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How teachers support students during design activities in the chemistry classroom

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Abstract
Design activities are increasingly used in science, technology, engineering and mathematics (STEM) education. Guiding students during these activities can be challenging for STEM teachers, who may be inexperienced in the field of design. In this study, we focused on a case of three chemistry teachers who implemented design projects in their classrooms. During the lessons, the students designed a self-heating or self-cooling cup, in which the energy effect of chemical reactions causes a heating or cooling effect on the cup's contents. Through an in-depth analysis of the conversations between the teachers and student groups, we aim to understand how teachers verbally support students and any factors that may influence this. We used concepts from scaffolding theory to analyze the support. By organizing the data into segments based on these scaffolding concepts, we were able to characterize the different approaches taken by the teachers. The types of support varied; for example, the teacher might take control of the process or stimulate the students' reasoning. The support appears to be adapted to the students, the lessons and the topics of the conversations. These are possible factors that may influence the way in which teachers support the students during design activities.

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

Introduction

Design activities are increasingly included in science, technology, engineering and mathematics (STEM) education. Design is often introduced as a professional practice, in which students learn how designers in their fields and subjects work. Design can also be used as a direct method for learning scientific concepts and may deepen students' understanding of disciplinary core ideas (Thibaut et al., 2018). This is called

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design-based learning, where conceptual learning is embedded in the process of designing (Kolodner et al., 2003). Besides these objectives, teachers have many different ideas about why design is important in the classroom (cf. Stammes et al., 2020). Kolodner et al. (2003) and Moore et al. (2021) mention the development of soft skills, such as working in groups, co-operation and creativity, as additional goals for the use of design in STEM education.

Regardless of the STEM subject with which design is linked, students need to learn about designing. For many STEM teachers, this is a new aspect in their teaching and comes with its own challenges. The guidance of students during design activities in the classroom is not straightforward and may pose difficulties for teachers, who are typically used to a more traditional approach to teaching. Teachers may feel uncomfortable with this new and challenging pedagogy (McDonald, 2016; Stricker, 2011), where they are more a guide than an instructor.

In this article, we focus on the subject of chemistry in relation to design activities. Chemical design is an important part of real-world chemistry and can be introduced as an engaging context for learning chemical concepts while simultaneously learning about chemical design practice (Gilbert, 2006). Chemistry is often experienced as abstract, since it requires the understanding and knowledge of substances and their reactions at the micro-level (atoms, molecules, ions and their interactions). Chemical design, however, requires the practical application of this understanding, which could be difficult to do and learn without proper guidance from the teacher. Chemistry is traditionally taught as a body of knowledge, with the teacher as an expert and knowledgeable instructor (cf. Van Driel et al., 2005), and there is little room for interpretation or deviation. Design education, on the other hand, also nurtures the creative aspect, with students acting as independent designers who are able to express and shape their own design ideas. It remains to be seen how, when implementing design in a subject like chemistry, this translates to the actual practice of guiding students during a design-based project. Teachers may need to strike a balance in their support of the students with regard to the difficulties of learning chemistry content and the difficulties of learning to design. This is made more challenging because teachers do not always have a clear view about what design is, and how to approach the design problems that students face (Stammes et al., 2020).

The manner in which teachers can support students in the design process in the chemistry classroom is understudied. Studies have focused on the content and composition of the lessons that contain design activities, and the feedback that teachers provide (often over a period of time). This 'fixed' and pre-determined guidance from teachers is certainly useful (cf. Apedoe et al., 2008; Van Breukelen et al., 2016); however, little is known about how teachers engage students *while* they are working on their design activities, and the verbal comments and feedback provided about the students' designs in an unplanned, hands-on, adaptive manner. This can also be seen as interactive formative assessment (Cowie & Bell, 1999). The personal aspect of communicating with students verbally, enquiring about their choices, and verbally supporting them into the many considerations a designer would make is a skill that the teacher needs in order to guide students successfully through the design process. Research into design in STEM subjects rarely focusses on the teacher, their practices, or the choices that a teacher makes to guide students interactively.

Our aim is to gain insight into the ways teachers can verbally support students undertaking design-based projects in the subject of chemistry. For this purpose, we analyze and characterize the conversations between teachers and their students in an in-depth exploratory study, with the intent of understanding how teachers interact in different situations. We will also look for possible factors influencing the ways in which the teachers support their students. Our findings are useful for teachers who would like to implement design activities in their classrooms, or for teacher-training purposes.

Background

Design education and the role of teachers

Design is a situation that the designer finds him/herself in, and it is not just a process or a profession (Dorst & Dijkhuis, 1995). In that situation, there are multiple ways of making progress. A solution to a design problem is not always straightforward. The choices that a designer makes influence the design, its use, and the perception of the design as well. This has consequences for the ways design skills should be learned (McDonnell, 2016). Teachers guide students to transition from one phase to another in the design process (Goldschmidt et al., 2014), and need to be aware of the relationship between students and their design. Teacher guidance contributes to student learning, empowerment, identity formation and socialization into professional practice, and also engages students in reflective practice, critical discourse, transformative learning and self-authorship (Adams et al., 2016).

Design education can help us understand the aspects that may be important when supporting students. Goldschmidt et al. (2010) define three major profiles for design teachers: (1) instructor as a source of expertise or authority, (2) instructor as a coach or facilitator and (3) instructor as a 'buddy'.

High school engineering teachers previously identified 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 a guide rather than the knowledge base (Stricker, 2011). The last of these stresses on the different role that a teacher has during design education. These themes can also be found in other studies. The Learning by Design Cycle (Kolodner et al., 2003) proposes two cycles of activities to promote design thinking in the classroom. In the first cycle, the student engages in activities required to complete the design and its creative process. In the second cycle, the student performs activities that are centered on what a student needs to know and research to further the design. A design task can be structured in this way, so that students know what to do and the teacher can take the role of a guide to help students.

Approaches in design education

Dorst and Dijkhuis (1995) describe two paradigms for design methodology: design as a rational problem-solving process, and design as a process of reflection-in-action. The first process considers design to be a logical and rational process, which can be objectively observed. The designer gathers information and follows a design procedure using 'scientific' laws. Design as reflection-in-action considers every design problem to be unique, with the designer using their skill to tackle the problem. The process of designing is a 'reflective conversation'.

Stolterman (1994) argues that these paradigms are also used by design teachers when instructing students how to design. There are teachers who follow a more rational practice and others who follow the reflective practice. In the rational problem-solving process, it is inherently assumed that there is a rational way of coming from a problem to a solution and that the designer needs to be guided. The guidelines are transferable, implying that design principles are not dependent on the designer or the situation. The guidelines also serve as a criterion for a 'good' or 'bad' design, since following the guidelines should lead to the right solution. In such, it is process oriented.

In the reflective practice, it is assumed that the designer is guided by their own ideals and values. A skilled designer will act according to their own rational thinking and decision making, even though this is not visible in their apparent behavior during the design practice. The process is not generic, but focusses on a specific situation. Contrary to the rational approach, where the guidelines themselves serve as criteria, the designer themself needs to have the ability to recognize and judge quality. The reflective approach is product oriented.

In the practice of teaching design, these paradigms may very well occur interchangeably, and can at times enhance or conflict with each other. For instance, during design-based projects in the classroom, teachers can at times be the instructor, transferring rational arguments for design choices, but can also take up a facilitator role, guiding and coaching students with questions and feedback that ask the student to reflect on their design ideas.

A study by McDonnell (2016) on the practice and role of a design teacher in higher education describes the conversations that the teacher had with his students when discussing their designs. The author noticed that the teacher instructed his students very precisely on *what they needed to do*, but refrained from informing them *how to think*. Instead, the teacher encouraged design reasoning. There is a contrast in how the teacher supports the students' doing and thinking. For the latter, the teacher guides, suggests, coaches and facilitates, but does not think for the student. The teacher invites students to notice features in their designs (positive and negative) and lets them reflect and make design choices. This is also an example of how teachers use both rational and reflective approaches: the *doing* is supported with a rational approach, and the *thinking* is supported through a reflective approach.

This contrast between a rational and a reflective practice may also present itself when chemistry and design come together in the classroom. As Stolterman (1994) discusses, one's preconceptions about what a designer is influence the fundamental assumptions about design practice. While a designer is sometimes perceived as an engineer, they may also be seen as an artist or craftsman. A similar dichotomy can be seen in chemistry as well, where the theoretical aspect is heavily structured and guided in education, whereas chemistry practice throughout history has been one of trial and error, with chemists using their own rationale and instinct to come up with a solution for a problem. Now, when chemistry and design come together, a teacher may use rational and reflective approaches in both subjects.

Design in chemistry and other STEM subjects

Research into design-based learning often discusses what to learn, what activities to perform with students, how to arrange these activities, and what the learning outcome is for the student. For example, Kolodner et al. (2003) introduced the Learning by Design Cycle, containing two cycles of activities: activities related to design and its creative process, and activities concerning what to know and research to further the design. Some studies focus on the learning outcomes of students and the effectivity of concept-learning during design projects (e.g., Apedoe et al., 2008; Van Breukelen et al., 2016). In these studies, the composition of activities during the project and the support from the teacher is highly structured. This structure makes it difficult to see how teachers can adapt their support to the level of students.

The introduction of design in the classroom creates a situation that is different from traditional science education. Design based learning requires teachers to control their classroom in a different way (Kolodner et al., 2003) and research also shows that teachers' behavioral investment (assisting students) and emotional investment (showing interest) is vital for the students (Zhang et al., 2020). To address the dynamic nature of teacher support during design projects, many studies use the term 'scaffolding' (see, for instance, Kolodner et al., 2003; Adams et al., 2016). In the next sections, we discuss the general concepts of scaffolding and use them in this article to describe the support that teachers can provide when guiding students during design projects.

Support in the form of scaffolding

The term 'scaffolding' is broadly used to describe various types of support in different areas of education. While scaffolding can be provided in the form of assignments, procedures, lesson material or computer aids, it can also be applied through verbal support. In our study, we are most interested in this last form of scaffolding, as we want to understand the way in which a teacher can guide students verbally.

In the literature, scaffolding is approached and defined in different ways. We consider scaffolding to be the tailored support provided by a teacher or knowledgeable peer, through which a student reaches a certain required level of competence in a subject. In this context, scaffolding has also been described as 'calibrated support' (Stone, 1998) and temporary and responsive support (Jadallah et al., 2011). It is meant to make learning accessible and manageable (Hmelo-Silver et al., 2007).

Dimensions of scaffolding

In order to describe scaffolding, we can use certain constituent concepts, hereafter referred to as dimensions of scaffolding: (A) responsiveness, (B) degree of teacher control and (C) scaffolding means. These dimensions can be used to analyze and describe the support provided by teachers.

A. Responsiveness

In the literature, the tailoring of scaffolding is sometimes called contingent teaching (e.g., Van de Pol et al., 2010; Broza & Kolikant, 2015). Contingency is mentioned as a fundamental characteristic of scaffolding (Wood et al., cited in Koole & Elbers, 2014). To teach contingently, it is important to diagnose the student's position or level of understanding, and then adapt the support and perform an intervention (Broza & Kolikant, 2015; Van de Pol et al., 2010).

Koole and Elbers (2014), however, suggest that responsiveness is an indicator of contingency. Rojas-Drummond et al. (2013) also use responsiveness to address contingency. Responsiveness can be defined as 'noticing and responding to a student's idea either by rephrasing the idea, probing for further clarification, or shifting the direction of the discussion in a way that addresses the idea' (Levin et al., 2009; Maskiewicz & Winters, 2012). We will use responsiveness in our study to address the aspect of contingency.

Responsiveness is a content-focused criterion used to assess how a teacher stays close to the students' ideas and needs. Pierson (2008) defines low, medium and high responsiveness, discerning whether the teacher follows up on student comments and whose idea is responded to. Low responsiveness means there is no follow up to a student's comment, or the response is limited to a yes/no answer or repeating the comment. If the teacher does follow up on the student's comment, but focusses on an idea that the teacher themselves introduced earlier in the interaction, the responsiveness is medium. The responsiveness is high if the teacher responds to the idea of a student, either displaying teacher reasoning (high 1) or by inviting the student to display their reasoning (high 2).

B. Degree of teacher control

The degree of teacher control (Van de Pol, 2012) describes how a teacher either takes more control of the learning process and reduces the cognitive load of students or allows students to learn themselves with the least amount of interference. The degree of teacher control is defined from lowest to highest in five steps, with the lowest being a broad and open response from the teacher and the highest being a closed response (giving the answer to a question). Table 1 lists the five different degrees of teacher control, and the characteristics of the teacher's response.

C. Scaffolding means

Van de Pol et al. (2010) distinguishes various scaffolding means (questions, feedback, hints, instruction, explaining, modelling) that a teacher can use. In the literature on design education, we find descriptions of support in terms of feedback and questions. In the design discourse, feedback and questions also implicitly contain hints, instructions and explanations to some extent; therefore, in our study, we look at feedback and questions as means of scaffolding.

Questions can be in various forms. Cardoso et al. (2016) describe the use of low-level questions, deep reasoning questions and generative design questions. These questions are either used to elicit known information (low-level questions), prompt students to dive into aspects known by the teacher but not typically by the students (deep reasoning questions) or let students think of new ideas generally not known by the students or the teacher (generative design questions). Deep reasoning questions have a converging effect, leading

Table 1 Degree of teacher control. Adapted from Van de Pol (2012)

	Degree of teacher control	Characteristics of teacher's response	Teacher provides new content	Teacher elicits a(n)…
1	Lowest	Broad and open	No	Elaborate response
2	Low	Detailed but still open	No	Elaborate response, explanation (why…)
3	Medium	Gives an option (yes/no, multiple choice)	No	Short response
4	High	Gives a hint or suggestion	Yes	Response
5	Highest	Gives an explanation or the answer to a question	Yes	No response

toward a specific goal or problem to solve, while generative design questions have a divergent nature, helping the student to think of new ideas. In an earlier study (Sheoratan et al., 2024), we found these questions being used in practice for design-based projects in chemistry education. We also reported the types of feedback that teachers provided to their students when supporting them during chemical design assignments, namely encouraging feedback, clarifying feedback and steering feedback. Feedback is an important part of communicating design issues to the student. (Goldschmidt et al., 2010).

With these dimensions from the scaffolding literature, we can specifically describe the different support that teachers provide in the classroom.

Aim of this study

We will follow teachers during their guidance of students undertaking design-based projects in the chemistry classroom, studying the types of verbal support teachers provide, how they apply their support and what possible factors influence their support. We believe the guidance of teachers during the early stages of a design assignment is crucial for the student while largely intangible for the inexperienced chemistry teacher. While every phase in the design process could very well require guidance from a teacher, we mainly focus our study on the early stages of the problem description, design brief and idea generation by following teachers during the lessons incorporating these early phases.

We use the different dimensions found in scaffolding theory to characterize the support given by teachers. With the help of these characterizations, we can gain an understanding of the type of support given. By analyzing the conversations between teachers and students in an in-depth manner, we believe we can elucidate how the teachers apply their verbal support and possibly identify any influencing factors.

Our research questions are:

- *RQ1: How can the verbal support that teachers use to aid students during design activities for chemistry be characterized in terms of responsiveness, degree of teacher control and scaffolding means?*
- *RQ2: What are possible factors influencing the support that teachers provide?*

Educational context

In 2018–2019, three chemistry teachers from the same school in the Netherlands, including the first author, introduced three design-based chemistry projects in three Grade 9 (14–15-year-old students) classes from the pre-university stream in the Dutch educational system. The teachers collaborated closely and came together multiple times during the year to discuss the projects, how to guide the students and what their role should be in the process. After each design project, the teachers reflected on how to improve their support of students for the next design project.

The data for this case study comes from the third and final project, performed in 2019. The project was named ‘the thermo challenge’, a project adapted from the works of Stammes (2021) and Apedoe et al. (2008). In this project, students are required to design a self-heating or self-cooling cup. The lesson series ran for four lessons, the first two of which were analyzed in the present study. These two lessons were selected because, at this stage, the students are the most engaged in discussing the design problem, challenges and ideas they have, and learn most about the concept of reaction energy through experiments. The interactions they have with teachers during this phase will contain discussions that deal with design and design choices to a high degree.

In lesson one, the students are introduced to the design challenge. They have to cool down or heat up a beverage of their choice through the use of an endothermic or exothermic reaction, and design a cup to accomplish this safely while travelling. After a whole-class instruction by the teacher, the students work in groups to discuss the design problem and draw or write down their ideas. During the lesson, the students also perform chemistry experiments where they learn and experience how the temperature changes during selected endothermic and exothermic reactions. In lesson two, students perform experiments to learn how the reaction speed can be influenced, from which they learn how to improve their design ideas. They also continue their design ideas by discussing and drawing several designs and mechanisms for their cup. During lessons three and four, which are not part of this study, students make generic prototypes and test and evaluate whether their designs work as expected.

Lessons one and two involve conversations between the teachers and students, who are brainstorming and learning about design, chemistry and making design choices. We therefore expect that an in-depth analysis of these lessons will give valuable insight into the ways in which chemistry teachers guide their students during design-based chemistry projects.

Method

We performed a qualitative analysis of the conversations between the three chemistry teachers and their student groups over two lessons, resulting in data from six lessons. The analysis of lessons with the same content led by different teachers allows us to observe a variety of conversations and interventions undertaken by these individuals. In this section, we discuss the participants, data collection and data analysis.

Participants

The three chemistry teachers all identify as male and have different backgrounds, although all had some experience with design education at the time of the study. The first teacher has a rich background with 17 years of teaching experience in chemistry, biology and physics in lower secondary education, as well as experience in teaching design in STEM for younger students (grade 7). The second teacher is a chemistry teacher in lower and higher secondary education, with 7 years of experience. The third teacher is a chemistry and physics teacher in lower secondary education, with 11 years of experience. Both the second and third teachers had experience with providing engineering design lessons during physics classes (grade 8) prior to the project. None of the teachers had experience in implementing design projects in the chemistry classroom.

In total, 81 students were present in the three classes, divided into small student groups. Each group consisted of four to five students, and was tasked with designing one cup as a team. There were five to six groups per classroom. The students may have received basic knowledge about designing during technology education in the previous year at school from different teachers; however, design had not been introduced in chemistry before this project, and the students had never designed in the context of chemistry education.

Data collection

During each of the first two lessons on the chemistry design project, we captured the conversations of the student groups using audio-recording devices on each of their tables, and used one clip-on microphone for the teacher to record his conversations with the student groups. In the classroom, two video cameras were placed to record the lessons. The cameras were positioned so that all groups could be observed, and the recordings were used as supporting data to understand the context in which the conversations took place. Generally, the students were working in groups at their tables, and the teacher walked around the classroom. The teachers had conversations with the student groups, either prompted by a question or not. After the lessons were completed, the audio data were transcribed and these transcriptions were used for further analysis. All participants whose data were used, including the teachers and the students and their parents, gave active (i.e. signed, written) informed consent for us to collect and use these data for our research. The research was conducted in compliance with the standards of the involved ethical committees.

Data analysis

The data were analyzed by the first and second author. The second author acted as an independent researcher. We first structured the data and selected the parts relevant to our study. To do this, we defined *interactions* and *turns* (Van de Pol & Elbers, 2013). An interaction is the conversation between a teacher and a group of students. When a teacher walks away or starts talking to students of a different group, we considered the interaction finished. Each interaction consists of so-called turns, which are defined as a response from a teacher or student. This response begins from the moment a person starts speaking until they stop or are interrupted. We use the terms '*teacher turn*' and '*student turn*' to make clear who is speaking.

The first author read the transcripts of the audio and identified the interactions and turns in the transcripts. All interactions in which teachers address the class as a whole, the topic of the conversation is not focused on the task (for example, discussions about grades, non-school topics), or the students talked among themselves without communicating with the teacher were excluded from further analysis and acted as supporting data to understand the context when needed. This selection resulted in 211 interactions, which were subjected to further analysis.

We identified interactions that included conversations about design or the process of designing, while others focused solely on chemistry-related concepts, experiments or the tasks that students needed to do. Since we are specifically focused on the conversations in which design is addressed in the context of chemistry, we selected only the interactions that contained design. Of the 211 interactions, 60 interactions contained conversations about design. We continued our analysis with these interactions.

We analyzed these interactions in three steps. The first step concerns the individual teacher turns, while the latter steps concern the interactions as a whole and the similarities between interactions. We summarize these here, and then describe each step in more detail.

Step 1: Characterizing teacher turns through the analytic coding of topics and scaffolding dimensions

Step 2: Segmentation and description of interactions with the use of scaffolding dimensions

Step 3: Finding common aspects within segments

Step 1. Characterizing teacher turns through analytic coding with scaffolding dimensions

We used analytic coding (Cohen et al., 2011) to code the individual teacher turns in the 60 'design' interactions, identifying 299 teacher turns in which teachers discuss design steps. We coded these for (1) the *topic* that the teacher addressed, and (2) the *scaffolding dimensions* that describe the way the teacher supports the students.

For the topic, we used well-known phases in design education (problem description, design brief, idea generation, prototype, test and evaluation) as the initial codes. We used open coding to add codes when needed.

For the scaffolding dimensions, we coded for (A) responsiveness, (B) degree of teacher control and (C) scaffolding means, as described in "Dimensions of scaffolding" section. Here, we describe how we coded for these dimensions.

A. Responsiveness (Pierson, 2008) was coded in relation to the conversation a teacher had with the students. We coded the teachers' responsiveness as low, medium, high 1 and high 2. If the teacher does not respond to the student or talks about something unrelated to the idea or question that the student raises, we coded this as low responsiveness. If the teacher responds, but the idea to which they respond was originally their own, this counts as medium responsiveness. If it was the students' idea, we count this as high responsiveness. There are two forms of high responsiveness: if the teacher displays their own reasoning in their response, we call this high 1; if the student reasoning is displayed, this counts as high 2.
B. The degree of teacher control (Van de Pol, 2012) was coded based on the content of the response, ranging from 1 (lowest) to 5 (highest; see Table 1). For example, an open question like 'What is going on here?' was coded as 1, whereas a question in which the teacher gives options, such as 'Are you going to do an exothermic or endothermic reaction?', was coded as 3. If the response of the teacher did not contain any control, it was coded 0. An example of this is when a teacher only responds with 'okay', or 'thanks'.
C. For the types of questions, we looked at whether the questions were low-level questions, deep reasoning questions or generative design questions. In terms of feedback, we used 'encouraging feedback', 'clarifying feedback' and 'steering feedback' as codes (Sheoratan et al., 2024). When a turn consisted of multiple means, we noted this, and coded each of them.

Step 2. Segmentation and description of interactions with the use of scaffolding dimensions

In the previous steps, we coded the data at the level of teacher turns. These individual teacher responses show how the teachers adapt their support to the student at a micro-level.

In an interaction, there are multiple teacher turns with student turns in between. Now that we know (from step 1) what types of micro-supports the teachers use, we are interested in determining whether different interactions show similarities in the way teachers support their students. This may point to the patterns or factors that teachers use to adapt their support to the students.

In order to further analyze the 60 interactions, we split the data into *segments* of interactions that share similarities in the scaffolding dimensions. In step 1, we coded for (A) responsiveness, (B) degree of teacher control, and (C) scaffolding means. Of these three dimensions, the first two (responsiveness and degree of teacher control) are ordinal variables with a rank or order, while the third (scaffolding means) is nominal. This makes the responsiveness and degree of teacher control useful in ordering the interactions based on these dimensions (see Fig. 1).

We placed each interaction in a segment based on the occurrence of either low or high *responsiveness* and low or high *degree of teacher control*. After that, we described each segment with the help of the scaffolding dimensions. The dimension of s*caffolding means* contains nominal variables that describe which types of questions and feedback occur in the data. We used *process mining* to gain insight into how scaffolding means are used in the segments. Process mining, generally, is the extraction of knowledge from so-called event logs of process data, with the aim of discovering, monitoring and improving real processes (Van der Aalst, 2013). Process mining has also been used to analyze student behavior in higher education (cf. Van der Aalst et al., 2015; Mukala et al., 2015). In our study, we use process mining as a method to visualize the use of scaffolding means within a segment. We created *process diagrams* from the data. These diagrams were created using the open-source library *bupaverse* (Janssenswillen et al., 2019) made for R, a programming language for statistical computing and graphics (v4.3.2; R core team, 2023). Our process diagrams present an aggregated result of all the interactions within that segment, and describe which questions and feedback teachers use and how they use them from the start to the end of an interaction. This visualization helped us to characterize the teacher support within a segment. The diagrams can be used to quickly see the (co-)occurrence of, and the relationship between, scaffolding means in a segment. While each diagram also shows the number of occurrences of scaffolding means, the goal in this small case study is rather to understand than to quantify the use of scaffolding means.

Step 3. Analyzing the interactions for common aspects within segments

In this step, we aim to determine how teachers and students react to each other, under what circumstances they do so, and whether we can identify differentiating features in the data that may have influenced the support provided by the teacher. To accomplish this, we read the interactions again to understand the situation and the context of the conversations. We performed a detailed analysis of the interactions within each segment, looking at other aspects or features related to the interactions to determine whether there are commonalities between the interactions. Other aspects or features include the topics that were discussed in the interaction, as well as identifiers such as who the teacher was, which student group was

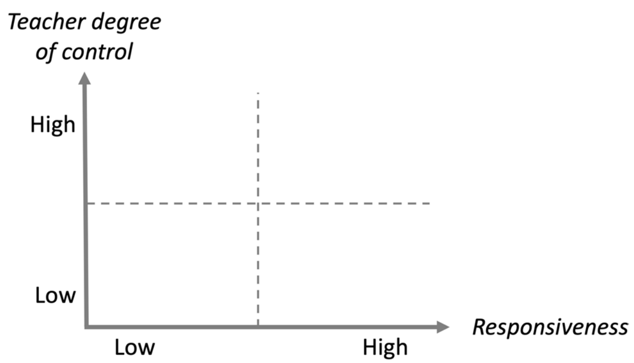

Fig. 1 Segmentation for interactions will be done based on the ordinal dimensions of responsiveness and degree of teacher of control

addressed by the teacher and which lesson the interaction occurred in. Segments that have interactions with common aspects could indicate that the aspects influenced the teachers' scaffolding.

Results

Step 1: Characterizing teacher turns through the analytic coding of topics and scaffolding dimensions

Topics

We analyzed the 60 interactions that contained conversations about the design steps. In these interactions, there were many teacher turns, of which 299 turns addressed design specifically. Different design phases were addressed. Table 2 lists the different topics found in the teacher turns.

We found differences between lessons 1 and 2 in terms of the topics comprising the teacher turns. In lesson 1, problem description, design brief and idea generation constituted the largest portion of teacher turns during design conversations. In lesson 2, the focus shifted to the design brief and idea generation. This finding was expected, considering the content of the lessons and the progress that students make during the lesson series.

In lesson 2, chemistry concepts and experiment outcomes cross-over with the ideas that students have for their design. We added subcodes for these events: '*idea generation implementing experiment outcomes*' and '*idea generation implementing chemistry concepts*'. Students and teachers started to make links between chemistry and design. The conversations that teachers and students had in this context deal with the chemical knowledge needed to improve the design. For this, teachers generally refer to the outcomes of the experiments performed by the students in the first lesson to discuss design aspects.

Table 2 The number of teacher turns in the data, including the subtopics of design steps and their occurrence in the data

	Number of teacher turns		
	Lesson 1	Lesson 2	Total
Number of teacher turns in all interactions (211 interactions)	421	453	874
Number of teacher turns in interactions discussing design (60 interactions)	171	244	415
Teacher turns with design steps as topic	135	164	299
Problem description	18		18
Design brief	41	19	60
Idea generation	68	101	169
Idea generation implementing experiment outcomes		3	3
Idea generation implementing chemistry concepts		26	26
Prototype	8	5	13
Test		3	3
Evaluation		7	7

Scaffolding dimensions

We coded the teacher turns on the use of (A) responsiveness, (B) degree of teacher control and (C) scaffolding means. No new codes were added; we were able to code everything with the codes found in the literature.

In Table 3, we give an overview of the different codes and an example of how this is reflected in the data.

One example from our data for responsiveness and degree of teacher control is provided for each code to illustrate the content. With these examples, all types of questions and feedback are covered.

Step 2: Segmentation and description of interactions with the use of scaffolding dimensions

We segmented the data based on the responsiveness and degree of teacher control. In Fig. 1, we proposed a segmentation, which we used as a basis. We found that the interactions mostly contained low and medium responsiveness. We considered the occurrence of at least one high responsive teacher turn to be an important distinguishing aspect of an interaction, since this means that the teacher responds to the ideas of the student instead of the teacher giving their own ideas on some subject. Therefore, an interaction with at least one high responsive teacher turn was categorized into the segment of 'high responsiveness'.

For the degree of teacher control, we separated the interactions and made three distinctions: high degree of teacher control with codes of 3 to 5, mixed degree of teacher control with codes from 1 to 5, and low degree of teacher control with codes 1 to 3. We added the mixed degree of teacher control as a separate distinction because there were a number of interactions in which the degree of teacher control varied considerably from low to high. This resulted in a total of six segments, shown in Table 4.

In the next section, we go into each segment and describe the third dimension, the scaffolding means, and how they are used in each segment.

Segment 1

This segment contains interactions in which the teachers take relatively high control of the conversation, while displaying low/medium responsiveness. To illustrate the occurrence of scaffolding means and how the teacher moves from one means to another, Fig. 2 shows a process diagram of the scaffolding means used in segment 1.

The diagram shows only the teacher turns; student turns are left out in this visualization. The diagram should be read as follows. On the left and right sides of the diagram, the circles with 'start' and 'end' denote the start and end of an interaction. Every node in the diagram is the sum of a particular scaffolding means *at any time*, and in *all interactions* of this segment. The color of the node reflects the number of occurrences. The arrows show how a teacher turn with a specific scaffolding means is preceded or followed by another scaffolding means; for example, in Fig. 2, the diagram shows the sum of all 13 interactions. Of these, five interactions started with a teacher turn comprising clarifying feedback, two interactions started with a teacher turn consisting of encouraging feedback, and so on. If we look at one of the nodes, for example the steering feedback in the middle of the diagram, we see there were six instances of this scaffolding means in the segment. There are arrows going into the node, which means

Table 3 Examples of teacher turns from the data and their scaffolding dimensions

	Responsiveness	**Type of question and feedback**
Low	'How does this work?'	Low-level question
Medium	'You can add that to your design brief. It makes your design stronger if you think about the materials that you use. Is it indeed good for the environment? Those are criteria that you can add if you want.'	Clarifying feedback
High 1	'You are now looking at the average temperature, but I think that warming a drink is especially interesting for the winter.'	Clarifying feedback
High 2	'Yes, exactly. Very good. Now you are thinking of the right things. That is why you need to think about your design.'	Encouraging feedback
	Degree of teacher control	
1	'What do you think?'	Deep reasoning question
2	'What are some other ideas?'	Generative design question
3	'Which idea is it going to be?'	Low-level question
4	'You could think of more possibilities. This is all meant to help you get inspiration.'	Steering feedback
5	'Air is a very bad conductor of heat.'	Clarifying feedback

Table 4 Segments in our data, based on the types of responsiveness and degree of teacher control contained in the interactions

	Low/medium responsiveness (no high responsiveness turns)	High responsiveness (at least one high responsiveness turn)
High degree of teacher control (3–5)	**Segment 1** (13 interactions)	**Segment 4** (7 interactions)
Mixed degree of teacher control (1–5)	**Segment 2** (10 interactions)	**Segment 5** (17 interactions)
Low degree of teacher control (1–3)	**Segment 3** (6 interactions)	**Segment 6** (7 interactions)

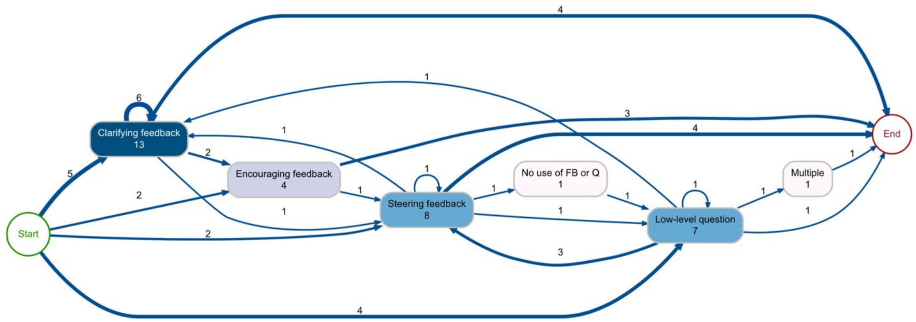

Fig. 2 Process diagram of segment 1, showing the scaffolding means (questions and feedback types) given within this segment

that one instance of steering feedback came after clarifying feedback, one after encouraging feedback and three after a low-level question by the teacher. One teacher turn with steering feedback was followed by another steering feedback; this can be seen as the arrow that circles to the same node again.

The scaffolding means used in segment 1 are predominantly types of feedback, where clarifying feedback and steering feedback are given most often. When the teacher used questions, these are low-level questions. The teachers seemed to start these interactions with clarifying feedback and low-level questions. Most often, the final teacher turn with respect to design steps contained clarifying feedback and encouraging feedback. This can be seen in the diagram, because we see thicker arrows coming from these means and going to the end on the right. The teachers did not use any deep reasoning questions.

Segment 2

Segment 2 contains interactions with a mixed degree of teacher control (both low and high) and with low/medium responsiveness. The process diagram with the scaffolding means is given in Fig. 3.

The segment contains clarifying feedback, encouraging feedback and low-level questions, with occasional use of deep reasoning questions and steering feedback. Clarifying feedback and encouraging feedback occur mostly at the start and the end of the interaction. The teachers seemed to provide multiple turns of clarifying feedback in some instances.

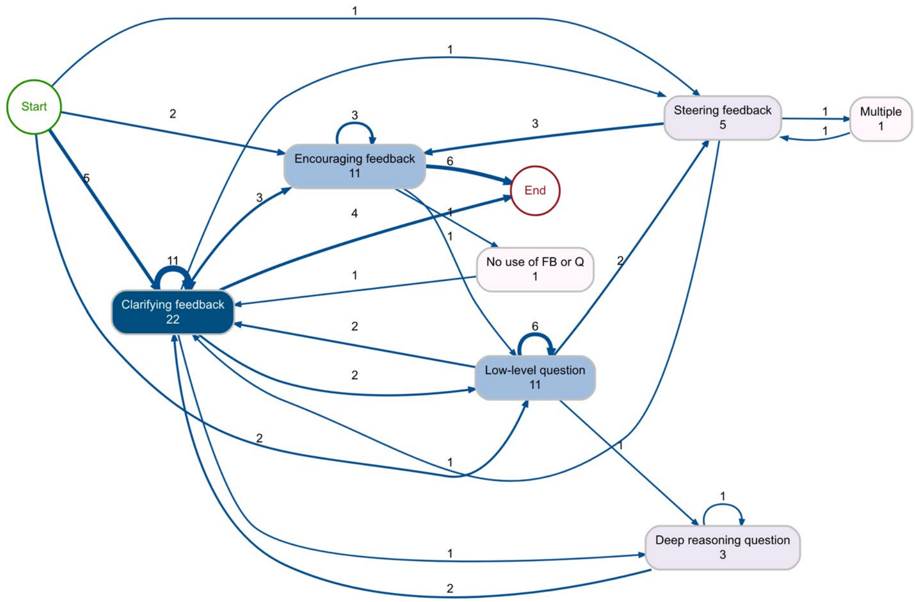

Fig. 3 Process diagram of segment 2, showing the scaffolding means (questions and feedback types) given within this segment

Segment 3

Segment 3 is a relatively small segment in which the teacher uses a low degree of teacher control and has low/medium responsiveness. Figure 4 gives the process diagram with the scaffolding means for segment 3.

Teachers used clarifying feedback and low-level questions to support students in these interactions. There was occasional steering feedback and encouraging feedback.

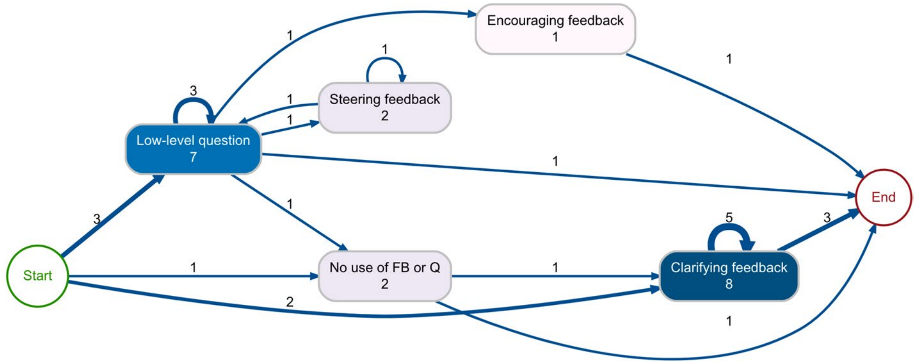

Fig. 4 Process diagram of segment 3, showing the scaffolding means (questions and feedback types) given within this segment

Segment 4

This segment contains interactions with a high degree of control, that contain at least one high-responsive teacher turn. The appearance of a high-responsive turn means that the teacher somehow comments directly on ideas of the student. In Fig. 5, the process diagram is given for the scaffolding means in this segment.

This segment typically comprises a lot of clarifying feedback and some use of encouraging and steering feedback. The use of questions was limited to very few teacher turns in the interactions.

Segment 5

Segment 5 contains the interactions with a mix of the degree of teacher control, and at least one high-responsive teacher turn per interaction. The process diagram of the scaffolding means used in this segment can be seen in Fig. 6.

The diagram contains a lot more links between different scaffolding means compared to previous segments. We can see that low-level questions and clarifying feedback are predominant, but steering feedback, encouraging feedback and deep reasoning questions are also used more often. Most of the interactions start with a low-level question.

Segment 6

Segment 6 is a smaller segment, containing few interactions; however, these interactions are of interest due to the low degree of teacher control (open and broad questions and feedback), while still containing high responsiveness, meaning that the teacher addresses or responds to the ideas of the students. The process diagram of the means used in this segment can be seen in Fig. 7.

In the diagram, we can see a combination of a many low-level questions, deep reasoning.

A summary of the use of scaffolding dimensions can be seen in Table 5. Here, we can notice that the segments 1 to 4 contain more feedback from the teacher, and segments 5 and 6 contain more teacher questions.

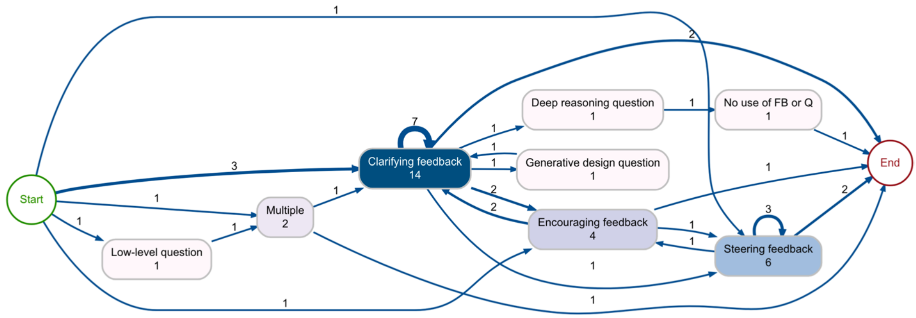

Fig. 5 Process diagram of segment 4, showing the scaffolding means (questions and feedback types) given within this segment

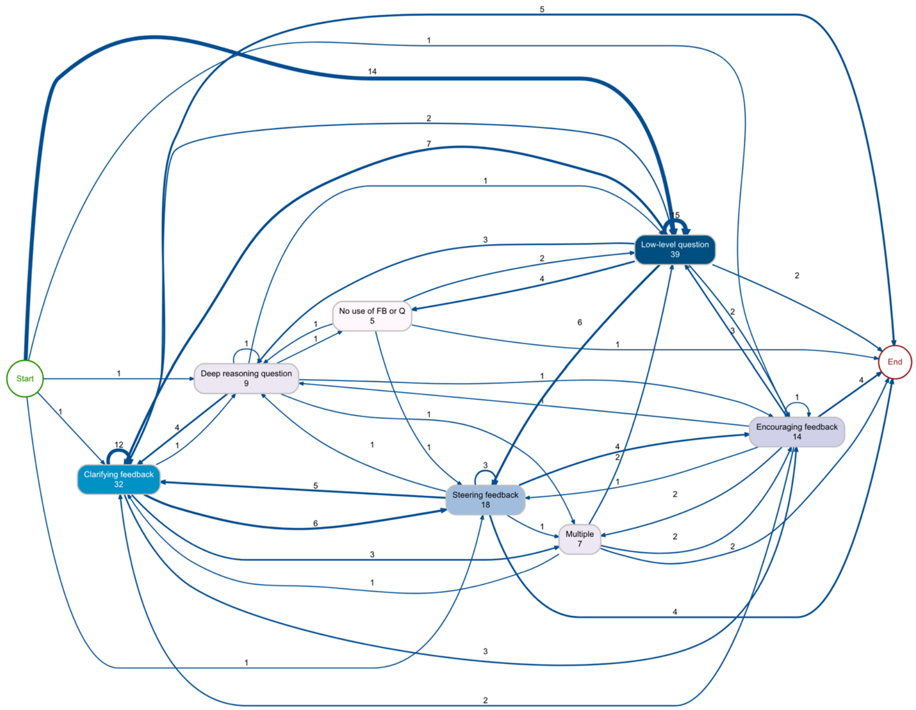

Fig. 6 Process diagram of segment 5, showing the scaffolding means (questions and feedback types) given within this segment

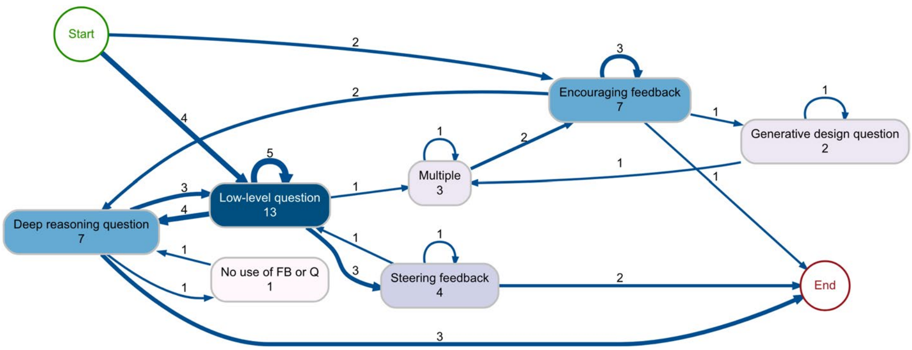

Fig. 7 Process diagram of segment 6, showing the scaffolding means (questions and feedback types) given within this segment

Step 3: Analysing the interactions for common aspects within segments

For most segments, we identified common aspects between the interactions. We discuss each segment here, looking at aspects other than the scaffolding dimensions, to see how they may relate to each other.

Table 5 A summary of the scaffolding means that occur in the six segments

	Low/medium responsiveness (no high responsiveness turns)	High responsiveness (at least one high responsiveness turn)
High degree of teacher control (3–5)	**Segment 1** Teachers predominantly use clarifying and steering feedback. Low-level questions are used. There is some use of encouraging feedback.	**Segment 4** Teachers use clarifying feedback, steering feedback and encouraging feedback. There is very limited use of low-level questions, deep reasoning questions and generative design questions.
Mixed degree of teacher control (1–5)	**Segment 2** Teachers use clarifying feedback, encouraging feedback and low-level questions. The start and end of the interactions contain mostly clarifying feedback and encouraging feedback. In the middle turns of the interactions, the teachers also use some deep reasoning questions. When giving clarifying feedback, there is a relatively strong follow-up of more clarifying feedback from the teacher.	**Segment 5** Teachers predominantly use low-level questions and clarifying feedback. They also use steering feedback, encouraging feedback and deep reasoning questions. Most interactions start with a low-level question.
Low degree of teacher control (1–3)	**Segment 3** Teachers use clarifying feedback and low-level questions. Occasionally there is steering feedback and encouraging feedback.	**Segment 6** Teachers use a combination of low-level questions, deep reasoning questions and encouraging feedback. There is some use of steering feedback and generative design questions.

Segment 1

We found that the feedback given by the teacher is used to explain a certain design phase and the tasks that students need to do. The teacher also corrects students or gives options. The questions that are asked in this segment are either diagnostic (to the effect of '*what can I help you with*') or suggestive ('*you know you can also do [something better], right*?').

In Example 1, we see part of one interaction in which the students do not know what to do and ask the teacher. The students had received a worksheet where they could write down different ideas for their design materials and mechanisms. The teacher explains what to do through different kinds of feedback. Here, we see that the teacher does not get involved in the ideas or the design of the students, but rather comments on more general aspects and mentions the tasks and the attitude with which these should be completed.

Example 1

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S1	What should you do here on the dots?				
T	You can perhaps think of more possibilities [to accomplish the design goal]. This is all meant to help you get inspiration. We give some suggestions, but perhaps you have other ideas too. If so, you can write them down here.	Idea generation	Medium	4	Steering feedback
S1	Just like here.				
T	Just like there. Perhaps you may think of other materials [to use]. If you thought of other, different materials, then you can think, like, 'I am going to try to draw this principle and this principle with these things, try to design something'. Or perhaps you first have a design, and afterwards you think, 'okay, I've used this mechanism in my design'. Anyway, you can use this to get inspiration for your different designs.	Idea generation	Medium	4	Clarifying feedback
S1	Oh, okay. So, should we use different materials and stuff in the second [idea]?				
T	You can. In that case, make sure that they are different ideas. You can use the same materials if you want to.	Idea generation	Medium	4	Encouraging feedback
	…				

The teacher answers the questions that the students have, and explains the tasks and concepts that the student needs to understand. The teacher seems to push the students to start or complete a specific task. Another way of guiding the students in this segment is that the teacher thinks along with the student and involves himself in the experience. We can see this in a short selection of an interaction in Example 2.

Example 2

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S1	3 °C to 7 °C for a cold drink is quite tasty, right?				
T	That is good, yeah. I do like that. It sounds a bit like a refrigerator temperature.	Design brief	Medium	4	Encouraging feedback

In this example, the teacher 'joins' in with the experience that the student is proposing. By doing so, the teacher answers the question from the student and encourages them to continue with this idea. It is therefore a teacher turn with a high degree of teacher control (4), similar to Example 1; however, here the teacher uses his own opinion and personal likes to guide the students.

The interactions in segment 1 are relatively short, with most of them containing only one to three teacher turns. The interactions in this segment are from teachers 2 and 3 only. In the classrooms of both teacher 2 and 3, there was a group of students that seemed harder to motivate and keep on task. This was established with the use of other interactions about behavior and classroom management that were left out of this study, but served as supporting data. In these data, we could see that the groups occasionally received corrective feedback from the teachers. The majority of interactions that the teachers had with these groups fall into this segment. No specific relationship was observed between the topic and the segment.

Segment 2

The content of this segment is varied. In some teacher turns, the teacher implores students to think about their design (see Example 3). The teacher draws attention to design aspects in the student's ideas and asks them to think about how to improve their design.

Example 3

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
T	I think that you should think carefully. (…) In [step] 3 or 4, the question is 'how can you keep the substances apart from each other?' You do not want to throw the chemicals in your soup, do you? Yes, maybe it is edible, I don't know, but maybe it is not.	Idea generation	Medium	4	Steering feedback

When the design challenge is not yet understood, the teacher explains the project by using the examples and experiences of the students. The teacher uses low-level questions, asking about what the students are doing, and gives clarifying feedback. In Example 4, we see the teacher encouraging students and asking about their design. The students, however, seem unable to answer the questions and experience difficulties with the task. The teacher then helps and clarifies the design challenge and the tasks more elaborately.

Example 4 (teacher turns that do not specifically deal with design steps are not coded here)

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
T	You are thinking of even more ideas. That's good!	Idea generation	Medium	5	Encouraging feedback
S1	Good, isn't it?				
T	Yes, it is looking very good. Nice ideas. Which one is it going to be?	Idea generation	Medium	3	Low-level question
S1	Of these?				
T	Yes, do you already know?	Idea generation	Medium	3	Low-level question
S1	No. It is difficult.				
T	This means that it is also in here, right? (*Teacher points at worksheets. From the context we can infer that there is an open compartment in the design drawing, meaning chemicals might spill into the drink.*)	Idea generation	Medium	3	Low-level question
S1	Yes, only that is more for cooling. We are going to warm something up.				
T	You can warm this up in the same way, right?	–			
S1	You can't use any matchsticks or anything.				
T	No, what were you going to use to heat it up?	–			
S1	Coal.				
T	No, what did you research in the previous lesson? In the previous lesson you did laboratory experiments. If you mix two substances, you get an exothermic reaction that warms it up. Those two substances are what you are going to mix.	–			
S2	Oh, then it must be closed.				
T	Yes, it must be closed. Otherwise, it will indeed get into your… what are you going to warm up?	Idea generation implementing chemistry concepts	Medium	5	Low-level question
S2	Coffee.				

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
T	… Coffee, you don't want that. It also has to be separated at first, because they are two substances and you have to bring them together in one way or another. Then it gets warm and you hang it* in there. The idea of you letting something get warm and put your coffee in it, which then heats up your coffee that way—that's a really good idea. Only then you have to think about how you are going to make sure that the things that have to get a little warm, how you initially keep those two substances separated and then how you get them together. For next week, for [the lab assistant], you really have to write down which substances they are and how much you need. You are going to actually make the design and try it out.	Idea generation	Medium	5	Clarifying feedback

*The cup with the substance that needs to be heated

In the segment, the teachers respond to their students in many more ways. They explain, inform, manage tasks, suggest ideas and answer questions. The segment therefore contains a varied mix of different ways in which the teachers support students.

Segment 2 contains interactions that mostly occur in lesson 2, during which students are working on their design based on the laboratory experiments they performed and the information they received in lesson 1. The interactions mostly deal with the topic of idea generation. There are no other apparent similarities between the interactions.

Segment 3

In this segment, the teacher asks what the students are doing, answers a short question, or points to what a student can or cannot do. Example 5 shows an interaction within this segment. Although the student idea does not seem to make much sense (using a chimney to make something cool down), the teacher does not point that out. This is typical for this segment; in most cases, the teacher checks up on a group of students but does not get involved with the group process and their design. He allows the group to continue with their own ideas without interfering too much.

Example 5

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
T	Ladies and gentleman, how far along are we here?	Idea generation	Low	1	Low-level question
S1	Maybe we should make a small chimney at the top.				

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S2	No, something like air holes.				
T	How does this work?	Idea generation	Low	2	Low-level question
S1	It is like, heat will go out of the chimney.				
T	Okay. So it will be become colder inside? Less warm?	Idea generation	Medium	3	Low-level question
S1	Yes.				
T	Okay. Interesting.	Idea generation	Low	0	Encouraging feedback

In segment 3, the interactions involved teachers 1 and 3 and were relatively short. The content is rather varied, but mostly the teacher is checking up on students and answering their simple questions.

Segment 4

The content shows parallels with segment 1, with the teacher commenting on the design tasks, explaining them, giving information and steering the process. By contrast, in the segment 4 interactions, the students have ideas to which the teacher responds, and the teacher reflects on the design aspects together with the students and motivates them to continue their work. In Example 6, one such student idea is reflected upon by the teacher.

Example 6

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S1	Do they have a freezer at school?				
T	Yes, but the whole idea is that you're going to do it without a freezer.	Idea generation	High 1	4	Clarifying feedback
S1	[To student 2:] we need nitrogen because we can't use a freezer.				
S2	Nitrogen?!				
T	Well thought out.	Idea generation	Low	4	Encouraging feedback
S1	Nitrogen makes it cold, doesn't it?				
T	Yes, it does. Go find out if you can use nitrogen for this.	Idea generation	High 1	4	Steering feedback
S1	Sure, for everything.				
T	What are your requirements? You have five minutes to cool it down. Give this some more thought later… Someone should now do those tests and someone should also think about it… Because transporting nitrogen and carrying it with you…	Idea generation	High 1	4	Steering feedback

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S2	Is dangerous.				
T	Yes, exactly. If you want to drink this as an adult, you really want to start selling this in the store. How cool is it that you can just grab something in the store and do something with it and then you get an ice cream? I think that's a groundbreaking idea.	Idea generation	High 1	4	Encouraging feedback
S2	We are going to put a new product on the market, Steven. We're going to be millionaires because of the cappuccino. *(Students give each other a high five).*				
T	Then use substances…	Idea generation	High 1	4	Clarifying feedback
S3	Which you can easily take with you.				
T	Exactly, which you can actually package in this.	Idea generation	High 1	4	Clarifying feedback
	…				

This example shows a group of students who are enthusiastic about their idea, and the teacher guiding them using a combination of steering, encouraging and clarifying feedback. The teacher clarifies what the design challenge is about, steers them so that they stay on the design task, and encourages them by complimenting their good ideas. The teacher mostly responds to the ideas of students, which makes this a good example of a high-responsive interaction. The responsiveness is high 1, meaning that although the idea is the students', the teacher is doing the reasoning. We can see that in the example as well. The interactions in this segment rarely show high 2 responsiveness (teacher responding to student reasoning).

Segment 4 contains interactions that in all but one instance involved teacher 3, most often when talking to one specific group of students. This group of students had wild ideas for making a cappuccino ice cream, as can be seen in Example 7, and the teacher often encouraged their enthusiasm. From the supporting data (excluded interactions concerning behavior and classroom management), we gathered that the group also seemed difficult to keep on task. The teacher used a high degree of control to get the students to work on the right things. Most often, the interventions in this segment were on the topic of idea generation.

Segment 5

Segment 5 distinguishes itself by containing a lot of support in which the teacher invites the student to explain or elaborate their ideas, and then steers the conversation by addressing key aspects of their ideas and designs. Usually, questions are used to start the conversation. In Example 7, the teacher asks about the wall of the cup, and one student explains the idea. The students also respond to each other, questioning the design idea. The teacher keeps asking questions to help clarify the problem. At the end, the teacher gives some steering feedback at a higher degree of control to round up the conversation and push the students to continue their thinking process.

Example 7

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
	…				
T	Looks nice. Do you need such a thick wall?	Idea generation	Low	3	Deep reasoning question
S3	Which wall?				
T	This is a wall, right? And then it comes here…	Idea generation	Medium	3	Low-level question
S3	This is actually a kind of cup, this is the pull tab and there is water here. Here, with a valve, you throw the ammonium… what's it called, ammonium chloride in it.				
T	Oh, you're making a valve. Okay, and then you close it with a screw cap or something? Does the water come directly into the can?	Idea generation	High 1	2	Low-level question
S3	And if I want to drink from the can I have to take it out, and then there are chemicals on it.				
S4	Yes, you just take that off.				
T	You just take that off. How?	Idea generation	High 1	2	Low-level question
S1	You can't throw it away, can you, in the environment?				
S3	You can stick a cloth on the side.				
T	A cloth?	Idea generation	Medium	2	Low-level question
S1	You can't throw it away in the jungle.				
T	That's something to think about guys. You can add a cloth, but I would have the idea that I will get chemicals on my hands. Will it sell? Well, think about it for a moment.	Idea generation	High 1	4	Steering feedback

This example is typical for this segment. Many interactions contain questions that invite the students to explain their ideas, and end with the teacher giving some critical reflection, encouragement, or some final thoughts for the students to move on.

Segment 5 does not have any discernible characteristic with respect to the teacher or the students; however, this segment contains almost always interactions on the topic of idea generation.

Segment 6

The support is mostly given through lots of questions where the responsiveness is often 'high 2', meaning that the teacher not only puts the spotlight on the ideas of the students, but also lets the students reason about their ideas themselves. An example of an interaction in this segment is given in Example 8.

Example 8 (teacher turns that do not specifically deal with design steps are not coded here)

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
T	Are you okay ladies?	Design brief	Low	1	Low-level question
S1	Sure.				
S2	What temperature is good for an iced coffee? I wouldn't really know what…				
T	What do you think?	Design brief	High 2	1	Deep reasoning question
S1	At zero degrees.				
S3	I think above.				
T	Above zero, under…?	Design brief	High 2	2	Low-level question
S2	I really have no idea.				
S3	Under ten, minimum.				
T	How could you find out?	Design brief	High 2	2	Deep reasoning question
S3	Experiments.				
T	Do you ever drink iced coffee?	Design brief	High 1	3	Low-level question
S2	Yes!				
T	Okay. Where do you get your iced coffee from?	Design brief	High 1	2	Low-level question
S2	From the refrigerator.				
T	Refrigerator! How cold is an ice cold? Do you like that, by the way, from the fridge?	Design brief	High 1	2	Low-level question
S2	A freezer is also possible, but not too long in the freezer because then it will freeze.				
T	But how cold is a refrigerator?	Design brief	High 1	2	Low-level question
S1	Five?				
S2	Is a refrigerator five degrees?				
T	No idea. How do you find out?	Design brief	High 1	2	Deep reasoning question
S1	Go to the refrigerator.				
T	Go to the refrigerator. Have a look. *(laughs)* And then ask, 'How hot are you?'. Then it says, 'I'm cool'.	Design brief	Medium	2	No use of FB or Q
S2	Sometimes it is written there.				
T	How do you find out?	Design brief	High 1	2	Deep reasoning question

Who	Turn	Subtopic	Responsiveness	Degree of teacher control	Scaffolding means
S3	Is there a refrigerator here somewhere?				
T	You could ask someone. You can look it up, yes. Have you already decided whether you are going to heat something up or cool it down?	–			
S1	Cooling down.				
T	Then I would advise you: go to the lab assistant, take the experiments you need and get started. You will be sitting at the table anyway, so keep discussing with each other, but then you can start with that. You need time for that.	–			

The teacher keeps asking questions to the students to let them come up with the answer. He does not tell the students the answer, but lets them think. When the students seem to have reached a satisfying answer, the teacher tells the students what they can do next.

The interactions in segment 6 are all from lesson 1. This was the lesson in which students explore the design problem and think of ideas to solve the problem. The interactions in segment 6 involved teachers 2 and 3 only. The topics in these interactions are the design brief and idea generation.

Summary of findings

Students are supported in different ways. Each segment is a collection of interactions that share similar responsiveness and degrees of teacher control. In Table 6, we summarize the findings of the segments.

Discussion

Reflection on findings

In this study, we found that teachers support students in various ways. At the extremes, the support involved strong steering and structuring by the teacher with the effect of having students follow a certain procedure (segment 1), or contrastingly comprised many enquiries and questions with the aim of instilling a more open-ended design approach in the minds of the students (segment 6). These can be seen as forms of design as a rational problem-solving practice and design as a process of reflection-in-action, respectively, as discussed in the background (Dorst & Dijkhuis, 1995). The rational approach suggests that there are pre-set rules that students should follow and that teachers can point to, so that students are guided properly. In our study, this seemed to happen with student groups who were unable or unwilling to continue and needed the push, such as those in the interactions within segment 1 and to some extent segment 4. The teacher commented on which tasks to do next. The reflective approach in our study manifested mostly in the idea generation step of the design process, showing that teachers were interested in, and asking questions about, the students' ideas. This seemed to occur most often in segment 6, where teachers ask a lot of questions and reflect together with the students. Segments 4 and 5 also deal with student ideas; however, in these segments, the teacher did the groundwork for the reflection most of the time. Regarding the use of feedback and questions, segments 1 to 4 seem to rely more on feedback and segments 5 and 6 more on questions. The support with low/medium responsiveness seems more related to feedback as a scaffolding means, and a high degree of teacher control is guided in a similar manner as well. A mixed and low degree of teacher control seems to be related to a higher use of questions.

Segment 6 is also an example of how teachers in a design context may tell the students what to do, but leave the thinking to the students (see for instance Example 8 in "Step 3: Analysing the interactions for common aspects within segments" section). The teachers scaffold the *thinking* of students and encourage design reasoning. This is similar to the findings of McDonnell (2016), who found that teachers gave precise information about what to do but refrained from instructing on how to think.

Experienced teachers can adapt their support to their students, the lesson containing specific activities and goals, and the topic of the conversation they have with students. It is noteworthy that our findings indicate that the way in which the teachers support design shows a similar adaptivity; for example, segment 1 contains instances in which the students seem to have difficulty moving forward and the teacher uses a high degree of control and different kinds of feedback to guide them. In segments 2 and 3, the low degree of teacher control, the low/medium responsiveness and the low-level questions could indicate that the teachers deliberately refrain from interfering. Students are engaged in the tasks and the teacher apparently does not want to disturb the group process. Segment 4 is similar to segment 1 in that it seems to be centered on specific groups of students, but focusses on students who are susceptible to the reasoning of the teacher. One teacher in particular provided support with high responsiveness and a high degree of teacher control in segment 4. In all interactions in segment 5, idea generation is the most common subtopic, and is supported through a mixed degree of teacher control and high responsiveness. The content and scaffolding means of each interaction varied, but a recurring theme is that the teacher asks students to elaborate on their design ideas. The teacher uses the students' ideas as an instrument to give information and feedback to the students. In segment 6, the lesson content and activities may be an indicator of the type of supporting provided by the teachers because this low degree of control and high-responsive support only appears in the first lesson. This could indicate that the content and activities of a lesson influence the type of support that teachers provide. A possible explanation for these findings could be that lesson one has less time pressure than lesson two, which enables the teacher to give a different form of feedback and ask different questions.

In all the segments, we identified possible influencing factors that shape the support provided by the teachers. This adaptivity can be seen as a method by which teachers tailor their support to the student, indicating that teachers are generally scaffolding their students. It would be interesting to observe how the scaffolding develops across multiple design projects over a longer period, and how this scaffolding is tailored to specific student groups and situations.

The literature on scaffolding for design projects in STEM subjects often describes scaffolding in a more static way, in the form of tasks, rituals and phases or activities during the lessons (e.g., Kolodner et al., 2003). The research in the present study focusses on the 'unplanned' and interactive verbal support in the classroom. The possible influencing factors for both static support and unplanned interactive verbal support from the teacher are two notable additions to the knowledge about guiding design projects in the classroom and scaffolding theory in general.

Method

In our initial efforts looking for patterns in the support that teachers provide, we noticed that finding similarities in the data is not straightforward. The many different codes and diverse interactions made it difficult to compare the data. Grouping the interactions into segments on the basis of responsiveness and the degree of teacher control gave us a different perspective, working as a lens for looking at the complex data.

Limitations

We only looked at the *verbal interactions* that deal with design steps; however, the students and teachers participated in many non-verbal interactions during the project as well. Also, verbal interactions before and after the project (during other chemistry lessons) may have informed teachers about their students' positions, ideas and attitude toward designing.

We did not look at the student results for the design project, such as their design drawings or final design products. We therefore do not know whether the provided teacher support led to better designs. Analyzing the student design results could help understand the effect of the teachers' support.

Implications for practice

Teachers in the field can learn from this research and apply it to their own practice. There are multiple ways to support students, and giving teachers examples from research such as this can be helpful. Understanding the two extremes in supporting, i.e., the rational and reflective approaches, and that both can be applied in practice under different circumstances can be insightful for teachers.

This research also indicated that various factors covering multiple aspects might influence how teachers support students. At this point, we do not know whether teachers consciously notice these different aspects and make decisions based on that. Nevertheless, teacher training could contain video images, examples or reflective exercises in which teachers discuss and think about their own methods of supporting students and why, when and how to implement different types of support.

Future research

In our research, we used scaffolding dimensions, such as the responsiveness, degree of teacher control and scaffolding means, to understand the support that teachers provide. We can understand how teachers support students during the design process at the level of individual responses. The interventions by the teachers are adapted to the responses that the students give. In this way, there is a sort of micro-adaptivity present in the data, suggesting that the teachers scaffold their students. However, in a broader sense, scaffolding requires a tailoring of support over a longer period. This entails the withdrawal of support when students develop themselves and become more competent, and the transfer of responsibility for task performance from the teacher to the student (see for example Van de Pol et al.,

Table 6 A summary of the content of interactions in the six segments, and possible influencing factors

	Low/medium responsiveness (no high responsiveness turns)	High responsiveness (at least one high responsiveness turn)
High degree of teacher control (3–5)	**Segment 1** The teacher answers questions, explains or pushes students to work on the tasks that need to be done. The teacher does not get involved with the students' ideas or design, but comments on the tasks and the attitude, sometimes giving their own opinion, and suggests what to do. The interactions are relatively short. This support is found to occur between specific groups and teachers.	**Segment 4** The teacher responds to student ideas and reflects on design aspects together with the students. The teacher motivates, explains or informs. This support is found with specific groups and teachers, mostly on the topic of idea generation.
Mixed degree of teacher control (1–5)	**Segment 2** In this segment, we see various ways in which the teacher supports his students. The teacher draws attention to design aspects. If something is not clear or the students get stuck, the teacher explains, informs, reflects, manages tasks, suggests ideas and answers questions. The interactions occur mostly during the lesson in which the students implemented information from previous experiments in their design. The interactions deal mostly with the topic of idea generation.	**Segment 5** The teacher invites the students to explain their ideas and gives some critical reflection, encouragement and some thoughts about how to continue. The interactions deal mostly with the topic of idea generation.
Low degree of teacher control (1–3)	**Segment 3** The teacher, in most cases, checks up on a group of students, listens to their ideas, but does not get involved in the group process or the students' design. The interactions are relatively short. This segment seems to contain no specific manner through which the teacher guides the students. The segment contains the interactions of two teachers.	**Segment 6** The teacher asks the students many questions to let them think for themselves and reason out their own idea. Usually the conversation is student-initiated. Alternatively, the teacher asks the students to explain their idea and gives information to help them. When the students seem to reach a satisfying answer, the teacher tells them what they can do next. This support occurs in lesson 1 during the design brief and idea generation phases.

2010). In future research, it would be interesting to analyze whether teachers tailor their support over a longer period and how they achieve this.

In this discussion, we have tentatively indicated factors that influence the support provided by teachers. The decision-making process of teachers—if there is such a conscious method—is still a black box, however. Future research could focus on *why* a teacher chooses for a specific way of supporting students and what types of factors influence this decision.

Concluding remarks

In this study, we analyzed a case of three teachers who introduced design-based chemistry projects in their classroom. We wanted to know how the verbal support that teachers use to aid students during design activities in chemistry can be characterized in terms of responsiveness, degree of teacher control and scaffolding means (RQ1), and whether any factors influence the support that teachers provide (RQ2). We observed a variety of ways in which teachers supported the design activities in chemistry. Based on the scaffolding dimensions, we categorized our data into six segments, which were found to reflect different forms of teacher-provided support. The scaffolding dimensions made it possible to characterize the support. At the extremes, we found that teachers use steering support to take control of the process on the one hand, and a more open form of support through which teachers stimulate the reasoning of the students. Between these extremes, there are variations in the support from teachers. The support seems to be adapted to the students, the lesson (containing specific activities and goals) and the topic of the conversation.

The method for analyzing our data—a multi-dimensional perspective of scaffolding, organizing interactions at a higher level with these dimensions and then zooming in again for an in-depth analysis—and the use of computer software such as *R* to do so allowed us to see possible relationships that would not be easily noticed in our raw data.

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Declarations

Conflict of interest Three teachers and their (81) students participated in this study, including the first author of this article. The study was held in compliance with the ethical standards of the school and the university involved. The teachers, students and the students' parents gave active informed consent for the use of the data collected and of the storage of the transcribed and anonymized data for 10 years. The research reported in this article was carried out within the Dudoc-Bèta program, with financial support from the Dutch Ministry of Education, Culture and Science. The authors have no competing interests to declare that are relevant to the content of this article.

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