanding what teachers and students talk about and how chemistry teachers support the students with their designs. During the lesson, students worked on the design of a self-heating or self-cooling cup, while also performing chemistry experiments to learn about the energy effects of reactions. Such a lesson reflects what design activities in the chemistry classroom could look like. We described the topics that teachers and students talk about, revealing that teachers support students through several types of feedback and questions. We also found that teachers support design tasks in a more open, constructive, and encouraging way than is used for experiments and chemistry concepts, which are supported in a closed, clarifying, and steering manner.

Keywords Design · Chemistry education · Design-based learning · Teacher–student interaction

Introduction

Learning through design contexts is a popular instructional model in science, technology, engineering, and mathematics (STEM) subjects, as it engages students in rich learning opportunities (Brophy et al., 2008). Design tasks help students to learn science by implementing their subject knowledge. Furthermore, these tasks also enable students to learn design skills, use their creativity, and take responsibility for their learning. The Next

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Generation Science Standard (NGSS) proposed the use of engineering practice to complement the experience of science practice, thereby deepening student experience and understanding of science concepts and practices (Bybee, 2014). The goal of technology and engineering education, according to the Standards for Technological and Engineering Literacy (STEL), is to develop students with broad knowledge and capabilities, who understand the interactions between technology, engineering and society (ITEEA, 2020).

In many schools, however, designing is not a mainstream activity. The increasing use of design projects in education presents STEM teachers with a new role, their inexperience of which may potentially pose difficulties for them. The distinction between 'teacher' and 'student' is less present during design projects, and the teacher is more a guide than an instructor or a repository of knowledge (see for instance Stricker, 2011). Teachers may feel uneasy with this new pedagogy (Stricker, 2011), as it moves away from the security and stability they typically experience.

In chemistry, one of the STEM subjects and the focus of this study, the research, production, and design of substances and new materials are important practices, and are often used as a context for learning about chemistry concepts. During chemistry classes, students can be introduced to chemical design, such as the product design of toothpaste or the production of a polymer; however, design-based chemistry projects, where students learn about concepts through the process of designing, are rare. To learn about reactions and processes, students in secondary chemistry education perform experiments, which are usually predetermined activities in which they analyze a teacher-expected outcome. This is far from the way chemical engineers work and the way in which chemistry evolves in reality.

Designing requires skills that are not readily present in chemistry education at the secondary education level. In addition to the problem-solving skills and scientific reasoning (amongst other skills) required in both chemistry and design education, designing also requires skills related to creativity, team work, (technical) drawing, and sketching. Furthermore, chemical design is also significantly different from engineering design, which is largely already present in science and technology subjects in school. Chemical design activities require the practical application of a chemical understanding of substance properties, reaction types, and the energy effects of reactions. While chemical design requires carefully measured substances mixed in practically irreversible processes, engineering design uses the construction of different materials to create a product. The latter generally has much more scope for tinkering and making swift adjustments. For students, experience is required in performing chemical design in the classroom. At the same time, chemistry teachers in most schools do not have experience with guiding students or student groups through design projects.

Undertaking design activities requires teachers to control and manage their classroom situation in a different way, and for some teachers this is difficult (Kolodner et al., 2003). Teachers need to organize the class, orchestrate and sequence the activities, and help students connect the science to the design (Kolodner et al., 2003). Design activities require the teacher to provide adaptive guidance, paying attention to the needs of the students. Considering the variety and creativity with which students can make new designs, the guiding role that teachers need to take is one where versatility and adaptability is important. Other studies that we have seen contain projects where the lesson, the composition of the project, and the teacher support is highly structured. These studies focus on the learning of students and the effectivity of concept learning (e.g. Apedoe et al., 2008; Van Breukelen et al., 2016), and while the importance of the role of the teacher is acknowledged, its dynamic and adaptive nature has not been studied. Design teachers interact with students in the classroom, talking with them about the design and its features. Through conversations with students, teachers guide them through the design activity and provide verbal support targeted at the knowledge level of the students to help them reason about their design.

In an in-depth case study, we analyzed the verbal support of experienced chemistry teachers who performed design-based chemistry projects with their students in the classroom. Our goal is to understand how teachers adapt their verbal support to students during design assignments, and how these can be integrated in the chemistry classroom. This specific area of research is, to a certain extent, uncharted, and this study leads to scientific insights into the possibilities and opportunities for teachers to adaptively and dynamically support design assignments for chemistry. The interactions between teachers and students are expected to include different means (i.e., feedback and questions) of supporting students during the design assignment. Mapping these means and connecting them to the context of the conversation helps us understand how teachers adapt their support based on the topics discussed. Furthermore, the results give practical pointers to help teachers of other STEM subjects who implement design tasks in their lessons.

Background

The role of a teacher in design education

In design education, teachers guide students and help them transition from one phase to another in the design process (Goldschmidt et al., 2014). This is not necessarily a linear pathway. Design problems can have multiple solutions, and the designer not only shapes the design, but also needs the awareness that choices have consequences, which in turn has consequences for the way design skills are acquired (McDonnell, 2016). Teachers therefore need to be aware of the intricate relationship between students and their design. Their guidance, on the one hand, contributes to student learning, empowerment, identity formation, and socialization into professional practice, while on the other hand it engages students in reflective practice, critical discourse, transformative learning, and self-authorship (Adams et al., 2016).

In a study on the practice of a design teacher in higher education (students from the 3rd year of a bachelor's degree and one graduate student) in the context of an Industrial Design course, McDonnell (2016) described the role of the teacher by analyzing his conversations with students when discussing their individual designs. She saw that the teacher gave very precise information on what to do but refrained from instructing and informing on how to think; instead, the teacher encouraged design reasoning. There is therefore a contrast between doing and thinking, and for the latter, the teacher guides, suggests, coaches, and facilitates, but does not do the thinking for the student. While reminding the students of the purpose and the tasks, the teacher also emphasizes the role of the students as the designers and pushes them to make choices. In this process, the teacher draws attention to features in the designs of students (both positive and negative), and invites students to notice them as well. In this process, the teacher does not explicitly mention negative aspects, but addresses these indirectly. Besides taking up the role of an expert or authority and a coach or a facilitator, the teacher may also act as a 'buddy' (Goldschmidt et al., 2010) and give the students a feeling of being on their side ('we'), while also maintaining what the student needs to do and leaving choices to them ('you') (McDonnell, 2016).

Engineering teachers in high school display four themes with regard to teaching strategies: (1) the use of competitions, (2) problem-based learning and teaching, (3) emphasis on creative thought and work, and (4) the teacher serving as guide rather than the knowledge base (Stricker, 2011). We can see several of these themes reflected in other literature as well. To promote design thinking in the classroom, the Learning by Design Cycle (Kolodner et al., 2003) proposes two cycles of activities. The first cycle deals with activities that students need to do with respect to the design and its creative process. The second cycle deals with activities concerning what the student needs to know and research in order to further the design. These cycles structure the design tasks for the student, so that the teacher can take the role of a guide. This combination of problem-based learning, creativity from students and guidance from the teacher resembles the themes described by Stricker (2011), and can be found in research on design activities for STEM in secondary education.

Design activities and chemistry education

Chemistry education, like other STEM subjects, uses laboratory experiments to help students understand the subject. The use of experiments touches upon the two cycles of 'need to know' and 'need to do'. The laboratory setting in science education provides students with opportunities to engage in investigation and inquiry (Hofstein & Lunetta, 2004). Not only is performing experiments useful for the student, but it can also be an instructional tool for teachers and a means of assessing student understanding (Hofstein, 2004). For chemistry, experiments are performed to improve the understanding of subject-specific concepts. When implementing design activities in the chemistry classroom, experiments can serve to improve the design itself and steer design choices. Experiments become a part of the 'need to know' in order to perform the design activities. It is important for teachers to carefully balance investigative activities and iterative design (Hmelo et al., 2000; Kolodner et al., 2003).

In a study by Apedoe et al. (2008) exploring a design project in the chemistry classroom, students were tasked with designing a self-heating or self-cooling cup. The lesson content, incorporating design activities and experiments, and the support provided by the teacher were rigidly structured over several lessons. Students exhibited better concept understanding and had more interest in engineering after the project. The results of such studies show the possible setups for design activities in chemistry, and their success. Apedoe et al. (2008) focused on the learning of chemistry concepts within structured lessons where the support is predetermined. The rigidly structured support, however, seems to contrast with the coaching, facilitating, reflective, and transformative guidance that Adams et al. (2016) and McDonnell (2016) described as beneficial for design education. The dynamic support that teachers provide to students in the context of design activities in the chemistry classroom is a required element to learn design skills, from the perspective of design education. This in turn may support the understanding of chemistry practice, in addition to the learning of chemistry concepts.

Scaffolding

Studies of design education in STEM subjects often describe the activity of a teacher in terms of scaffolding. Scaffolding is described as the titrated support (Tabak, 2004) and tailored support (Van de Pol et al., 2015) provided by a teacher or knowledgeable peer, through which a student reaches the required level of competence (Warwick et al., 2013). Scaffolding is also defined as temporary and responsive support (Jadallah et al., 2011).

It is suited to the situation and the student, as well as dosed in such a way that a teacher supports only as far as needed. Scaffolding does not only mean that the student reaches a certain learning goal, but also that the student becomes adept in solving similar problems in new contexts. Because the teacher carefully assesses the situation of the student and decides how to support them through various means, scaffolding inherently means that support is adapted or adjusted to the learner's needs.

Scaffolding comes in many different forms. Saye and Brush (2002) define hard scaffolding and soft scaffolding, where hard scaffolding is the support given through books and assignments and soft scaffolding is support given through verbal interaction with the teacher. Warwick et al. (2013) distinguish direct scaffolding and indirect scaffolding. Direct scaffolding, similar to soft scaffolding, is the verbal support from the teacher, and is meant to situationally and temporally support a student's problem solving. Indirect scaffolding is the setup of a task in advance to structure the student's activity and restrict the degrees of freedom. No single form of scaffolding is sufficient to support students, however (Puntambekar & Kolodner, 2005). Often a mix of scaffolds is used; for example, Tabak (2004) described the 'synergy' of using different scaffolds that cooperate and interact to offer a robust form of support. Puntambekar and Kolodner (2005) described 'distributed scaffolding', where scaffolding is provided through a sequence of social and material support.

We see these notions of synergy and distributed scaffolding in different studies. In the study by Apedoe et al. (2008), the teacher leads whole-class discussions, and the students undertake both team and individual activities. In a study by Van Breukelen et al. (2016) on physics design activities in secondary education, scaffolding is given through a sequence of activities that students must perform. Here, the notions of synergy and distributed scaffolding are present within the design project.

Scaffolding suggests that teachers adapt their support to the student, or help the student to rise to the level of competence needed for answering/continuing the design task. One can argue that within design education there is a transactional relationship between the learner and the learning environment; the design project shapes the learner, and the learner has the possibility to influence the design project or the learning environment (see for instance Lippman, 2010). Lippman (2010) discusses that a so-called responsive design approach understands this transactional relationship, and recognizes that no one person possesses all knowledge. The individual team members need each other and must take up their role in the design process. This implies that a teacher, who is aware of this valuable responsiveness and communication, is required to promote the dialogue with and between students.

Supporting design activities with feedback and questions

Giving feedback is a common practice in design education. This is often done during the so-called 'critique': a communication event in which students present their design and others give their feedback. This form of feedback provides students with information to understand the principles of design form and content, and also teach them to communicate like a designer (Dannels et al., 2008).

Feedback can come in many different forms. Hattie and Timperley (2007) state that feedback is used to provide corrective information, alternative strategies, clarification, and encouragement, as well as to evaluate correctness. Information given by the teacher to the student can only be called feedback if there has been an effect in the desired direction (Boud & Molloy, 2013). Some difficulties can be that students find feedback too general, insufficient, unclear, or inconsistent (Steen-Utheim & Hopfenbeck, 2019).

Teachers need to take care to ensure effective feedback, as they need to balance their approach between students who may perceive the feedback as criticism, causing anger, hurt feelings, or resistance, and students who are dependent on the teacher, who might feel insecure and wait for approval and explicit guidance (Goldschmidt et al., 2010). This emphasizes the usefulness of feedback in the form of a dialogic approach (see for instance Steen-Utheim & Hopfenbeck, 2019), where feedback is a two-way interactional process between teacher and students.

Besides giving feedback, scholars also describe the use of questions as important means to teach and guide students through the design process. In design education, three types of questions have been defined: low-level questions, deep reasoning questions and generative design questions (Cardoso et al., 2016). Low-level and deep reasoning questions are convergent in nature, and usually the answer is known by the student (low-level) or requires reflection and reasoning (deep reasoning questions). Generative design questions are used to increase the options or directions for students and are divergent in nature. The answer to generative design questions is often not known by the students or the teacher.

Feedback and questions can be divergent or convergent, and thus either broaden or sharpen the ideas of students, respectively. In this study, we refer to feedback and questions as means with which teachers support design activities. Through their use, teachers can strengthen the understanding of a subject, provide information, or tap into the experience of students.

In our earlier study (Sheoratan et al., 2021), several forms of feedback and types of questions were reported by teachers in secondary and higher education when they described their scaffolding practice for design projects. In Table 1, feedback and questions, along with examples from this earlier study, are presented.

Table 1 Categories of feedback and questions from a previous study (Sheoratan et al., 2021)

Forms of feedback and their categories	Types of questions and their categories
Corrective information	*Low-level questions*
Something is missing	Where are you?
Do this again	What is the problem?
What [this] actually means is not…	What is the goal?
Alternative strategy	Can you continue now?
If you do this, then…	Can you explain this?
Look this up	Can you improve the cooperation?
Information to clarify ideas	*Deep reasoning question*
What this means is…	What does this mean for your design?
Encouragement	What do you need to do and what do you need for that?
Well done!	*Generative design questions*
You are going in the right direction	What other kinds of ideas can you think of?
Evaluate correctness	
This is not right	

The categories of feedback are grouped into forms of feedback listed by Hattie and Timperley (2007), and the categories of questions are grouped into types of questions reported by Eris (2004)

More and different forms of feedback and questions may be used in the classroom besides these reported practices. We want to elucidate how these means are used in the classroom and how the dialogue between teacher and students is shaped to support students during design activities.

Aim of this study

In this study we analyze a case in which three teachers introduce and guide design-based chemistry projects in their classrooms. Here, we are interested in the adaptive verbal support that the teachers provide. Because designing is non-linear and can have multiple solutions, this support is expected to be diverse, situational, and tailored to the needs of the students. Besides design, the teachers will likely also address chemical aspects during design-based chemistry projects. During our analysis, we therefore specify the topics of conversations that teachers and students have, in order to understand how teachers support different aspects of the projects.

In our analysis, we confine ourselves to the verbal interactions between a teacher and their students during the lessons, and characterize the support that teachers provide in terms of feedback and questions.

Research questions

For this study, we wanted to know what teachers and students talk about, and how teachers support students verbally during the conversations. Specifically, we looked at the means (such as feedback and questions) that teachers use to support students. Due to the setup of the design tasks during the lesson (this is detailed in the next section, see also Table 2), we expected to see conversations between teachers and students related to: (1) design steps such as design problem, design brief, and idea generation, since the design tasks in this lesson were meant to address these; (2) the experiments; and (3) the chemistry concepts. These were considered to be the main topics of conversation. We were also interested in whether other topics occur.

We formulated the following research questions:

RQ1 How can the topics of conversations held by teachers and students during a design-based chemistry project be characterized?

RQ2 How can feedback and questions on these topics used by teachers be characterized, and how are they used to support students during a design-based chemistry project?

Educational context

The data collection for this study was conducted in the Netherlands over the course of the school years 2018–2020. Three participating chemistry teachers introduced three design projects in their chemistry classes for 3VWO students (Grade 9, ages 14–15 years). VWO is the pre-university stream in the Dutch educational system. The design project discussed in this study was the third in a series of three different design projects performed in the

Table 2 Design projects that were conducted in three chemistry classes. The third project is described in more detail to explain the context of the design activities performed by the students in this study. The data used in this study comes from lesson 1 of the third project, "the thermo challenge"

Design projects	Length	Objective of the project for students
1: Toothpaste	Two lessons	Fictive clients (on paper) ask student groups to make a toothpaste out of natural products. Every group gets a different client that poses requirements with respect to taste, color, ingredients, and texture. Students experiment with commercial toothpastes and given recipes to design and develop their own toothpaste and test its effectivity.
2: Water purification	Two lessons	Student groups are required to design a setup to purify a quantity of dirty water with the help of ordinary items, and make an extrapolation of costs and time for a larger water purification plant.
3: The thermo challenge	Four lessons	With the help of endothermic or exothermic reactions, student groups design a self-heating or self-cooling cup that makes use of the energy effect of a separate reaction. 1: In the first lesson, students receive information about the design objective through a whole-class instruction. In their own groups, they divide the tasks for this lesson. They discuss the problem, choose their beverage to heat up or cool down, discuss the requirements for their design, and draw or write down preliminary design ideas. They also perform chemistry experiments with endothermic or exothermic reactions to experience the effect on the temperature of the substances. 2: Students continue to think about their design in lesson 2 and draw ideas for their self-heating or self-cooling cup. They also perform experiments to learn how reaction speed can be influenced, with the intention of gaining information to improve their design. 3: In lesson 3, with the information from the previous lessons and their own ideas, students start making (generic) prototypes and test whether their design works as expected. As homework for the next lesson, students improve their prototype at home. 4: Students can continue testing and adjust their prototypes in lesson 4. They show the teacher their ideas and prototypes and results. They also evaluate their design with the help of given questions.

classroom throughout the schoolyear. In every class, the students were divided into five or six groups, with four to six students each, working on their designs in teams. In total, the three classrooms together had 81 students. Table 2 details the projects and gives an overview of their contents.

For this particular study, we chose to take the first lesson of "the thermo challenge" project (see Table 2), a project adapted from the works of Stammes et al. (2021) and Apedoe et al. (2008). Over the course of the lesson series, the students design a self-heating or self-cooling cup. Apedoe et al. (2008) argue that this design task has relevance and relatability for the students' lives and encourages student ownership, as well as being a good example of a project where a careful consideration of materials is needed. The lesson we chose for analysis was the first of a series of four lessons of 50 min (see Table 2), and was selected because it contains both design tasks and experiments. During a whole-class instruction, students are introduced to the design task: they have to design a cup that can heat up or cool down a self-chosen beverage. After the instruction, students continue the work in groups until the end of the lesson. They discuss the type of beverage they want to heat up or cool down, think about different ideas, and consider the requirements of the design. Each group of students has worksheets to help them analyze the design problem and brainstorm about the design brief and the ideas they have. Besides the design tasks, the students also perform chemical 'cookbook' experiments, in which they learn about endothermic and exothermic processes when mixing various combinations of substances. The insights gained from these experiments are to be used in the designs in other lessons (lessons 2, 3, and 4). In our project, the student activities are structured to a certain extent, but there is room for the verbal support of teachers. The combination of design tasks and experiments in one lesson is an example of what chemical design projects can look like, and requires teachers to strike a balance between supporting design skills, chemistry knowledge, and practical skills.

Method

We performed a qualitative analysis of the conversations of three chemistry teachers with groups of students from their respective classrooms. We collected data during one lesson run by each of the three teachers. Focusing on three cases of the same lesson allows us to see possible variations in the support provided by teachers. By using analytic coding and open coding (Cohen et al., 2011) for the conversations between the teachers and groups of students, we gain a deeper insight into the nature of the verbal support used.

Participants

For this study, three teachers from the same school, including the first author, collaborated in a professional learning community with the intention of investigating how to integrate design assignments in the chemistry classroom and shape the guidance needed from teachers. The small group of teachers allowed for an in-depth study, with close collaboration and discussion amongst each other. The teachers are all male and teach chemistry, but have different backgrounds. Teacher A has a rich background, with seventeen years of experience in teaching chemistry, biology, and physics in lower secondary education. Teacher B is a chemistry teacher in lower and higher secondary education, with seven years of experience.

Teacher C has eleven years of experience in teaching both chemistry and physics in lower secondary education.

All three teachers had some experience with design education at the start of the study. Teacher A had experience with teaching design in STEM for younger students (grade 7), and teachers B and C gave engineering design lessons as part of physics classes (grade 8); however, none had previous experience in implementing design projects in the chemistry classroom. Before, during, and after the design projects, the teachers came together to discuss the design projects and how best to support students with them. The teachers also discussed their role as coach, facilitator, and guide during the design projects. We provided the findings from our earlier study (see Table 1) to the teachers, in addition to inputs and starting points for guiding students through feedback and questions. After each design project, the teachers reflected on how to improve the support they would provide for the next design project.

Data collection

During the first lesson of the thermo challenge project, held in 2019, audio and video data were collected in the three classrooms. The teachers, students, and parents gave active (i.e., signed, written) informed consent for the collection and use of research data for this study. The teachers wore a clip-on microphone, through which the conversations between the teacher and (groups of) students could be heard. On the tables of the five or six student groups (with four to six students each) in each classroom, we also placed recording devices to record audio of the student conversations and as supporting data. The video recordings were made with two cameras to capture the classroom from two angles, in order to observe all the tables and groups. For the students and teachers in this study, the use of audio and video equipment in the classroom was new. Although the cameras were placed as discrete as possible, the presence of the equipment could influence the behaviour of the students and teachers. There was no separate meeting or lesson for the students and teachers prior to the projects to get used to the presence of the equipment. However, during project one and two (see also Table 2), the equipment was also placed in the classroom and recordings were made. The students and teachers therefore had some experience by the time project three started.

The video recordings was used as supporting data to understand the context in which the conversations took place. This data, for example, showed us which group was having a conversation with the teacher. Sometimes, a student from another group approached the teacher, and then we noted this as well. The video data was also useful for noticing if the teacher made gestures or pointed at something, and thus understanding the conversation he was having with the students.

For this study, the audio files of the teacher recordings were transcribed, and these transcriptions were used for further analysis.

Data analysis

The data were analyzed by the first and second authors. The second author acted as an independent researcher. The analysis consisted of three parts, which are detailed in the Sect. "Analysis of the topics of teacher–student interactions, "Analysis of the use of teacher feedback and questions" and "Analyzing the relationship between the topics of interactions and the use of feedback and questions".

Analysis of the topics of teacher–student interactions

The first author started by viewing the video data and reading the transcripts of the audio. On the footage, we saw no indication that students behaved differently due to the presence of the equipment. With the help of the video data, we identified the interactions in the transcripts. An interaction is the conversation between a teacher and a group of students, starting with the arrival of the teacher at a student group and ending when the teacher leaves the group. Each interaction consists of several turns, defined as the response that an individual gives, defined from the moment that (s)he starts talking until (s)he stops talking or is interrupted.

We selected the interactions where the conversation dealt with the design assignment itself; other interactions were not considered relevant for this study. A not-relevant interaction contains, for instance, discussions of grades, discussions about the use of a mobile phone, classroom management, school schedules, etc. When a teacher displayed both relevant and not-relevant turns within an interaction, we included that interaction in our analysis, but focused only on the relevant teacher turns. In total, the three individual lessons that we analyzed consisted of 116 teacher–student interactions, with 421 teacher turns. The selection of relevant turns resulted in 336 teacher turns for further analysis.

The topics of the teacher turns were classified using the method of analytic coding (Cohen et al., 2011). As mentioned above (see Sect. Research questions), we expected to see topics related to (1) design steps, (2) the experiment, and (3) chemistry concepts. The first author read the interactions and coded the teacher turns within these interactions with topics, then reviewed these codes together with the second author until consensus was reached. While coding, we also found that students asked questions about the overall task (4), so a code for this topic was added. This code contains situations in which students and their teacher discuss what to do next, how to divide tasks among students in the group, and the scope and procedure of the project. We used open coding (Cohen et al., 2011) to define subtopics within each topic to further denote the context of the teacher's response. A breakdown of the topics and subtopics of the teacher turns can be seen in the results presented in Table 3 (Sect. Analysis of the topics of teacher-student interactions).

Analysis of the use of teacher feedback and questions

For all 336 teacher turns, we coded the types of feedback and questions used. This was an iterative process, in which we went back and forth between teacher responses and student responses and reading the whole interaction. The feedback and questions were coded in two cycles. In the first cycle, we used analytic coding (Cohen et al., 2011) to code the teacher turns. We used our earlier findings (see Table 1) as a basis for the coding process. For feedback, we initially used the forms of feedback mentioned by Hattie and Timperley (2007), but when reviewing the codes, we identified three overarching types of feedback that reflected the teacher responses more clearly; teachers used feedback to (1) steer students in a certain direction, (2) clarify concepts or tasks, or

Table 3 Topics identified in the teacher turns

Total number of teacher turns	Number of teacher turns per topic	Topic	Subtopic (number of teacher turns)
336	135	Design steps	Idea generation (68) Design brief (41) Problem description (18) Prototype (8)
	108	Experiment	Procedure/what to do (77) Outcomes and interpretation (21) Practical safety and precautions (10)
	32	Chemistry concepts	Endothermic/exothermic reaction (18) Warmth/energy (9) Chemical safety (5)
	61	Task	Procedure (46) Performance (15)

(3) encourage students to start or continue with a certain task or idea. These three categories were therefore used to describe the types of feedback provided by teachers. To categorize the types of questions, we coded them as low-level questions, deep reasoning questions, or generative design questions (Eris, 2004; Cardoso et al., 2016).

Analyzing the relationship between the topics of interactions and the use of feedback and questions

In our study, the coding process generates qualitative data with respect to the different categories found in the data and their co-occurrences. Instead of producing tables with numerical values of the co-occurrences of categories, we chose to visualize the data in alluvial diagrams. This is a type of flow diagram that is generally used to show the structural or temporal change in a network (Rosvall & Bergstrom, 2010; Yeung, 2018). In our study, however, we used these diagrams to provide a visual overview of the various topics and their links to the types of feedback and questions used by teachers, thereby depicting not only these relationships but also the proportions of interactions in which they were used. This facilitated comparisons and the detection of variations in the support that teachers provided in different topics.

We made four diagrams, one for each topic, using the open-source graphing library *plotly* for R, a programming language for statistical computing and graphics. In the diagrams, the codes are represented by nodes, from or into which the streams flow. The width of nodes (placed vertically) and the width of lines or streams (between the different nodes) correspond to the number of occurrences of that code in the data. On the left side of each diagram, we listed the subtopics of that topic. In the middle, the different subcodes for feedback and questions were listed. The right side contains the overall codes for the feedback and questions. We then used these diagrams as a visual aid to identify key elements, patterns, and differences in the data. We then went back to the transcripts to read the interactions again, so that we could understand and characterize how teachers try to support students' design activities.

Results

Analysis of the topics of teacher–student interactions

The interactions between a teacher and students or student groups covered four topics: design steps, experiment, chemistry concepts, and task. The majority of teacher turns comprised responses in the context of design steps and experiments. In the design steps topic, we identified the subtopics idea generation, design brief, problem description, and prototype. These activities were also central to the design lesson studied here (see also Sect. Educational context).

The experiment topic contained the subtopics procedure/what to do, outcomes and interpretation, and practical safety and precautions. Regarding 'procedure/what to do', the teachers and students talked about practical aspects and teachers helped students to continue their experiments if they were experiencing difficulties. The teachers helped the students to understand what they needed to do with the results of their experiments in the subtopic 'outcomes and interpretation'. In the subtopic 'practical safety and precautions', the teachers mostly pointed out the correct use of lab goggles and coats and stressed safe working during the experiments.

Teacher–student interactions on chemistry concepts were also observed, in which the teachers supported the understanding of students while they made design choices or performed experiments. Due to the nature of the design assignment, many of the conversations were about endothermic and exothermic reactions, and about the concepts of warmth and energy. Furthermore, teachers discussed matters of chemical safety with the students, particularly regarding the use of acids or bases during the experiments. This is different from the subtopic 'practical safety and precautions' under the experiment topic, as the teacher here focuses on chemical properties instead of practical safety measures.

The observation of interactions regarding the goal and tasks of the design assignment showed that the teachers explained the task again when clarification was needed. We added this topic to the categorization of turns. Within the topic of task, the teacher either discussed the procedure and explained again what needed to be done, or focused on the performance on the design activities as a whole and discussed with students what was allowed and what was not.

The topics of design steps, experiment, and chemistry concepts had a different focus than the task topic. The first three topics deal with content-specific details, while the topic of task is a more general conversational topic regarding the overall task. Table 3 shows the number of turns comprising each topic and subtopics.

Analysis of the use of feedback and questions by the teachers

The analysis of the types of feedback and questions resulted in the identification of three types of feedback—encouraging feedback, clarifying feedback, and steering feedback—and three types of questions: low-level questions, deep reasoning questions, and generative design questions. Besides defining singular types of feedback and questions, we also identified teacher turns in which the teacher used a combination of multiple types; for example, the teacher gives feedback and asks questions in a single monologue, perhaps to give an aggregation of ideas or concerns that students need to work on. We listed these teacher turns as a separate category. There were also turns in which teacher responses did not contain new information. These turns were usually short, and contained responses such as “oh”, “hm”, or “okay” (interpreted as ‘I hear what you say’). Such turns were coded as ‘no use of feedback or questions’, and were not considered supportive to the understanding of students. Table 4 lists examples for each of the categories and subcategories of feedback and questions.

Analyzing the relationship between the topics of interactions and the use of feedback and questions

The combination of topics and types of feedback and questions is visualized in the alluvial diagrams in Figs. 1, 2, 3 and 4. The alluvial diagrams allow us to compare the use of feedback and questions in different topics and detect differences and similarities. Here, we examine these findings and share examples of conversations to illustrate the content and forms of the support provided by the teachers. In these findings, we go through all the four topics (design steps, experiments, chemistry concepts, and task) and describe the use of feedback and questions within these topics.

1. Design steps

The topic of design steps was supported by the teachers in a variety of ways. Compared with the other topics, we see here that encouraging feedback is used relatively more often: the encouraging feedback row in Fig. 1 is wider than in Figs. 2, 3, and 4. We can also see that the use of generative design questions is present in the topic of design steps (Fig. 1) but not in the other topics (Figs. 2, 3 and 4).

On the left of the diagram, we see the subtopics of the design steps topic. Idea generation and design brief are supported through various means: they have multiple streams of varying widths going to almost all variations of feedback and questions. To illustrate the use of the means in this topic, four examples are given below.

Example 1 shows a short interaction, where the variation of different types of feedback and questions can be seen. The teacher (T) asks the students (S) to explain their idea, and then uses feedback to steer the students to think of more ideas. When the student asks a question about the task, the teacher clarifies the task and, at the end of the same response, points the attention back to the generation of ideas. The teacher here seems to focus specifically on getting the students to think about design ideas.

Example 1

		Content of turn	Means	Topic and subtopic
1	T	You have come up with an idea. Can you explain what is happening there?	Low-level question	Design: Idea generation
2	S1	You have two substances. One is in this box and the other in that. Then push this up. Then you rub…		
3	T	Great. Okay, very good. Think of some other mechanisms too. Just keep thinking about it, so that at some point you can choose which is the best mechanism.	Steering feedback	Design: Idea generation
4	S1	Are we going to make this too?		

Table 4 Types of feedback and questions used by teachers

Examples of teacher turns	Subcategory	Category
"You are still on the right track, but these are indeed questions for you to think about. You are constantly coming up with ideas. Just list them for yourself. What kinds of ways could there be to get that whipped cream out? Start doing this *(teacher points to experiment)* in the meantime, otherwise you won't have enough time. For each test, you have to measure [the temperature] for at least three minutes. Maybe you should just do two [tests] at a time so you can get those two thermometers you got… Yeah, exactly."	Multiple	Combined
"Yes, I would do that. If it is possible, I would." *(Responding to students asking whether the teacher would like to try their design once it is finished)*	Encouraging feedback	Feedback
"You have to mix these substances listed here, yes. So, this is about citric acid and sodium hydrogen carbonate."	Clarifying feedback	
"But then maybe we have to put in the restriction here that we can't work with pressurized bottles in school and can only use the chemicals we have here, so it might be helpful to stick with these chemicals. I really like that you are thinking in all directions, but I think this is just a bit too much…"	Steering feedback	
"Have you already decided whether you are going to warm up or cool down?"	Low-level question	Question
"So, what is going on there?"	Deep reasoning question	
"Okay, that is possible. What are other ideas? After that, we need to start thinking about what the safest ideas are. Draw it, sketch it, or… Well, it doesn't matter. Think about how you want to do this. Where should that other substance go? (…) Where is that other substance that has to react?	Generative design question	
"Okay."	No use of feedback or questions	No support

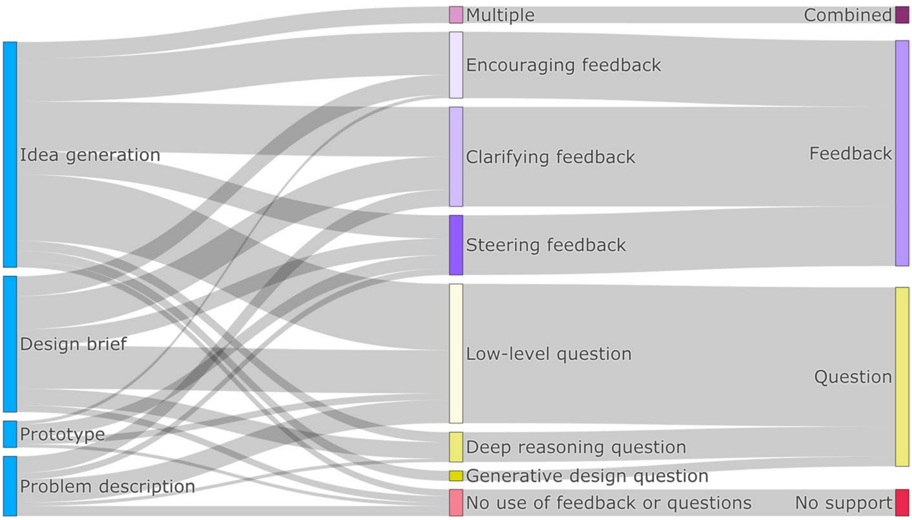

Fig. 1 Design steps (135 teacher turns)

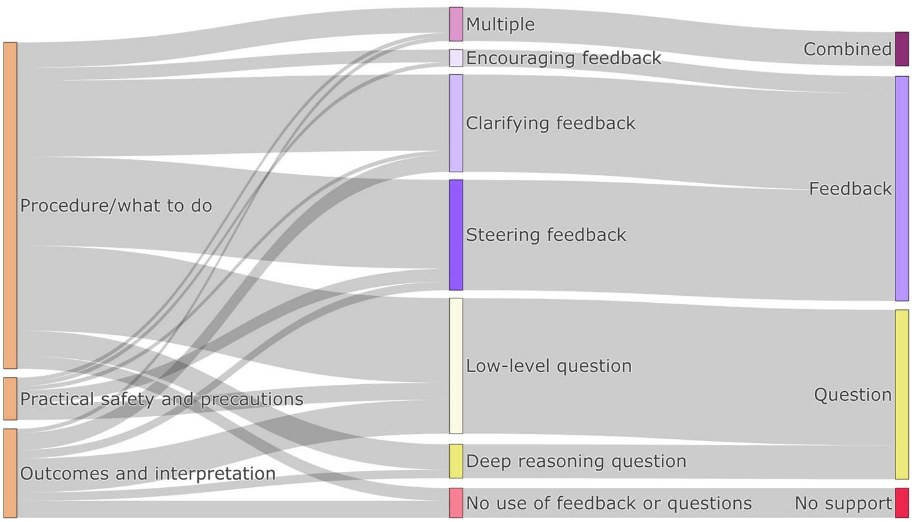

Fig. 2 Experiment (108 teacher turns)

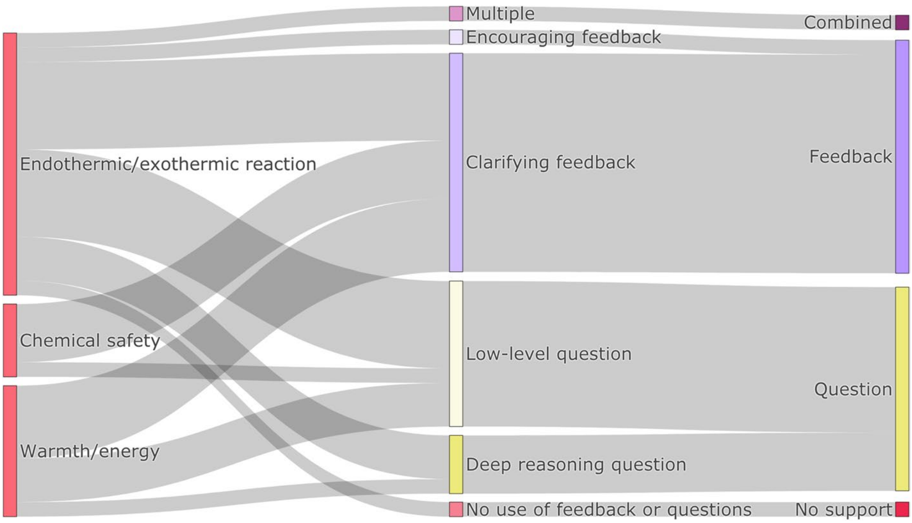

Fig. 3 Chemistry concepts (32 teacher turns)

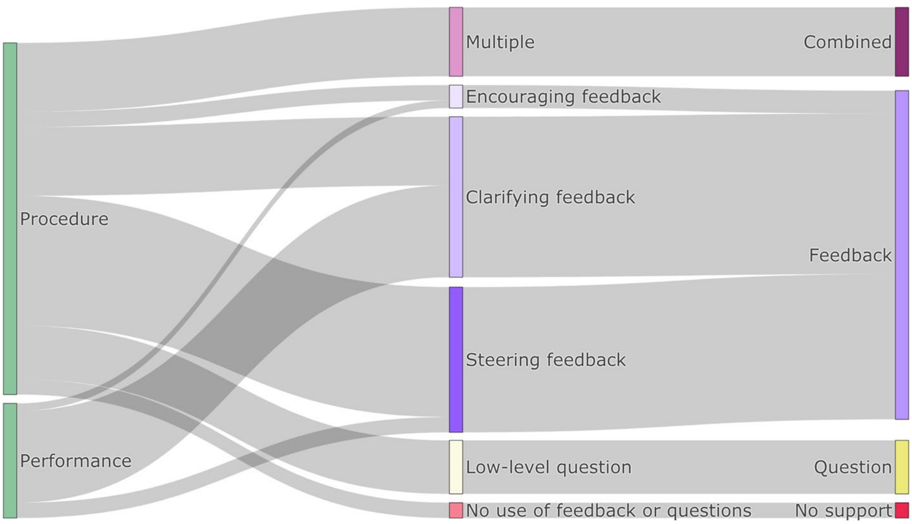

Fig. 4 Task (61 teacher turns)

		Content of turn	Means	Topic and subtopic
5	T	Yes, the goal is that later on you make a prototype as best as you can, so it has to be a realistic idea. Also, really think: if I'm going to do this, what would this look like? It may very well be the case that not everything works 100% in your prototype, that's okay. But you can simulate as much as possible. Think about that too. You don't have to do that yet; come up with some ideas first.	Clarifying feedback	Task: Performance

A variation of means can also be seen in Example 2, where the teacher first asks questions to understand the idea that students have. After hearing the idea, the teacher seems to question its feasibility first, and then chooses to place the responsibility for the design idea back with the students. This is an example of how teachers search for balance between steering students in a certain direction and encouraging them to learn and find out for themselves what the best idea is.

Example 2

		Content of turn	Means	Topic and subtopic
3	S2	Is it possible to use ice cream?		
4	T	Ice cream?	Low-level question	Design: Idea generation
5	S3	That you cool down an ice cream, that you then have such a thing…		
6	T	So, you wanted to make the heat of a cola can disappear in the heating of the ice cream?	Low-level question	Design: Idea generation
7	S2	No, the opposite, making the ice cream cold.		
8	T	Oh!	No use of FB or Q	Design: Idea generation
9	S2	So that, say, liquid ice cream… But that is not possible at all, is it?		
10	T	But then it is not a drink?	Low-level question	Design: Idea generation
11	S2	No.		
12	S3	Or you have a sort of squeeze cup, and then you can squeeze it as it cools down. That also exists!		
13	T	I think you should look up whether that is feasible, because when you are in the tropics and it is 30 degrees [Celsius] and you want to cool it down to – 10 or something. That's a difference of 40 degrees isn't it? Maybe it is possible, you have to take that from your measurements of course…	Steering feedback	Design: Idea generation
14	S4	Warm lemonade is not tasty.		
15	S3	Cold lemonade is also very nasty.		
16	T	I think that ice cream is a challenge. It is, of course, your assignment, but it does sound very…	Encouraging feedback	Design: Idea generation

Encouragement during design tasks is often given by the teacher thinking along with the students. Example 3 shows how one teacher uses his feedback to clarify what is possible, and then encourages the students by saying that he would be interested in the product.

Example 3

		Content of turn	Means	Topic: subtopic
1	S1	What does this say here?		
2	T	You can also set your own requirements.	Clarifying feedback	Design: Design brief
3	S2	Yes, can we also make ice cream with this?		
4	S1	Sir, would you buy a cappuccino ice cream?		
5	S2	Then we make the cappuccino like this, and we put it in a mold with a stick and you have an ice cream.		
6	T	Then I think the requirement is that you want the minimum temperature lower.	Clarifying feedback	Design: Design brief
7	S2	But would you like a cappuccino ice cream?		
8	S1	It is just a question of whether it is possible.		
9	T	Whether it is possible is yours to discover. You certainly can try.	Clarifying feedback	Design: Design brief
10	S1	So, can we do it? Can we also reduce the minimum temperature to – 20 °C?		
11	T	Yes.	Clarifying feedback	Design: Design brief
12	S1	How cold is the freezer?		
13	S3	–7 °C.		
14	T	You can see whether that is feasible.	Clarifying feedback	Design: Design brief
15	S2	Sir, would you buy a cappuccino ice cream?		
16	T	I would, yes.	Encouraging feedback	Design: Design brief
17	S2	Yes.		
18	T	Just to taste and try.	Encouraging feedback	Design: Design brief

As we mentioned before, generative design questions comprise a relatively small portion of all interactions. Instead of using questions, we see that teachers more commonly use feedback to comment on and encourage the generative aspect of designing. Teachers draw attention to idea generation when students do not think of it themselves. In Example 4 below, the teacher mentions the generation of ideas as part of the bigger assignment. While he asks a generative design question in between, the teacher further continues to give instructions and clarify what needs to be done with respect to the generation of ideas.

Example 4

		Content of turn	Means	Topic: subtopic
1	S1	Is it a good idea to add some kind of sugar to the ice cream?		
2	T	I like that very much, yes. Yes, seriously. That you make it a little bit sweeter.	Encouraging feedback	Design: Design brief
3	S1	Slightly sweeter, so it tastes a bit like ice cream. And it has to be on a stick.		
4	T	That is your opinion. That is your requirement: it must be on a stick. The requirement for the ice cream. You don't have to fill in everything, okay?*	Clarifying feedback	Design: Design brief
5	S1	Well, I do want to do that. I don't like it when a box* is empty. Do you think this drawing is good enough, or is something else needed here?		

		Content of turn	Means	Topic: subtopic
6	T	You also need to think of other ideas.	Clarifying feedback	Design: Idea generation
7	S1	What do you mean?		
8	T	That this is only one way to…	Clarifying feedback	Design: Idea generation
9	S1	We have one box.*		
10	T	You can also think of a completely different way in which you can achieve a cappuccino.	Clarifying feedback	Design: Idea generation
11	S1	How to achieve a cappuccino…		
12	T	Yes, how do you get a cappuccino?	Generative-design question	Design: Idea generation
13	S1	It must be frozen. You can put it in nitrogen, but then you can't bring it with you.		
14	T	No, exactly. So, you can think of some more ideas that hopefully are a bit more realistic. Those guys are now testing…	Clarifying feedback	Design: Idea generation
15	S1	Yes, I said, "You do that, I'll finish this.“		
16	T	That's good, but try to make some other drawings as well.	Steering feedback	Design: Idea generation
17	S1	Yes, but we don't have that much space anymore because it's a cartoon.		
18	T	Yes, so this is actually one thing. You have one more piece of paper, you can also use the back. Fine, fill it up.	Steering feedback	Design: Idea generation

*The conversation refers to the box on the worksheet in which they write their ideas

2. Experiment

With respect to the experiments, we again see that teachers use various means to guide students through different situations. On the left of the diagram, we can see that the largest share of teacher turns within this topic deals with the subtopic 'procedure/what to do' (Fig. 2), with the teachers providing guidance on the experiment task and what needs to be done. This happens in different ways. Sometimes teachers start by clarifying the assignment so that the students can continue. This is illustrated in example 5, in which the teacher takes the responsibility and reduces the cognitive load by explaining what needs to be done.

Example 5

		Content of turn	Means	Topic: subtopic
1	S1	Do you just have to mix this together every time? This and this and then measure with a thermometer? *(Student points to reaction tubes)*		
2	T	Let's see. Here it says what is what. *(Teacher looks at experiment procedure on paper)*	Clarifying feedback	Experiment: Procedure/what to do
3	S1	We are doing exothermic reactions.		

		Content of turn	Means	Topic: subtopic
4	T	Yes, exactly. So, you have 1 and 2, so one is 1 and the other is 2. Magnesium is written on it, so this is the magnesium and belongs to experiment 1, and this belongs to experiment 2. What you have to do is use the stopwatch and the thermometer. You need to know how fast it gets hot and how hot it gets. Then, indeed, you are meant to mix A and A together and B and B together, so those two and those two together. It is especially important that you do this with a timer and a thermometer. I think it's fine if you use your mobile phone for that.	Clarifying feedback	Experiment: Procedure/what to do

In Example 6, also within the subtopic 'procedure/what to do', we see that the teacher uses a different approach and keeps using deep reasoning questions about a relatively simple matter, relying on the logical thinking of the students themselves. The example illustrates how one of the students understands what to do and explains it to a fellow student.

Example 6

		Content of turn	Means	Topic: subtopic
1	T	Leo, you just had a question.	Encouraging feedback	Experiment: Procedure/what to do
2	S1	Yes, can we put those test tubes together [*mix the contents]* and then add the water?		
3	T	Where should water be added?	Low-level question	Experiment: Procedure/what to do
4	S1	Water. *(Student points to experiment procedure on paper)*		
5	T	Why should water be added?	Deep reasoning question	Experiment: Procedure/what to do
6	S1	Here, ammonium chloride and water. *(Points to experiment procedure on paper)*		
7	T	Yes, but what do you think is in the test tube.	Deep reasoning question	Experiment: Procedure/what to do
8	S2	Water.		
9	S1	Water.		
10	T	And what's in the other?	Deep reasoning question	Experiment: Procedure/what to do
11	S1	Ammonium chloride.		
12	T	Yes, exactly. Do you think you need to add more water?	Deep reasoning question	Experiment: Procedure/what to do
13	S1	Yeah, no.		
14	S3	Why not?		
15	S1	Because there is water in there.		
16	S3	Is there water in there?		
17	S1	Yes.		

Another situation that occurs during the performance of experiments is when teachers focus on practical safety and precautions. Teachers respond mostly with simple low-level questions, such as: 'Can you put your lab glasses on?' or they directly state what needs to be done: 'button down your lab coat.'

3. Chemistry concepts

In the topic of chemistry concepts, a large share of the support consisted of clarifying feedback (Fig. 3). We found no steering feedback in this topic, and although there is some use of encouraging feedback, it is a relatively small part of the support given in this topic relative to the other topics (see Figs. 1, 2, and 4).

Example 7 contains a situation in which the teacher uses clarifying feedback and explains that the assignment relies on the concept that, when brought together, substances can cause an energy effect through endothermic or exothermic reactions. This clarification was apparently needed, as the students did not grasp that chemistry concept yet. The teacher seems to add information to the ideas that the students already have without imposing, as if to brainstorm together. This shows how the teacher speaks at the level of the student.

Example 7

		Content of turn	Means	Topic: subtopic
		…		
15	S3	Well, we are still discussing a little bit about what we need to do.		
16	T	Okay. But… you do not know yet whether you want to cool down or warm up, for example?	Low-level question	Chemistry concepts: Endothermic/exothermic reaction
17	S4	Warming up, yes. That does seem more convenient to me.		
18	S3	Yes, cooling down will be difficult because you then need to use a reaction that becomes cold. That is usually with air pressure, that it becomes cold.		
19	S4	Or you put, let's say, those ice cubes. That when you squeeze them, they get cold. Like, there are those plastic things and you put water in them. If there is something in there, then it becomes cold, you can just put it in the freezer.		
20	S3	Only, when you are in a tropical area, and you are walking for an hour and a half, those things will have melted.		
21	S4	That is normal with ice cubes.		
22	S3	Yes, exactly…		
23	T	We have substances here at room temperature. If you mix them together, [the reaction] gets very cold.	Clarifying feedback	Chemistry concepts: Endothermic/exothermic reaction
24	S3	Yes, then that is also handy, actually.		

		Content of turn	Means	Topic: subtopic
25	S4	Can [the reaction] then also be reversed or are they no longer usable afterwards?		
26	S3	A one-time reaction.		
27	T	Yes, that's going one way for now. We can get them back to their original state with a chemical process, but if you mix them now, you will always see the same, that it gets cold.	Clarifying feedback	Chemistry concepts: Endothermic/ exothermic reaction
28	S3	Maybe if you can fill it up or something, you can put it back in. Are they corrosive substances or toxic substances?		
29	T	You shouldn't drink them. You have to assume, I think, you don't want to put what we are offering through your drink… At least, if that's what you meant…	Clarifying feedback	Chemistry concepts: Chemical safety
		…		

In the topic of chemistry concepts, support is also given with low-level questions and deep reasoning questions. The low-level questions can be used in a diagnostic way, with the teacher first asking questions like 'what do you want to do?' or 'what does that say?', before going into other means of support. Alternatively, low-level questions are also used to help students move in small steps towards the answer. Example 8 is such a case, where the teacher first connects to the knowledge that students have with the help of low-level questions, and then asks a deep reasoning question where the students need to connect the information they have to come to an answer. Even though the steps towards the solution are small in this example, the interaction demonstrates the use of questions as a means to support students in moving towards the answer.

Example 8

		Content of turn	Means	Topic: subtopic
1	S1	Sir, we want to cool something, is that endothermic or exothermic?		
2	T	Hmm… What does an endothermic reaction do? What does an exothermic reaction do?	Low-level question	Chemistry concepts: Endothermic/ exothermic reaction
3	S1	It takes energy.		
4	T	Yes, exothermic: heat is released. If something is an exothermic reaction and heat is released, does the environment get warmer or colder?	Low-level question	Chemistry concepts: Endothermic/ exothermic reaction
5	S1	I think warmer.		
6	T	Warmer. What do you want? You want to make it colder. What do you need then?	Deep reasoning question	Chemistry concepts: Endothermic/ exothermic reaction
7	S1	Endothermic.		

		Content of turn	Means	Topic: subtopic
8	T	Exactly, very good.	Encouraging feedback	Chemistry concepts: Endothermic/ exothermic reaction

4. Task

During the design assignment, teachers spent time reexplaining the procedure of the overall task to students or student groups. Although the teachers did not specifically support the design steps, experiments, or chemistry concepts, and the level of the conversation is different, we found it noteworthy, as this reflects how the teachers manage the inexperience the students have regarding design assignments. When students are stuck on the task itself, are unclear on what to do, or have questions about what is or is not allowed, the teachers mostly respond either with clarifying feedback or steering feedback. Example 9 starts with the teacher responding to a question about whether the students need to work together on the same assignment. The teacher answers the question and takes the opportunity to stress the division of tasks among group members, explaining why students need to think about their design before starting the experiments. These clarifications help the students to stay on track with the design assignment.

Example 9

		Content of turn	Means	Topic: subtopic
1	T	Yes, this is your team that you do the whole assignment with. In a moment, in ten minutes, it is wise to continue in two groups. One group will think about ideas, the other group will think about doing the research and they will carry it out.	Clarifying feedback	Task: Procedure
2	S1	There is no point in doing the research without ideas, right?		
3	T	First you think: do I want endothermic or exothermic? Then you go to [the lab assistant], saying: 'We want to do the endothermic tests.' Or you go to [him]: 'We want to do the exothermic tests.' You only get one of the two. [The lab assistant] wants to know which, and then you will be given those experiments. After that, the others can maybe think… Of course, you are all sitting at a table, so consult with each other. Maybe you have ideas but one person writes them down, or draws them, showing what that cup will look like or what the whole design will look like.	Clarifying feedback	Task: Procedure

Sometimes, teachers combine multiple types of feedback and questions in one longer answer. This happens across all topics; however, it occurred more frequently when providing support for the task. The teacher combines feedback and questions of different sorts together in one monologue. In Example 10, one such situation is given. The teacher asks a low-level question and, without waiting for the answer, continues with steering feedback. The teacher takes control of the process in order to push the students forward and let them focus on the smaller tasks within the design assignment.

Example 10

		Content of turn	Means	Topic: subtopic
1	T	Do you already know whether you want to make it hot or cold? Then I advise you make agreements about who will now be doing the research.* You are here at the table after all. You can keep brainstorming together, but then you can also start the research. You also need time for that.	Multiple (low-level question, steering feedback)	Task: Procedure
2	S1	Should I get [the materials for the experiment] there?		
3	T	Yes. Then you can let [the lab assistant] know: ‘I need an endothermic or an exothermic reaction’. Then you get the experiment in which you can test either endothermic or exothermic reactions.	Clarifying feedback	Task: Procedure

*The teacher refers here to the experiments

Conclusions from results

This study focused on a case of three teachers introducing design assignments in the chemistry classroom. We analyzed the conversations that teachers and students had during a design-based chemistry project. First, we were interested in the topics of these conversations (RQ1). The conversations between teacher and students covered the following topics: design steps, the performance of experiments, chemistry concepts, and the overall tasks. Design steps discussions included conversations on the generation of ideas, the design brief, the problem description, and the prototype. The experiment topic comprised discussions on the procedure of the experiment and what the students needed to do, the outcomes and interpretation of the results, and practical safety and precautions. When talking about chemistry concepts, the teacher and students discussed endothermic and exothermic reactions, the concepts of warmth and energy, and discussed chemical safety. In the task topic, we observed conversations about the procedure of the entire design assignment and discussions about what was and was not allowed in the design assignment.

Second, we wanted to know what types of feedback and questions teachers use to discuss these topics, and how they are used to support students (RQ2). In our data, we identified the provision of feedback categorized as either steering feedback, encouraging feedback, or clarifying feedback, and questions in the form of low-level questions, deep reasoning questions and generative design questions. Each topic appears to be guided in a different way. The design steps were supported through a variety of means, and students were encouraged during their work on the design tasks. We also observed the use of generative design feedback and questions, stimulating students to think of new ideas. The experiments were guided with the notion of safety in mind. Teachers used clarifying feedback regarding the procedure, so that students could continue with their tasks. Chemical concepts were similarly supported. In conversations about the overall task, students were often unclear about what exactly had to be done. Teachers mostly explained what to do and clarified the boundaries of the tasks so that students could continue.

We conclude that teachers provide more open, constructive, and encouraging support for the design tasks, while experiments and chemistry concepts are supported in a closed, clarifying, and steering manner.

Discussion

Research into how teachers verbally support students in design-based chemistry projects is mostly uncharted territory. Much is known about design education and chemistry education, but not about the cross-section of these areas and how best to support students during design activities in the chemistry classroom. In our study, we observed how teachers support students with the different topics in a design assignment. The findings show that teachers encourage, guide, and coach students in design thinking, while telling students what to do during the experiments. This reflects the findings of McDonnell (2016) with respect to the role of teachers in design education. It was interesting to observe that the chemistry teachers in this study guided students using encouragement and coaching because regular chemistry lessons are often more guided through instruction and steering. This type of support may also have been influenced by the focus of teachers on the design aspect in our study, which was the main novel part of the assignment in their chemistry classrooms. The experiments and the chemistry concepts in the project were not central to the assignment, but used as means to think about the design. Specifically for chemistry, the steering on the topic of experiments may also be inherent to the subject, where attention to safety and precautionary measures in practice are required. The teachers try to remove the cognitive and practical hurdles that experiments and chemistry concepts contain, so that the students can finally start designing.

The use of feedback and questions shows similarities with our earlier study, in which we interviewed teachers about their support during design projects in the classroom (see Table 1). We found that the types of feedback provided in this study needed a different categorization than the one used in the previous study. The practical guidance analyzed in the current study further shapes the interview-derived findings of the earlier study.

Here, we found that the use of generative design questions was relatively low. We expected that generative design questions would have been more prevalent in the design tasks of the project (see, for instance, Eris, 2004; Cardoso et al., 2016). The stimulation of divergent thinking is an important part of guiding idea generation in the design process. It is interesting to see that the teachers in this study use feedback instead of asking questions to provide 'divergent' or generative design ideas. This is in line with literature where design feedback can direct both convergence and divergence (Daly & Yilmaz, 2015). Future studies could elaborate on the use of divergent feedback and question possibilities in design-based chemistry projects or those of other STEM subjects, as this may complement the more convergent nature of STEM subjects in general and add to the skill set of students (Land, 2013).

In our study, we focused on teacher support, not on student outcomes. Other studies have placed more emphasis on the student outcomes or the design task itself (e.g., Van Breukelen et al., 2017; Kolodner et al., 2003; Apedoe et al., 2008). Future research into the connection between verbal support and student outcomes is needed to precisely understand how teacher support influences student outcomes. We did perceive, however, that students had many questions about the design tasks during the lesson. There seems to have been an uneasiness and unfamiliarity with design and its goal. This could be because the students were not used to this form of lesson during their regular chemistry classes, despite having undertaken two design projects earlier in the year. Due to this lack of experience, they may have felt insecure. To properly and effectively perform design assignments, students need experience with this form of education.

This study is a first step in exploring what chemistry teachers do to guide students in secondary education and how they use verbal support. This support can be seen as part of scaffolding students to learn about design and chemistry. In the context of scaffolding, more research is needed to understand how teachers adapt their support to the students. Scaffolding consists of a continuous adaptation of support to the situation that the learner and teacher are experiencing. This 'tailoring' of support dynamically changes depending on the needs of the student and the assessment and estimation by the teacher of where the student stands relative to the learning needs and goals. To gain a broader perspective on scaffolding in the context of design-based chemistry projects requires a study of the tailoring of their support over a longer period of time.

We were able to gain useful practical insights through this in-depth case study by characterizing the varied and adaptive support provided by teachers. The results of this study may prove insightful for other chemistry projects, or design projects in other STEM subjects. 'Regular' experiment setups in the chemistry classroom could be improved by the guidance of design-based practices. In our results, we see that the teachers take control on certain subject-specific aspects, such as safety and conceptual knowledge. At the same time, teachers encourage student creativity on other topics, facilitating a more student-centered approach. Also, teachers scaffold *doing* and *thinking* differently (McDonnell, 2016). The topic of the conversations may be different for other STEM subjects, but we expect a similar variation in the verbal support that teachers provide to their students. Our findings on how teachers support design steps, and that each step can be supported with different means, can also be useful for design teachers.

The use of alluvial diagrams to visualize relations and proportions in the findings is a methodological contribution, and using this as a tool for analysis may prove useful for other areas of exploratory or descriptive research. Visualizations in general may help both the researcher and the reader to understand and untangle data regarding complex processes, such as scaffolding, by showing a multi-faceted image of how teachers operate during teacher–student interactions. In our study, this worked as a method for recognizing patterns and spotting distinctions in the data. It can support and reduce the workload when analyzing, as it can work as a lens to focus on patterns in the data from different angles.

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