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What beliefs do chemistry teachers have about instructional explanations? An exploratory investigation

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Instructional explanations in chemistry lessons are planned language products explicitly communicated by the explainer (teacher) to effectively convey specific subject matter (chemical content) to the addressees (students), aligned with didactic principles. The primary aim of these explanations is to enhance students' understanding of the concepts presented. While previous studies have largely focused on establishing general quality criteria for subject-appropriate and audience-centered instructional explanations, limited research has explored chemistry teachers' beliefs about instructional explanations in the classroom. This paper addresses this gap by presenting insights from an exploratory investigation into these beliefs within the context of chemistry lessons. Semi-structured, guided interviews were conducted with chemistry teachers (N = 13) from various types of German schools, with data analyzed using Kuckartz and Rädiker's qualitative content analysis methodology. Findings indicate that chemistry teachers hold complex and sometimes contradictory beliefs about the use of instructional explanations. On one hand, they recognize instructional explanations as essential due to the abstract nature of chemistry content (*subject matter perspective*) and as beneficial for student learning (*audience perspective*). On the other hand, they express concerns that instructional explanations may foster cognitive passivity among students and reinforce a transmissive approach to knowledge transfer. This insight suggests that teachers' practical perceptions of instructional explanations differ in some respects from those emphasized in educational research. However, results suggest that teachers' beliefs about instructional explanations evolve throughout teacher training, becoming more positive at advanced stages. Additionally, insights gained from teacher interviews into the interrelated and simultaneous beliefs about the advantages and disadvantages of instructional explanations highlight the nuanced perspectives that teachers bring to their practice. They demonstrate that teachers use instructional explanations in a deliberate and context-sensitive manner, balancing their effectiveness for specific learning goals with considerations of student autonomy and engagement. Finally, the findings provide relevant implications for teacher education and practice, as well as directions for future research.

Introduction

"Providing explanations is the bread and butter of the science teacher's existence" (Osborne and Patterson, 2011, p. 632). The ability of a (chemistry) teacher to explain subject content appropriately to students is a crucial aspect of their professional competence, particularly their pedagogical content knowledge (Gess-Newsome, 2015; Kulgemeyer and Riese, 2018; Carlson *et al.*, 2019). Within the context of instructional explanation, the teacher plans and verbally communicates specific subject matter to a particular group of students, who are the intended addressees. The aim is to expand the learners' understanding of the subject matter (Fairhurst, 1981; Findeisen, 2017). The instructional explanation is based on principles of didactic action (*e.g.*, linguistic clarity and the use of visual and verbal support methods) with communicative aspects between the explainer (teacher) and the audience (students) being pivotal (Duffy *et al.*, 1986; Kulgemeyer and Tomczyszyn, 2015). Consequently, the teacher consistently adjusts both the subject content being explained and the manner of explanation to meet the individual learning needs of the students (adaptivity; Treagust and Harrison, 2000).

The ability of the teacher to explain significantly impacts teaching quality and, consequently, student understanding and learning outcomes (Findeisen, 2017; Cairns and Areepattamannil, 2022). Effective instructional explanations that foster understanding, can increase students' motivation and interest in chemistry topics (Schopf, 2018). Studies by Wilson and Mant

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(2011a, b) also reveal that, unlike teachers, students most often identified the ability to explain well as a key quality of a good science teacher.

This article specifically focuses on *planned instructional explanations* in chemistry lessons, which are deliberately provided by teachers and can be seen as a part of their personal pedagogical content knowledge (pPCK; Gess-Newsome, 2015; Carlson *et al.*, 2019), encompassing both the rationale and meaning-making aspects of instructional explanations. *Spontaneous ad hoc explanations* that arise during teacher–student interactions and can therefore be attributed to teachers' personal pedagogical content knowledge and skills (PCK&S; Gess-Newsome, 2015) or, alternatively, to their enacted pedagogical content knowledge (ePCK; Carlson *et al.*, 2019) – which emphasizes instructional explanation in action or rather within a specific teaching moment – are not part of our exploratory investigation.

Challenges in giving instructional explanations

In recent years, various studies in learning psychology (*e.g.*, Leinhardt, 1990; Renkl, 2002; Wittwer and Renkl, 2008; Wittwer *et al.*, 2010; Acuña *et al.*, 2011; Lee and Anderson, 2013), and (science) education research (*e.g.*, Treagust and Harrison, 1999; Osborne and Patterson, 2011; Geelan, 2013; Kulgemeyer, 2019; Lindl *et al.*, 2020; Cairns and Areepattamannil, 2022; Kulgemeyer and Geelan, 2024) have emphasized the fundamental importance of instructional explanations in school teaching and learning processes, identifying specific quality characteristics (see section "Theoretical framework"). Especially in chemistry education research, however, there are comparatively few studies on instructional explanation (*e.g.*, Thiele and Treagust, 1994; Oversby, 2000; Treagust and Harrison, 2000).

Despite the recognized importance of instructional explanations in science education research and their frequent use in everyday chemistry lessons, (prospective) teachers still face challenges in preparing and delivering these explanations. These challenges include addressing subject-appropriate demands, such as accurately explaining chemical concepts, while also meeting audience-centered requirements by delivering explanations in a way that enhances understanding and aligns with didactic principles, such as providing appropriate visual and verbal support. Indeed, many (prospective) teachers perceive explaining as a primary teaching challenge (*e.g.*, Merzyn, 2005), and studies reveal deficiencies in their ability to explain (*e.g.*, Findeisen, 2017). Consequently, teachers may avoid planned explanations, potentially hindering student understanding (Aeschbacher, 2009).

The role of teachers' beliefs in instructional explanations

Therefore, it is essential for chemistry teachers to recognize the importance of instructional explanations in teaching and learning and to have a clear understanding of what "explanation" entails (Kulgemeyer and Geelan, 2024). This knowledge, as part of a teacher's personal pedagogical content knowledge (pPCK; Carlson *et al.*, 2019), enables them to use explanations purposefully and effectively, fostering student understanding in chemistry lessons. In practice, this knowledge is applied in the classroom, transforming into enacted pedagogical content knowledge (ePCK; Carlson *et al.*, 2019).

Both areas of pedagogical content knowledge are shaped by various factors, including the specific learning and classroom context, individual teaching experiences, and, most notably, teacher beliefs (Gess-Newsome, 2015). Given their pivotal role in shaping instructional practices, teachers' beliefs about instructional explanations warrant closer examination.

Bandura (1986) identifies beliefs as key determinants of human actions, decisions, and information processing. In recent years, research on teacher beliefs has intensified, with numerous studies highlighting their influence on instructional practices (*e.g.*, Hashweh, 1996; Richardson, 1996). This underscores that the effective use of instructional explanations in the classroom requires not only a clear conceptual understanding of the term "explanation" but also consideration of teachers' underlying beliefs.

In general, beliefs are understood very broadly, encompassing various definitions. A frequently cited definition by Pajares (1992, p. 316) is: "[beliefs are an] individual's judgment of the truth or falsity of a proposition, a judgment that can only be inferred from a collective understanding of what human beings say, intend, and do". Consequently, beliefs are inherently subjective and individualized constructs (Richardson, 1996; Johnstone, 1997; Fletcher and Luft, 2011). In our exploratory investigation, we adopt the definition provided by Markic and Eilks (2008, p. 26), as it aligns with our research focus on the beliefs held by individuals within the teaching–learning context and the resulting actions. According to their definition, beliefs encompass "all mental representations that teachers or student teachers consciously and unconsciously hold in their minds, which influence, to a certain extent, their (potential) behavior as teachers within their subject". Beliefs are linked to a person's attitude and knowledge, but they do not necessarily have a rational origin and are not logically structured (Gess-Newsome, 1999; Richardson, 2003; Al-Amoush *et al.*, 2012).

When specifically comparing beliefs and knowledge, a distinction can be drawn: knowledge is more factual, objective, and often subject to verification (Nespor, 1987; Pajares, 1992). Following the model of *Teacher Professional Knowledge and Skill* (Gess-Newsome, 2015) as well as the *Refined Consensus Model of Pedagogical Content Knowledge* (Carlson *et al.*, 2019) in the context of education and science education, teacher knowledge comprises both a professional knowledge base – such as subject-specific content knowledge and pedagogical knowledge – as well as pedagogical content knowledge (PCK). PCK itself is further categorized into three key dimensions: collective pedagogical content knowledge (cPCK), personal pedagogical content knowledge (pPCK), and enacted pedagogical content knowledge (ePCK) (Carlson *et al.*, 2019). All dimensions of PCK are facets of knowledge and can be acquired during teacher education and modified throughout one's professional career.

Beliefs, in contrast, are deeply personal, stable, and often subject-specific mental constructs. They tend to be more resistant to change and do not necessarily require factual support (Pajares, 1992). For instance, a teacher's belief in the effectiveness of a particular instructional strategy may be grounded not in empirical evidence but in personal experience or perceived success in the classroom.

Although knowledge and beliefs are interconnected, they do not always align. For example, a teacher might *know* that instructional explanations are effective in certain situations (*e.g.*, for complex chemistry topics with students who have limited prior knowledge), yet *believe*, based on past experiences, that student self-explanations work better for their students. Beliefs play a crucial role in teachers' daily decision-making, shaping, reinforcing, or adapting their knowledge while ultimately influencing their classroom actions. Moreover, they serve as cognitive filters that help teachers interpret and simplify the complexities of classroom dynamics. As Calderhead (1996, p. 719) notes, beliefs "help to interpret and simplify classroom life, to identify relevant goals, and to orient teachers to particular problem situations. Because of the complex [...] nature of classroom life, knowledge alone would be inadequate in making sense of classroom situations".

Although an exact distinction between personal pedagogical content knowledge and beliefs about instructional explanations is challenging due to their close interrelation, this paper focuses solely on teachers' beliefs. Our aim is not to assess teachers' (factual) knowledge of instructional explanations but rather to gain an authentic, unbiased, and practice-oriented understanding of their perspectives. This approach allows for a more open-ended inquiry, providing deeper insights into general beliefs as well as perceptions of the potential advantages and disadvantages of instructional explanations. Nevertheless, teachers' beliefs can still offer valuable insights into their personal pedagogical content knowledge.

Exploring chemistry teachers' beliefs

The relationship between teachers' beliefs and instructional explanations is crucial, as these beliefs determine if and how teachers incorporate such explanations into their classrooms. Specifically, teachers' beliefs influence their instructional practices (Nespor, 1987; Pajares, 1992; Hashweh, 1996; Richardson, 1996; Gess-Newsome, 1999; Gess-Newsome *et al.*, 2003; Cross, 2009), as well as student learning outcomes (Stipek *et al.*, 2001; Sabarwal *et al.*, 2021) and, most importantly, students' *understanding* of chemical concepts, which are often abstract and complex (Gage *et al.*, 1968; Duffy *et al.*, 1986). A well-constructed instructional explanation is essential for fostering student comprehension and avoiding cognitive overload (Sweller, 2005). While prior research has examined instructional explanations in science education and teachers' beliefs separately, little is known about the relationship between these areas, particularly regarding the specific beliefs chemistry teachers hold about instructional explanations. Investigating these beliefs is essential, as they are closely linked to teachers' instructional practices – shaping both their personal and enacted pedagogical content knowledge – and, consequently, impacting students' understanding. Our examination addresses this gap by exploring chemistry teachers' beliefs about instructional explanations and offering implications for teacher education and practice.

Since beliefs about instructional explanations can be more easily elicited through direct questioning of teachers than beliefs embedded in instructional explanation in action, *i.e.*, within the complexity of the classroom setting, we focus on *planned instructional explanations*, which are intentionally prepared in advance and deliberately provided by the teacher.

Although instructional explanations can occur both as planned and *ad hoc* within the teaching situation and may differ accordingly (as reflected in personal pedagogical content knowledge and personal pedagogical content knowledge and skills or enacted pedagogical content knowledge (Gess-Newsome, 2015; Carlson *et al.*, 2019)), we assume that direct questioning encourages teachers to consciously reflect on instructional explanations. This, in turn, is expected to provide deeper insights into their individual beliefs.

Through this, we aim to enhance the understanding of factors influencing personal pedagogical content knowledge, particularly in relation to instructional explanations and the "culture of explaining" (Kulgemeyer, 2019, p. 24) in chemistry education.

The research question guiding our exploratory investigation is as follows:

What beliefs do practicing chemistry teachers have regarding instructional explanations in chemistry lessons?

This overarching research question encompasses several subordinate questions. These include chemistry teachers' beliefs about general aspects of instructional explanations, such as their perceived importance, defining characteristics, and the prerequisites for their effective use. Additionally, it explores beliefs regarding the perceived advantages and disadvantages of instructional explanations in chemistry lessons, including comparisons with student self-explanations and other instructional methods.

The findings aim to provide insights into the beliefs of practicing chemistry teachers about instructional explanations, from which implications can be drawn for two key areas. First, teacher education and practice, to support (prospective) teachers in developing a comprehensive understanding of instructional explanations and recognizing their value in chemistry instruction. Second, future research, by identifying additional areas for exploration within the field of teachers' beliefs.

Theoretical framework

The entire exploratory investigation is guided by the central question of teachers' beliefs about instructional explanations. These beliefs play a crucial role in shaping their personal pedagogical content knowledge, which in turn determines whether and to what extent instructional explanations are applied and implemented in chemistry lessons. To gain meaningful insights into teachers' beliefs, the following section outlines the theoretical foundations of instructional explanations, which serve as a framework for interpreting teachers' responses from the interviews conducted for this exploratory investigation.

Contextual variations and terminology of the term "explanation"

The understanding and interpretation of the term "explanation" vary significantly across different contexts, sometimes resulting in misconceptions (Kulgemeyer and Geelan, 2024). For example, it is crucial to distinguish between everyday explanations, instructional explanations, and scientific explanations, as outlined by Hempel and Oppenheim (1948) (see Table 1).

In educational research, various terms are used in the context of explanations and/or the act of explaining. Alongside ''instructional explanation'', terms such as ''teacher explanation'', ''classroom explanation'' and, ''science teaching explanation'' also appear (Leinhardt, 1997; Treagust and Harrison, 1999; Osborne and Patterson, 2011; Treagust and Tsui, 2014; Kulgemeyer and Tomczyszyn, 2015). While all these terms refer to the same educational context and communication situation, each carries unique connotations. For example, although ''teacher explanation'' and ''classroom explanation'' describe the same communicative act, they emphasize different aspects: the former highlights the teacher's role, whereas the latter underscores the interaction between teacher and students. Additionally, ''explanation'' denotes the language product, while ''explaining'' refers to the (ongoing) process of creating that product. In our exploratory investigation, we use the broader term ''instructional explanation'', as defined in Table 1, which refers to any explanation given within an instructional context.

Types of instructional explanations in chemistry lessons: How, What, Why

Instructional explanations can generally be classified into three types: *How*-, *What*-, and *Why*-explanations (Osborne and Patterson, 2011; Klein, 2016; Findeisen, 2017). The *How*-explanation addresses actions, procedures, and processes within chemical-scientific work, aiming to foster students' procedural knowledge. For example, it might answer questions like, ''*How* should an experiment be designed and conducted to adequately investigate the water solubility of different alkanols?''. In contrast, the *What*-explanation involves clarifying chemical terms and statements through definitions (*e.g.*, ''*What* characterizes an alkanol molecule at the particle level?''). Although definitions may be part of instructional explanations, a definition alone is not sufficient as a complete explanation. Within chemistry lessons, causal *Why*-explanations are particularly significant (Braaten and Windschitl, 2011; Treagust and Tsui, 2014). These explanations often involve high cognitive demands as they aim to reveal the scientific foundations of complex chemical phenomena (*e.g.*, ''*Why* do different alkanols dissolve to varying degrees in polar or non-polar media?''). It is important to note that these three types of explanations are often interdependent, as they build on each other. For example, a *Why*-explanation may include background knowledge typically found in a *How*-explanation.

Regardless of the type of instructional explanation used, its effectiveness depends on the teacher's ability to adaptively tailor the explanation (Kulgemeyer and Tomczyszyn, 2015). An adaptive explanation is carefully planned and executed to suit both the subject matter and the audience, helping to prevent extraneous cognitive overload (Sweller, 2005), and enabling students to construct knowledge purposefully (Kirschner *et al.*, 2006). This approach is essential for fostering deep understanding, particularly when specific quality characteristics are met. In our exploratory investigation, we aim to explore in which situations during chemistry lessons teachers consider different types of instructional explanations useful and to what extent they consciously reflect on adapting them.

Steps in preparing effective instructional explanations in chemistry lessons

The preparation and delivery of an instructional explanation involve a multi-step process (Hargie, 2011). A foundational requirement for providing an effective instructional explanation is the teacher's professional knowledge of the subject matter. The teacher must fully understand the content he or she intends to explain. With this prerequisite in place, the teacher carefully prepares the explanation, approaching the content from two perspectives: subject-appropriate requirements (subject matter perspective: ''What subject content do I want to explain?''), and audience-centered requirements (audience perspective: ''To whom am I explaining this content?'') (Treagust and Harrison, 2000; Kulgemeyer and Tomczyszyn, 2015). The teacher's understanding of the content, awareness of cognitive, motivational, and volitional prerequisites, and knowledge of students' specific prior knowledge are all crucial (Kalyuga *et al.*, 2003; Wittwer *et al.*, 2010). As Cairns and Areepattamannil (2022, p. 1181) state, ''the effectiveness of instructional explanations is dependent on the teacher's awareness of the learners' current levels of understanding''. The explanation is then structured to integrate both perspectives, aiming to bridge the subject matter and audience effectively (Kulgemeyer and Tomczyszyn, 2015). Finally, visual and verbal support methods are employed to engage students through multiple sensory channels (Treagust and Tsui, 2014). Once prepared, the instructional

Table 1 Different understandings and definitions of the term ''explanation'' depending on the context

Term	Context	Given by whom to whom	Definition
Everyday explanation	Everyday life	From laypeople to laypeople	Brief, spontaneous explanation by non-experts using simple, everyday language, often in situations where knowledge is relatively balanced between participants (*e.g.*, giving directions; Findeisen, 2017)
Instructional explanation	School lessons	From teacher to student	A structured explanation prepared by a (chemistry) teacher on specific concepts for students in a (chemistry) lesson, typically involving an asymmetrical knowledge relationship (*e.g.*, explanation of the MO theory; Leinhardt, 1997; Vogt, 2016)
Scientific explanation (Hempel and Oppenheim, 1948)	Academic/ scientific	From scientist to scientist	An explanation grounded in laws and cause-effect relationships, used to understand and investigate scientific problems or develop solutions (*e.g.*, explaining protein design through computational methods; Hempel and Oppenheim, 1948; Leinhardt, 1997)

Table 2 The six quality characteristics of an instructional explanation (see Wittwer and Renkl, 2008; Aeschbacher, 2009; Kulgemeyer and Tomczyszyn, 2015; Findeisen, 2017; Schopf, 2018; Kulgemeyer, 2019; Ehras *et al.*, 2021; Elmer and Tepner, in press)

Quality characteristic	Definition
Subject-specific quality aspects	The instructional explanation accurately represents the subject matter, adhering to chemical conventions and specialized terminology. It incorporates chemistry-specific representational forms by integrating Johnstone's (2000) macroscopic, submicroscopic, and symbolic levels.
Linguistic clarity	The instructional explanation is communicated in a clear, understandable language, following semantic, syntactic, and idiomatic rules. This includes avoiding overly long sentences, using smooth transitions between concepts, and selecting precise terminology.
Structural organization	The instructional explanation is well structured and organized logically and coherently, conveying essential information in a concise format.
Use of visual and verbal support methods	Graphical aids (*e.g.*, drawings, animations) and/or verbal aids (*e.g.*, analogies, metaphors) are incorporated to reinforce and enhance the instructional explanation.
Student centration	The instructional explanation is tailored to suit the volitional, motivational (*e.g.*, interests), and cognitive (*e.g.*, prior knowledge) characteristics of students.
Appropriate speech and physical expression	The instructional explanation is delivered with clear articulation and vocal quality, supported by gestures, effective prosody and facial expressions.

explanation is delivered in the classroom, evolving dynamically as part of the communication process. It may be adapted or modified in terms of content and language based on student feedback (Kulgemeyer and Tomczyszyn, 2015).

Didactic research has identified six key quality characteristics that, when appropriately integrated into instructional explanations, enhance student comprehension. A high-quality instructional explanation is characterized by subject-specific quality aspects, linguistic clarity, structural organization, use of visual and verbal support methods, student centration, and appropriate speech and physical expression (Wittwer and Renkl, 2008; Aeschbacher, 2009; Kulgemeyer and Tomczyszyn, 2015; Findeisen, 2017; Schopf, 2018; Kulgemeyer, 2019; Ehras *et al.*, 2021; Elmer and Tepner, in press). Table 2 presents the six quality characteristics of an instructional explanation, along with their definitions as derived from scientific findings.

The six quality characteristics listed in Table 2 are directly relevant to our research focus, encompassing the overarching research question and the subordinate questions. In this regard, we examine the extent to which chemistry teachers' beliefs about instructional explanations align with the quality characteristics of instructional explanations identified in the literature.

Relationship between teaching beliefs and teaching practice and its relevance for instructional explanations

In educational research, numerous studies have explored the concept of beliefs particularly in recent years, with growing interest in the beliefs of various stakeholders involved in teaching and learning processes at both school and university levels. These studies include research on prospective teachers (*e.g.*, Veal, 2004; Markic and Eilks, 2008, 2010; Boz *et al.*, 2019; Kotul'áková, 2020), faculty and graduate students (*e.g.*, Taylor, 2003; Marbach-Ad *et al.*, 2014; Holland, 2018; Lee, 2019; Popova *et al.*, 2020) and in-service teachers (*e.g.*, Hashweh, 1996; Levitt, 2001; Stipek *et al.*, 2001; Luft and Roehrig, 2007; Mansour, 2009; Luft *et al.*, 2011).

Teachers' beliefs can be categorized in various ways. For example, Calderhead's (1996) early approach identifies five distinct yet interconnected areas of significant beliefs: beliefs about learners and learning, teaching, the subject, learning to teach, and self and the teaching role. This framework highlights the complexity within teachers' beliefs. However, studies often distinguish between transmissive (*i.e.*, traditional, teacher-centered) beliefs and constructivist (*i.e.*, modern, student-centered) beliefs (Koballa *et al.*, 2000; Markic and Eilks, 2008; Gibbons *et al.*, 2018; Kotul'áková, 2020; Welter *et al.*, 2021; DeGlopper *et al.*, 2023). Transmissive beliefs encompass a deductive teacher-centered approach. In the context of instructional explanations, this implies a direct transfer of information to students without consideration for quality characteristics related to subject matter appropriation and audience-centered adaptation, resulting in a non-adaptive explanation where students are passive listeners (Osborne, 1996; DeGlopper *et al.*, 2023). Many studies suggest that teachers with transmissive beliefs about teaching–learning processes face challenges when attempting to incorporate constructivist approaches and often misinterpret relevant classroom dynamics (Stipek *et al.*, 2001; Meschede *et al.*, 2017). Conversely, constructivist beliefs promote a student-centered, inductive approach in which students actively construct knowledge (Piaget, 1971; Osborne, 1996; Johnstone, 1997). Within instructional explanations, this approach views explanations as an interactive communication situation in which the teacher adapts explanations to the students' needs, enhancing their understanding.

Research indicates that teachers with constructivist beliefs tend to recognize students' alternative ideas more readily, employ diverse learning methods, and create more effective learning environments, ultimately leading to better student outcomes (Hashweh, 1996; Voss *et al.*, 2013). However, exceptions exist, as studies such as those by Simmons *et al.* (1999), Haney and McArthur (2002) and Savasci and Berlin (2012), reveal inconsistencies between teachers' beliefs and their instructional practices.

A substantial body of research focuses on the beliefs of practicing science teachers (*e.g.*, Luft and Roehrig, 2007; Mansour, 2009; Luft *et al.*, 2011). For example, Tsai (2002) surveyed 37 science teachers and found that most held traditional, transmissive beliefs about teaching and learning. Similar findings were reported by Al-Amoush *et al.* (2012, 2014). Research on student teachers shows comparable results, with the majority of samples exhibiting transmissive, teacher-centered beliefs (*e.g.*, Simmons *et al.*, 1999; Koballa *et al.*, 2000; Markic and Eilks, 2010).

In our exploratory investigation we also seek to classify the identified teacher beliefs about instructional explanations as either transmissive or constructivist.

Methodical approach

To gain deeper insights into the beliefs of chemistry teachers and address the research question, individual semi-structured, guideline-based expert interviews were conducted with 13 chemistry teachers. Interviews are widely regarded as an effective method for assessing beliefs (Aikenhead, 1988) and are frequently used in educational research for this purpose (*e.g.*, as seen in the studies by Koballa *et al.*, 2000; Levitt, 2001; Tsai, 2002; Gess-Newsome *et al.*, 2003; Luft and Roehrig, 2007; Al-Amoush *et al.*, 2012; DeGlopper *et al.*, 2023). Other methods for capturing beliefs include concept maps (*e.g.*, Fletcher and Luft, 2011), drawings (*e.g.*, Hancock and Gallard, 2004; Al-Amoush *et al.*, 2014), cross-sectional surveys (*e.g.*, Kahveci, 2009), and the use of Likert scales (Kulgemeyer and Riese, 2018).

Participants

For participant selection, we specifically approached teachers who were actively teaching chemistry at the time of the interview and had completed their teacher training (*e.g.*, excluding "Referendare", prospective teachers in the final stage of their training in Germany). All participants were in-service teachers with teaching experience, although the exact duration of their teaching experience was not collected. Teachers not meeting these criteria were not invited to participate, and none of the invited teachers declined.

A total of 13 teachers participated in the interviews. Although the sample size is small, we selected the 13 teachers from various school types and different grade levels to ensure a well-rounded representation of teaching contexts. Eight taught at schools where two interviewers from the research team were completing internships (teachers 1A–4A, 1B–4B). Five teachers (1C–5C) were recruited from our cooperation network affiliated with our student laboratory.

The letter-number codes assigned to each teacher were randomly chosen and hold no specific meaning. Due to Germany's multi-tiered school system, we were able to interview teachers from different secondary school types. Secondary education in Germany is organized by student academic performance and includes *Hauptschulen* (lower secondary schools), *Realschulen* (middle schools), and *Gymnasien* (grammar schools), with students attending from grades 5/7 to 9/10 or 12/13, depending on the state. *Gesamtschulen* (comprehensive schools), which resemble U.S. high schools, serve students of all academic levels and offer the same qualification as *Hauptschulen*, *Realschulen*, and *Gymnasien* (Risch, 2010; Döbert, 2015).

In Germany, natural sciences (biology, chemistry, and physics) are generally taught as separate subjects starting from secondary level one, meaning that chemistry teachers exclusively teach chemistry. In the German state of North Rhine-Westphalia, where this investigation was conducted, chemistry is typically introduced in grade seven and continues through grade twelve or thirteen, depending on whether the school follows the G8 or G9 system (two different timelines for completing secondary education; Döbert, 2015). (Chemistry) teachers in Germany are required to teach at least one additional subject, often another science like biology or physics, though it may also be in a non-science area such as art or English. Research suggests a relationship between the subjects of (prospective) teachers and their beliefs about teaching and learning processes (Großschedl *et al.*, 2015; Jeschke *et al.*, 2019; Welter *et al.*, 2021). Table 3 lists the additional subjects taught by the interviewed teachers.

Table 3 Relevant characteristics of participants at the time they were interviewed

Anonymized acronym representing the teacher	Gender	School type	Grade levels taught	Subject(s)
1A	Male	*Gymnasium*	5–12	Chemistry Biology,
2A	Male	*Gymnasium*	5–12	Chemistry, Biology
3A	Female	*Gymnasium*	5–12	Chemistry Biology, Physics
4A	Female	*Gymnasium*	5–12	Chemistry, PE
1B	Female	*Gesamtschule*	5–12	Chemistry, Biology
2B	Female	*Gesamtschule*	5–12	Chemistry, Biology
3B	Female	*Gesamtschule*	5–12	Chemistry, Biology
4B	Female	*Gesamtschule*	5–12	Chemistry, Maths
1C	Male	*Realschule*	5–10	Chemistry
2C	Female	*Gymnasium*	5–12	Chemistry, Biology
3C	Male	*Hauptschule*	5–10	Chemistry Geography
4C	Female	*Realschule*	5–10	Chemistry, English
5C	Female	*Realschule*	5–10	Chemistry Maths, Biology

To achieve a diverse representation of school types within the German secondary education system, we included teachers from *Realschulen* (N = 3), *Gymnasien* (N = 5), and *Gesamtschulen* (N = 4) in our sample, following the principle of purposive sampling (see Table 3; Patton, 1990; Gläser and Laudel, 2010). One teacher (3C) had taught at a *Hauptschule* for several years before transferring to a *Gymnasium* last year. Since he has more extensive teaching experience in a *Hauptschule* and referenced it frequently in his interview, he is classified under the *Hauptschule* category in Table 3.

The study was conducted with full adherence to ethical standards to protect participants' rights. Participation was voluntary, with participants informed about the investigation's purpose and their right to withdraw at any time. They were also assured that their personal data would be anonymized, and all teachers agreed to these terms (King, 1994).

Data collection

The interviews were conducted over a nine-month period, with an average duration of approximately 20 minutes, except for teacher 1A's interview, which extended to 46 minutes due to more detailed responses and occasional digressions unrelated to the interview questions.

All interviews took place in familiar settings, such as the chemistry teachers' offices or empty classrooms. Familiar locations were chosen to avoid artificial situations and to create a comfortable atmosphere (Girtler, 1984). Interviews were recorded using recording devices, and any questions or concerns from participants were addressed during the session. It was clarified that there were no "wrong" answers, encouraging participants to respond freely based on personal experience and viewpoints.

An interview guide structured around three main questions was used to provide orientation, while the semi-structured format allowed follow-up questions to be asked flexibly, adapting to the natural flow of conversation (DiCicco-Bloom and Crabtree, 2006). This approach maintained both flexibility and systematic structure in data collection, enhancing comparison and reliability. Consistency in questions across interviews helped ensure that differences in responses reflected genuine differences in beliefs rather than variations in question phrasing (Guest *et al.*, 2012; Hennink, 2014). To prevent semantic misunderstanding, the term "instructional explanation" was defined for participants at the outset, with the interviewer reading the definition aloud. Since the interviews were conducted in German, the following English translation – verified independently by both authors – was used: *an instructional explanation is a teacher's verbal presentation of a subject within a teaching–learning context, prepared in advance rather than giving spontaneously. The primary aim of an instructional explanation is to foster student understanding. A good explanation effectively facilitates comprehension, allowing students to receive and further process the conveyed information.*

In the following an overview of the semi-structured interview guide is presented:

(0) Opening Question: *How would you define the term "instructional explanation"?*

(1) General Beliefs: *What constitutes a good instructional explanation in chemistry class?*

Additional follow-up questions (prompts) if not brought up by the teacher

- *What prerequisites must a teacher fulfill to provide a good instructional explanation?*
- *How do you prepare for providing an instructional explanation?*
- *How do you structure an instructional explanation?*
- *What tools do you use when giving an instructional explanation?*
- *How do you determine if your explanation was successful?*
- *What topics are particularly suitable for instructional explanations? Why?*

(2) Reasons for the importance of instructional explanations in chemistry lessons*: What are the general advantages of an instructional explanation in chemistry class?*

Additional follow-up question (prompt) if not brought up by the teacher

- *What are the advantages of an instructional explanation in chemistry class compared to student self-explanations and other instructional methods?*

(3) Reasons against the importance of instructional explanations in chemistry lessons: *What are the general disadvantages of an instructional explanation in chemistry class?*

Additional follow-up question (prompt) if not brought up by the teacher

- *What are the disadvantages of an instructional explanation in chemistry class compared to student self-explanations and other instructional methods?*

At the start of the interview, teachers were asked an opening question to gauge their general understanding of instructional explanations. The semi-structured interview then focused on three overarching topics: (1) *General beliefs*, (2) *Reasons supporting the importance of instructional explanations in chemistry lessons*, and (3) *Reasons opposing the importance of instructional explanations in chemistry lessons*. Each topic was further divided into sub-questions, with the *General beliefs* section containing the most. While the main questions were consistently asked, sub-questions were introduced only if they had not already been addressed in the teachers' responses. To encourage detailed and uninterrupted answers, all questions were formulated to be as open-ended and narrative-generating as possible (Helfferich, 2011).

The interviewer adapted to the interviewee's thought patterns and assumed the role of an attentive, active listener. "Active listening" involves showing understanding and interest without verbally responding or evaluating, following the norms of everyday communication (Helfferich, 2011).

Data analysis

After completing all interviews, the data was transcribed according to a transcription guide to standardize language and focus on the semantic content of the speech (Kuckartz *et al.*, 2008). Additionally, complete anonymization of participants was ensured by removing personal information (*e.g.*, names, school affiliations, and other identifying details) from the transcripts (DiCicco-Bloom and Crabtree, 2006). To maintain anonymity and organize the interview data, each teacher was assigned a unique acronym in the format [number][letter]. The number represents the interview sequence within three sessions, and the letter indicates the teacher's group: Groups A and B each included four teachers, while Group C included five. The [number][letter] format serves only for data anonymization and organization; it has no interpretative meaning. Each transcript reference ends with "pos." to specify the data's position within the transcript. Subsequently, three members of our research group independently reviewed the transcriptions.

After transcription, a qualitative content analysis was conducted following Kuckartz and Rädiker's, 2022 approach. This systematic method aims to analyze text-based data by structuring content and identifying central themes and patterns. Our objective was to analyze the transcriptions systematically and methodologically through a multi-step, cyclical process, focusing on the research question. The method typically involves four main steps: (1) material selection, (2) category formation, (3) coding and (4) interpretation. Since the transcriptions serve as our material selection (step 1), steps 2 to 4 are detailed below. In step 2, three categories were derived from the interview guide's themes: K_1: *General beliefs*, K_2: *Reasons supporting the importance of instructional explanations in chemistry lessons* and K_3: *Reasons opposing the importance of instructional explanations in chemistry lessons*.

Each category comprises multiple codes. Depending on the category, the codes were generated either deductively (mainly all codes in category K_1: *General beliefs*) or inductively (code $K_{1.7}$: *Shift in beliefs* in category K_1: *General beliefs*, as well as all codes in the categories K_2: *Reasons supporting the importance of instructional explanations in chemistry lessons* and K_3: *Reasons opposing the importance of instructional explanations in chemistry lessons*). In deductive code formation, the codes were developed independently of the empirical data and were based on literature, incorporating, for example, the quality characteristics identified in previous research (Kuckartz and Rädiker, 2022). The deductive codes are as follows: $K_{1.1}$: *Definition*, $K_{1.2}$: *Prerequisites*, $K_{1.3}$: *Preparation*, $K_{1.4}$: *Types*, $K_{1.5}$: *Importance* and $K_{1.6}$: *References to quality characteristics* (including its subcodes $K_{1.6.1}$: *Subject-specific quality aspects*, $K_{1.6.2}$: *Linguistic clarity*, $K_{1.6.3}$: *Structural organization*, $K_{1.6.4}$: *Use of visual and verbal support methods*, $K_{1.6.5}$: *Student centration*, $K_{1.6.6}$: *Appropriate speech and physical expression*).

The individual categories and codes were then compiled into a codebook, with each code supplemented by definitions and anchor examples. The goal of defining these codes was to establish a high level of precision, ensuring that all coders shared a common understanding and thereby promoting consistency in data coding (Kuckartz and Rädiker, 2022). Anchor examples illustrate the accurate application of each code. Following the development of these codes, the interview transcripts – our data – were coded in line with step 3 of the qualitative content analysis methodology.

After the initial coding process, the codes and subcodes of categories K_2: *Reasons supporting the importance of instructional explanations in chemistry lessons* and K_3: *Reasons opposing the importance of instructional explanations in chemistry lessons* were inductively derived from the data to provide a more detailed representation of the research findings. For category K_1, this encompasses code $K_{1.7}$: *Shift in beliefs*, while for category K_2 the inductively generated codes consist of $K_{2.1}$: *Practical and time-saving considerations*, $K_{2.2}$: *Complexity of chemical content and terminology*, $K_{2.3}$: *Adaptivity*, and $K_{2.4}$: *Personal teaching style*. The inductively generated codes in category K_3 include $K_{3.1}$: *Negative connotation*, $K_{3.2}$: *Contradiction to constructivism* and $K_{3.3}$: *Inversion of the quality characteristic "Student centration"*. The complete codebook, including code definitions and anchor examples, is provided in Appendix (Table 6).

To ensure the reliability of the category system, we employed consensus coding (also known as subjective assessment). This process involved three coders independently reviewing and coding the interview transcripts, then meeting to discuss any discrepancies and differences in coding. Through these discussions, disagreements were resolved, codings were revised as necessary, and adjustments to the code definitions and examples in the coding guide were made during coding conferences (Guest *et al.*, 2012; Hennink, 2014; Kuckartz and Rädiker, 2022). This method, widely used in qualitative research, assesses intercoder agreement, which is critical to ensuring the research's trustworthiness and credibility, encompassing concepts such as dependability, confirmability, credibility, and transferability (Lincoln and Guba, 1985; Lewis and Ritchie, 2003). This process minimizes subjectivity and bias, strengthening the replicability of findings and ensuring they genuinely reflect participants' experiences and meanings, allowing similar results to be expected in a repeat study with comparable methods (Lewis and Ritchie, 2003; Hennink, 2014).

Following the consensus coding, intercoder reliability was assessed to further enhance the reliability and trustworthiness of our research (Hennink, 2014; O'Connor and Joffe, 2020). Intercoder reliability requires that at least two coders, working independently, "select the same code for the same unit of text" (Campbell *et al.*, 2013, p. 297), indicating the reproducibility of the coding. To ensure data representativeness, ten percent of the dataset was randomly selected and subsequently coded by an additional team member who had familiarized himself intensively with the topic (O'Connor and Joffe, 2020). We used MAXQDA software to calculate the degree of code overlap according to Cohen's Kappa, a statistical measure of the intercoder reliability that quantifies the level of agreement between coders (McHugh, 2012). Cohen's Kappa was chosen specifically because it accounts for chance agreement, providing a more accurate measurement (Hennink, 2014). The code overlap was 81.19%, indicating high intercoder reliability and a consistent interpretation of the data (Cohen, 1960; McHugh, 2012).

The interviews were conducted, transcribed, and coded in German. Key sections relevant to presenting and discussing the results were translated into English by both authors. These translations were then reviewed by bilingual colleagues within our research group to verify accuracy and maintain the integrity of the original data. After coding was completed, the findings were interpretated following step 4 of the qualitative content analysis methodology, as detailed in the following section.

Results

The findings reveal a complex and nuanced picture of chemistry teachers' beliefs, highlighting both the perceived advantages and disadvantages associated with instructional explanations in chemistry lessons.

Chemistry teachers' general beliefs about instructional explanations in chemistry class

Overall, the teachers attribute significant importance to instructional explanations, viewing both the explanations and the discourse surrounding them as essential ($K_{1.5}$). For instance, one teacher remarked, "The explanation is indeed a very important aspect in chemistry. It's beneficial to delve into it: What actually constitutes a good explanation?" ($K_{1.5}$; 3B, pos. 85). Another noted, "In chemistry class, explaining has a high priority" ($K_{1.5}$; 1B, pos. 23).

However, the results also indicate that many teachers are uncertain about what defines an instructional explanation or have not previously reflected on it in depth. As one teacher stated, "Actually, almost everything is an instructional explanation" ($K_{1.1}$; 3C, pos. 2), while another admitted, "I've never thought about it [instructional explanations]" ($K_{1.1}$; 5C, pos. 3).

Additionally, some teachers had not recognized the specific structure of an instructional explanation, with one commenting, "Regarding the structure of the instructional explanation, it was not entirely clear to me what was actually meant by that" ($K_{1.6.3}$; 3B, pos. 33).

These findings reveal a recurring pattern: while most teachers recognize instructional explanations as highly important, they provide little detail about their fundamental characteristics, such as clear definitions. Moreover, instructional explanations appear to remain an implicit aspect of their teaching rather than a subject of deliberate reflection, with many acknowledging that they have rarely, if ever, actively considered them in a broader sense.

However, the results suggest that chemistry teachers do implicitly reference various contextual aspects of instructional explanations. In the broadest sense, these can be seen as part of the learning context, including identifying prerequisites ($K_{1.2}$) and preparing explanations in advance ($K_{1.3}$).

Regarding the prerequisites for effective instructional explanations, the chemistry teachers emphasized the importance of aligning them with students' prior knowledge: "It is essential to pay attention to the students' prior knowledge [...]. You really have to consider this often: What technical terms do the students know, and which ones do they not? You often have to rein yourself in a bit. In chemistry, it's common to explain concepts less fully because students often have a different level of understanding. However, it's crucial to keep their prior knowledge in mind; otherwise, the explanation may not be beneficial for them. Therefore, you should meet them where they are" ($K_{1.2}$; 3A, pos. 91). Another teacher added, "If I create a plan for an [instructional] explanation that does not take into account the students' prior knowledge – especially if I have not analyzed the learning group – then it won't achieve much" ($K_{1.2}$; 4A, pos. 129). Regarding preparation, the results indicate that the interviewed chemistry teachers distinguish between the process of explaining (which involves preparation, *e.g.*, $K_{1.3}$; 1B, pos. 13: "I prepare it, I think about what I will explain to the students") and the explanation itself as a final product.

When analyzing teachers' perspectives on different types of explanations ($K_{1.4}$), it becomes evident that they do not explicitly classify explanations into distinct types based on content. However, a closer examination of their statements reveals that they do, albeit unconsciously and implicitly, differentiate between the three types of explanations and assign them varying degrees of importance depending on the instructional context. This pattern aligns with the tendency observed at the beginning of this section. Specifically, *Why*-explanations appear to be the most frequently employed in chemistry lessons, whereas *What*- and *How*-explanations are mentioned less often. Teachers primarily use *Why*-explanations to explore the underlying causes of complex chemical phenomena, making these more accessible to students. For instance, one teacher remarked, "We've done that now, but let's take another look: Why is it [the chemical phenomenon] like this?" ($K_{1.4}$; 3A, pos. 82). Similarly, *Why*-explanations are often used when introducing foundational concepts. As teacher 2C noted, "I think I do that [explaining] most when introducing concepts. I am thinking now of the beginning of the Q1 [abbreviated for "qualification phase", the final two years of secondary education in Germany, divided into Q1 and Q2, equivalent to 11th and 12th grades in the U.S.; Risch, 2010]: Brønsted acid–base theory, [...] redox reaction" ($K_{1.4}$; 2C, pos. 12). Other commonly explained concepts include the "particle model [...] [and] atomic structure, [which] are introduced to students at the intermediate level" ($K_{1.4}$; 3C, pos. 12), as well as orbital theory ($K_{1.4}$; 3C, pos. 22).

Throughout the interviews, the teachers mentioned various aspects they consider essential for a good instructional explanation. These aspects align with the six quality characteristics of instructional explanations discussed in the literature (see above; $K_{1.6}$). Table 4 presents these quality criteria alongside three exemplary statements from the teachers.

In summary, the qualitative content analysis of the interview data indicates that the teachers interviewed attribute a fundamentally high level of importance to instructional explanation. Moreover, they primarily use explanations when conveying complex content, particularly *Why*-explanations. While often applied unconsciously, the teachers' statements suggest that they implicitly consider the six quality characteristics for effective explanations, as outlined in the literature, when planning and delivering their instructional explanations. Consequently, their beliefs largely align with these six quality characteristics.

Chemistry teachers' beliefs about the advantages of instructional explanations in chemistry class

Overall, the chemistry teachers surveyed were more inclined to express beliefs about the advantages of instructional explanations (K_2: *Reasons supporting the importance of instructional explanations in chemistry lessons*) than about their disadvantages. Primarily, they cited practical and time-saving benefits. From their perspective, instructional explanations require less preparation time compared to student-centered teaching methods, which take "much, much longer to prepare with the staged aids" ($K_{2.1}$; 2B, pos. 103). Additionally, instructional explanations offer significant time advantages during lessons. As one teacher noted, "Another advantage [of instructional explanations] is that they are simply very time efficient. If you explain something as a teacher compared to letting the students work on it independently, it is simply much faster. You just can't let everyone discover everything on their own in terms of time" ($K_{2.1}$; 2C, pos. 20).

The teachers recognized the importance of instructional explanations in chemistry lessons, identifying key moments for their use from both the *subject matter perspective* ($K_{2.2}$) and the *audience perspective* ($K_{2.3}$). From the subject matter perspective, instructional explanations are especially valuable due to the abstract nature of the chemistry content in chemistry lessons, one teacher remarked, "I believe that explaining in chemistry class generally plays a crucial role because it [the subject matter] is very abstract for the students" ($K_{2.2}$; 1B, pos. 23), while another noted, "There are certain topics where a teacher's explanation is absolutely necessary, and it [the chemistry lesson] won't work

Table 4 Matching of the teachers' statements to the six quality characteristics of an instructional explanation. Teacher statements have been translated by the authors

Quality characteristic	Statements of the chemistry teachers
Subject-specific quality aspects	– "But that only works with expert knowledge [of chemistry]. Without expert knowledge, it's just hard, and you find yourself stumbling" ($K_{1.6.1}$; 4A, pos. 116) – "At which level [according to Johnstone] are we currently? Explain it again in that way. Are we at the submicroscopic level? And then again and again: What do the different levels [according to Johnstone] mean?" ($K_{1.6.1}$; 3B, pos. 45) – "I believe you need a strong grasp of the content to explain it well, and you also need to be able to set priorities" ($K_{1.6.1}$; 2C, pos. 16)
Linguistic clarity	– "I try to explain as simply as possible, but using established terminology" ($K_{1.6.2}$; 2A, pos. 50) – "I also focus on using accurate chemical terminology" ($K_{1.6.2}$; 3A, pos. 69) – "You should carefully consider, for example, the vocabulary you use to explain a subject and ensure that you avoid using complicated sentences" ($K_{1.6.2}$; 1C, pos. 4)
Structural organization	– "I know what focus I want to have" ($K_{1.6.3}$; 2A, pos. 46) – "That you just know: What is the goal? What do I want?" ($K_{1.6.3}$; 3A, pos. 80) – "I'm trying to do this [the instructional explanation] logically and in small steps" ($K_{1.6.3}$; 2B, pos. 50)
Use of visual and verbal support methods	– "But if you have an analogy, like driving a car, it becomes more understandable" ($K_{1.6.4}$; 4A, pos. 119) – "[It is important] to use something like structural formulas, models, because they are simply more illustrative than if we talk about hypothetical things that they [the students] can't see" ($K_{1.6.4}$; 1B, pos. 45) – "My preparation is more visual in nature. What do I show them [the students]? I want to ensure that it's not just my verbal explanation" ($K_{1.6.4}$; 3C, pos. 14)
Student centration	– "When I throw a bunch of technical terms at them [the students], I know that not all of them will understand them" ($K_{1.6.5}$; 1A, pos. 12) – "[The instructional explanation] must connect with the students' prior knowledge. If I explain something to students who lack the necessary foundation, it won't be effective" ($K_{1.6.5}$; 2B, pos. 55) – "How do I know that they understood that [...]? Of course, questions [...] should be incorporated from time to time [...]" ($K_{1.6.5}$; 3B, pos. 70)
Appropriate speech and physical expression	– "[The instructional explanation is given] at a slow pace. Of course, always with eye contact" ($K_{1.6.6}$; 1A, pos. 7) – "Not to speak monotonously" ($K_{1.6.6}$; 2B, pos. 46) – "And when you explain the states of matter, I use my body to demonstrate that solid particles are stationary but can still move a little" ($K_{1.6.6}$; 3C, pos. 6)

without it" ($K_{2.2}$; 1C, pos. 8). According to the teachers, a key aim of instructional explanations is "to eliminate typical mistakes that students make [...] in advance" ($K_{2.2}$; 1A, pos. 18).

Teacher 1A also emphasized that "students like to have things explained to them" ($K_{2.2}$; 1A, pos. 16) and observed that a lack of explanation can be demotivating: "when there is no explanation, that's also very demotivating for the students. Sometimes, of course, they want to know: How do I do it now, and how does it work? So, I don't have the feeling that they're totally bored [...]. They actually enjoy it when you explain things to them" ($K_{2.2}$; 1A, pos. 77). However, the teachers noted a potential drawback in relying solely on explanations. For example, teacher 4A stated: "At some point, students then also come to expect a definitive explanation from the teacher" ($K_{2.2}$; 4A, pos. 114). In addition to addressing subject matter, the teachers highlighted the benefit of using instructional explanations to teach chemical terminology. Teacher 2B noted, "Advantage: I can point out the correct terminology" ($K_{2.2}$; 2B, pos. 37). They also adapt their language to students' needs while explaining: "I always try to adjust the terminology to the students [...]. This means I try to use the terminology well-directed, but also to explain to them again what the individual words mean" ($K_{2.2}$; 3A, pos. 87).

From the audience perspective, instructional explanations are valued for their adaptability to individual student needs: "The students receive the subject matter well-prepared, tailored to them, presenting the information" ($K_{2.3}$; 4B, pos. 15). Instructional explanations are also adapted to each learning group's unique needs: "I actually [...] noticed that every year I [...] do [the instructional explanation] somehow differently and anew because I realize: Okay, now they don't know what to do with it [the explanation]. For example, I have to change it somehow then. Sometimes also altering the order" ($K_{2.3}$; 3B, pos. 49).

The interviewed chemistry teachers also highlighted the advantages of instructional explanations over some student-centered methods. For example, teacher 1C contrasted instructional explanations with a student-centered "egg race" activity, explaining that the structured guidance provided by an instructional explanation prevents students from feeling lost: "If you just do an egg race with them [the students] and put everything in front of them, saying, 'Now find the solution to the problem,' they sometimes feel lost, don't know where to start [...] and they won't get anywhere like they might if you've given them a certain framework beforehand with an instructional explanation" ($K_{2.3}$; 1C, pos. 8).

This underscores the perceived advantage of instructional explanations, particularly for teaching theoretical and abstract subject matter, compared to explanations found in textbooks or explanatory videos: "[The explanation plays a] central role, especially in chemistry lessons, perhaps also in science in general, because much of the content is difficult to work on independently due to the high level of abstraction" ($K_{2.3}$; 2C, pos. 24). Instructional explanations allow teachers to respond spontaneously and tailor their explanations to students' individual needs: "I [the teacher] [can] address questions directly during an explanation, which a book or video cannot do" ($K_{2.3}$; 2B, pos. 26). This emphasizes the unique advantages of instructional explanations over widely available explanatory videos found on the World Wide Web (Knapp *et al.*, 2020). Ultimately, from both the subject matter and audience perspectives, a well-delivered instructional explanation in chemistry lessons cannot be replaced by an explanatory video.

Notably, several teachers expressed negative beliefs about instructional explanations at various points in the interview (see next section). Teacher 3C acknowledged this, pointing out that teaching style often reflects personal preferences ($K_{2.4}$). Identifying as a teacher-centered instructor, he contrasted his approach with current trends that emphasize facilitative, student-led methods. He explained, ''Of course, it's also a matter of style, what kind of teacher you are. I think that I am a rather teacher-centered teacher [...] I tend not to step back as much. Today's trend is to only moderate and accompany learning with lessons structured [...] in a student-centered way. I think that I am rather unfashionable, preferring that students focus on me. That's why an instructional explanation usually goes faster. [...] And sometimes I feel that you can create misconceptions in a [student] group [setting]. If I give four students a difficult topic in a group and they are supposed to teach it themselves, and the result is nonsense, then unfortunately that misconception can become ingrained. That's why I'm a fan of instructional explanations and not so much of cooperative forms of learning led by the students'' ($K_{2.4}$; 3C, pos. 20).

Chemistry teachers' beliefs about the disadvantages of instructional explanations in chemistry class

Despite the general importance attributed to instructional explanations (K_1) and the specific reasons cited for their relevance (K_2), the interviewed chemistry teachers also identified several disadvantages associated with them (K_3: *Reasons opposing the importance of instructional explanations in chemistry lessons*). Notably, some teachers conveyed a negative connotation when discussing the term ''instructional explanation''. For example, teachers associated instructional explanations with a monologue or lecture format, considering it being ''not state of the art'' ($K_{3.1}$; 1C, pos. 22). Instructional explanations are also linked to perceptions of cognitive passivity among students and a transmissive, one-way transfer of knowledge. As one teacher noted, ''I have [...] no interaction with the students. I cannot [...] directly [...] ascertain whether the students have really understood this [...]'' ($K_{3.2}$; 1B, pos. 11) while another stated, ''[The students] are passive recipients'' ($K_{3.2}$; 2A, pos. 57). Some teachers also expressed concerns that instructional explanations contradict constructivist educational principles. Teacher 2C observed: ''If you were to teach just like that [exclusively with instructional explanations], there are numerous studies [in] constructivist learning theory that refuse the idea that you can impart content or knowledge, not to mention skills, just by explaining something'' ($K_{3.2}$; 2C, pos. 20).

These beliefs about instructional explanations have practical implications for how the chemistry teachers incorporate them into their lessons. For example, teacher 2C consciously limits her use in chemistry lessons, noting, ''it is a bit frowned upon for a teacher to explain something'' ($K_{3.1}$; 2C, pos. 12). She also tries ''to keep the phases of instructional explanations as short as possible, because students can quickly get lost in them'' ($K_{3.3}$; 2C, pos. 14).

All the quality characteristics for instructional explanations cited in the literature were mentioned across interviews (see above). However, a closer examination of the individual statements reveals that some teachers feel that not all quality characteristics are consistently met through instructional explanations, leading to critiques of this teaching method. This criticism particularly pertains to the quality characteristics of ''Student centration'', which also indirectly affects other characteristics, such as ''Use of visual and verbal support methods''. Since visual and verbal supports enhance student centration, these two characteristics are interrelated rather than entirely distinct. Teacher 1C illustrated this, stating, ''The disadvantage [of the instructional explanation] is that it is totally unrealistic. It is entirely abstract, such an explanation. Someone stands there and tells something, and whether it is true or whether they are telling something wrong or whether I, as a student, can imagine it, is another matter entirely'' ($K_{3.3}$; 1C, pos. 12). This highlights the perceived lack of ''Student centration'' and ''Use of visual and verbal support methods''.

Changes in chemistry teachers' beliefs about both the advantages and disadvantages of instructional explanations in chemistry class

No teacher exclusively described the advantages or disadvantages; instead, all expressed a balanced view, highlighting both, which reflects a nuanced perspective shaped by their training and classroom experience.

However, some teachers described an evolution in their beliefs over time, particularly a shift before and after their teacher training (''Referendariat''). For example, teachers 2B and 2C now have more positive beliefs towards explanations; however, this was not always the case. During their teacher training, they were encouraged to prioritize student discovery and active learning over the use of instructional explanations.

Teacher 2B emphasized the training focus on having students explore concepts independently through guided steps, recalling, ''How would you ideally do it in your Referendariat [teacher training]? That the students do an experiment and then work through everything themselves with step-by-step aid [material]. [...] That's what I took away as the ideal approach during my Ref [''Referendariat'']'' ($K_{1.7}$; 2B, pos. 103). She highlighted the discrepancy between teacher training ideals and practice: ''So in practice, I find myself explaining much more than was presented as ideal during Referendariat [teacher training]'' ($K_{1.7}$; 2B, pos. 103).

Teacher 2C shared a similar view, describing her initial attempts to avoid instructional explanations based on the student-centered philosophy promoted in her training. Over time, however, she recognized that short, well-structured instructional explanations could effectively introduce complex material, particularly in chemistry. She observed, ''The very beginning [of the interview], when you mentioned the topic, I thought that during my Referendariat [teacher training] I tried to completely ban instructional explanations from my lessons, because there was this mentality that everything had to be worked out by students. And now I am gradually starting to reintroduce it [the instructional explanation], because I have realized that there are situations [in the chemistry lesson] where a well-prepared, condensed 3- to 5-minute instructional explanation is actually very valuable. It can bring everyone onto the same page and serve as a good foundation for further learning'' ($K_{1.7}$; 2C, pos. 24). Teacher 2B echoed this sentiment, noting that while student-centered methods are ideal, the practical demands of lesson preparation make instructional explanations a more realistic option, adding: ''[It] takes much, much longer to prepare with the staged aids'' ($K_{2.1}$; 2B, pos. 103). These statements highlight the evolution of beliefs towards instructional explanations based on classroom experience, indicating a shift influenced by practical teaching realities.

Regarding the advantages and disadvantages of instructional explanations, the teachers' perspectives reveal a nuanced and ambivalent stance. All participants acknowledged both benefits and limitations associated with the use of instructional explanations in chemistry lessons. In terms of their beliefs, it becomes evident that they experience a certain internal conflict when using instructional explanations. On the one hand, they tend to believe explanations are inherently less student-centered. On the other hand, they place a strong emphasis on student-centered learning, particularly in subject matter instruction – an approach reinforced by their experiences during teacher training. This tension suggests that, while they recognize the pedagogical value of instructional explanations, they also see them as somewhat misaligned with student-centered methods.

Furthermore, the idea that instructional explanations can, in fact, be designed in a student-centered manner appears to contradict their implicit understanding or preconceived notions of what instructional explanations entail. Additionally, some teachers perceive the use of explanations as a teaching style that primarily involves the direct transmission of information to passive learners. This perspective reinforces a transmissive rather than an interactive or constructivist view of instructional explanations.

Table 5 presents a summary of our findings, structured around the three overarching topics: general beliefs, beliefs about the advantages, and beliefs about the disadvantages of instructional explanations.

Discussion and conclusion

This exploratory investigation aimed to examine chemistry teachers' beliefs about instructional explanations in chemistry lessons. The findings indicate that the interviewed teachers hold varied and sometimes conflicting beliefs about instructional explanations, which can influence how they utilize them in the classroom. For example, the tension and the simultaneity between these two perspectives is evident in the case of teacher 5C. On one hand, she viewed student-centered learning methods as essential to chemistry teaching, stating, ''I believe that chemistry lessons thrive on students doing a lot of experimenting and trying things out themselves'' (K_3; 5C, pos. 13). However, she also acknowledged the advantages of instructional explanations, particularly in addressing the abstract nature of certain topics and terminology. She explained, ''I also think that [student-centered learning approaches] cannot always be implemented in everyday school life and that [...] students are not yet ready [to work on the subject content individually] [...] to accurately formulate the result themselves [...]. Or they don't use any terminological language. [...] I think that explanations are simply necessary in these cases'' ($K_{2.2}$; 5C, pos. 13).

In general, the interviewed chemistry teachers valued their role in delivering instructional explanations, believing that it enhances the learning experience compared to students learning independently from textbooks or online videos. For example, teacher 2B stated, ''I [the teacher] [can] address questions directly during an explanation, which a book or video cannot do'' ($K_{2.3}$; 2B, pos. 26), while teacher 2C remarked, ''The only alternative [to an instructional explanation] would be a book text or something

Table 5 Summary of key findings from 13 interviews with chemistry teachers on their beliefs about instructional explanations

General beliefs	Teachers ...
	... Recognize instructional explanations as highly important in chemistry lessons.
	... Express uncertainty about a precise definition of instructional explanations, often indicating that they have not deeply reflected on the concept.
	... Emphasize the necessity of aligning instructional explanations with students' prior knowledge as a fundamental prerequisite.
	... Distinguish between the process of explaining (including preparation) and the explanation as a final product (a static outcome).
	... Implicitly differentiate between various types of explanations based on the subject matter, with *Why*-explanations being the most commonly used.
	... Hold beliefs that align with the six quality characteristics of instructional explanations when planning and delivering them.
Beliefs about the advantages	Teachers attribute the following advantages to instructional explanations:
	– Valued for their practicality and efficiency in optimizing lesson time
	– Considered essential due to the complexity of chemical content and specialized terminology
	– Appreciated for their adaptability, allowing explanations to be tailored to individual students' needs
	– Viewed as a reflection of personal teaching style and preferences
Beliefs about the disadvantages	Teachers attribute the following disadvantages to instructional explanations:
	– Often associated with a negative connotation, particularly linked to monologues or lecture-style teaching
	– Perceived through a transmissive lens, where instructional explanations are seen as a one-way transfer of knowledge
	– Viewed as conflicting with certain quality characteristics, particularly ''Student Centration'', as instructional explanations are not always perceived as actively engaging students in the learning process

similar, but then the opportunity for interaction is missing" ($K_{2.3}$; 2C; pos. 20). This "live" feature of instructional explanations – allowing real-time interaction with the instructor – is a straightforward yet unique advantage (Knapp *et al.*, 2020).

Nevertheless, some teachers expressed transmissive beliefs, viewing instructional explanations as a one-way transfer of knowledge, and associating them with negative connotations. This negative perception among some teachers regarding instructional explanations may lead to lower explanation quality compared to teachers who approach instructional explanations with a constructivist mindset (see "theoretical framework"; Kulgemeyer and Riese, 2018, for insights on the relationship between teaching approaches and their effects on teaching–learning processes see Trigwell *et al.*, 1999; Dubberke *et al.*, 2008). These findings suggest that the concept of an effective instructional explanation – identified in research as a means of enhancing student understanding – is not consistently reflected in the beliefs of in-service chemistry teachers, revealing a disconnection between educational research and classroom practice in their understanding of "instructional explanation". The negative connotation attached to the term "instructional explanation" has been recognized in other research (*e.g.*, Aeschbacher, 2009; Kulgemeyer, 2019). As a result, if teachers hold negative associations with explanations, they may be less inclined to use them purposefully in the classroom.

Furthermore, aligning with the common research distinction between transmissive (traditional, teacher-centered) beliefs and constructivist (modern, student-centered) beliefs, the findings indicate a notable tension. While teachers acknowledge the importance of instructional explanations, recognize most of the quality criteria identified in research, and emphasize their advantages from various perspectives, the majority also express negatively connoted beliefs that contribute to a rejection of instructional explanations in chemistry class. This rejection appears to stem from concerns that instructional explanations may hinder active student engagement or reinforce passive knowledge reception rather than fostering deeper conceptual understanding. This tension is evident among most, though not all, of the teachers interviewed. This aligns with findings from studies by Tsai (2002) and Al-Amoush *et al.* (2012, 2014), which suggest a transmissive belief system among in-service teachers.

When comparing our findings with previous research, three key commonalities emerge. First, the teachers agreed with the definition of instructional explanations provided at the beginning of the interview. Second, the interviewed teachers primarily use *Why*-explanations. We concur with Osborne and Patterson (2011, p. 631) on this point, who observe that: "explanations are driven [...] by the desire to answer the question 'Why?'". Third, they view fostering student understanding as a central goal of instructional explanations, consistent with findings by Findeisen (2017) and Elmer and Tepner (in press). However, a closer look reveals an additional goal: the interviewed chemistry teachers emphasize not only the understanding of subject matter but also the importance of conveying content in technically accurate language that students can adopt. This careful use of language bridges the demands of subject specific matter with the needs of the audience, ensuring accessibility without cognitive overload. Teacher 4B summarized this by saying: "I use terminological language [($K_{2.2}$; 4B, pos. 13)], but also language that is adapted to the students" ($K_{2.3}$; 4B, pos. 13).

The qualitative content analysis suggests that teachers prioritize different aspects of instructional explanations, with greater emphasis on the audience perspective than on the subject matter perspective. They particularly stress adapting explanations to students' prior knowledge and language level, and actively engaging them in the learning process. For example, one teacher noted, "A [good instructional] explanation [is one] that presents a complex issue in simple terms so that students with minimal prior knowledge can understand it. It is important to engage everyone, even those with very different levels of background knowledge, in a way that allows the [chemistry] lesson to progress" ($K_{2.3}$; 4A, pos. 102). The emphasis on the audience perspective may relate to the transmissive beliefs some teachers expressed about instructional explanations such as viewing them as monologues.

Since teachers' beliefs are closely linked to their instructional practices (Hashweh, 1996; Richardson, 1996; Gess-Newsome, 1999; Gess-Newsome *et al.*, 2003; Cross, 2009), including their approach to delivering instructional explanations, this connection may account for variations in their beliefs as well as the observed tension, depending on the type of school and the specific student groups they teach. The findings suggest that chemistry teachers who primarily work with students needing more structured, subject-matter-appropriate and audience-centered support in *Hauptschule*, *Realschule* and *Gesamtschule* tend to place greater importance on instructional explanations. This reflects more positive beliefs about their value than those held by *Gymnasium* teachers, who work with students requiring comparatively less instructional support.

For example, teacher 3C, who taught at a *Hauptschule*, stated, "I'm a fan of instructional explanations and not so much of cooperative forms of learning led by the students" ($K_{2.4}$; 3C, pos. 20). He added, "When things get complicated, I think a teacher has to jump in sometimes. I would find it very difficult to let students teach themselves the structure of an atom. I think a teacher just has to explain it" ($K_{2.4}$; 3C, pos. 22).

Similarly, teacher 4C from a *Realschule* noted, "Because the students themselves cannot come up with the content" ($K_{2.2}$; 4C, pos. 14). In contrast, teacher 2A, who teaches at a *Gymnasium*, described students during instructional explanations as "passive recipients" ($K_{3.2}$; 2A, pos. 38,57) and prefers using other methodological approaches. He explained, "I would never, I think, do a pure instructional explanation" ($K_{3.2}$; 2A, pos. 38).

This observation aligns with the findings by Chi *et al.* (1989), who noted that student self-explanations can create an illusion of understanding, particularly with abstract and complex content prone to misconceptions: "[The students] seem less accurate at detecting comprehension failures" (Chi *et al.*, 1989, p. 176). The risk of an illusion of understanding also applies to instructional explanations (Rozenblit and Keil, 2002). However, teachers possess diagnostic skills that allow them to address common misconceptions during explanations enhancing adaptivity.

It is also essential to understand why the interviewed chemistry teachers hold these partly inconsistent or ambivalent beliefs about instructional explanations and how these beliefs have developed. Research indicates that various factors shape teachers' beliefs about teaching (*e.g.*, Boz *et al.*, 2019). Socio-cultural factors, such as place of residence, the schools and universities attended, and current workplace, significantly influence belief formation (Hoy *et al.*, 2006; Savasci and Berlin, 2012). Personal experiences are particularly influential, as beliefs about explanations are shaped by prior experiences in school (*e.g.*, Markic and Eilks, 2008) and university studies (*e.g.*, Simmons *et al.*, 1999; Hancock and Gallard, 2004; Boz *et al.*, 2019). This process is often compared to a filter through which new experiences are perceived and interpreted (Kagan, 1992; Pajares, 1992; Johnstone, 1997; Stipek *et al.*, 2001). Therefore, decisions about instructional methods, such as the use of instructional explanations, are strongly influenced by past experiences. Our findings support this trend. Statements from teachers 2B and 2C in our investigation suggest that negative connotations and transmissive beliefs about instructional explanations are often reinforced during practical teacher training, where the emphasis on student-centered methods can overshadow a balanced view of instructional explanations (see section "Changes in chemistry teachers' beliefs about both the advantages and disadvantages of instructional explanations in chemistry class").

In conclusion, the origins of the interviewed teachers' beliefs about instructional explanations likely stem from their own school and university experiences. Since explanations may have been presented in a more transmissive manner in the past – and because scientific explanations are often delivered in lecture format at the university level – this could explain why some of the interviewed teachers hold transmissive beliefs about instructional explanations or view them as a transmissive teaching practice. Furthermore, it suggests that educators' willingness to consciously use instructional explanations diminishes if they do not perceive them as interactive communication opportunities (Kulgemeyer, 2019).

Implications

The implications of this exploratory investigation can be divided into two main areas: implications for teacher education/practice and implications for future research.

Implications for teacher education/practice

Although prospective teachers (as novice explainers) and practicing teachers (as expert explainers; *e.g.*, Meschede *et al.*, 2017) differ, the findings of this investigation offer valuable insights for university teacher training. The exploratory investigation reveals that the chemistry teachers hold diverse and sometimes conflicting beliefs about instructional explanations in chemistry lessons. While they recognize the importance of explanations, they also associate them with certain negative connotations. These mixed beliefs highlight the need for comprehensive teacher education programs designed to deepen teachers' understanding of instructional explanations and foster their effective use in chemistry teaching.

Research shows that beliefs correlate more strongly with future behavior when they remain stable over time and are easily retrievable through direct experience (Kagan, 1992; Glasman and Albarracín, 2006). Therefore, if (prospective) teachers have an inadequate understanding of what constitutes a good instructional explanation, or if they mistakenly view presentations and monologues as explanations, they may be less likely to utilize instructional explanations effectively. Integrating both theoretical and practical (meta-) knowledge about instructional explanations within a constructivist perspective (Kulgemeyer and Geelan, 2024) into teacher education is essential to cultivate a well-rounded, research-informed understanding of these instructional practices, including the quality characteristics outlined in the literature (*e.g.*, Ehras *et al.*, 2021).

We propose a three-step framework for developing an "explanation program" in teacher education, structured around three interrelated goals: establishing a theoretical foundation, facilitating practical application, and encouraging reflection on beliefs.

Theoretical foundation. Establishing a strong theoretical foundation on instructional explanations, informed by research in (science) education (according to *e.g.*, Treagust and Harrison, 1999, 2000; Kulgemeyer and Tomczyszyn, 2015; Findeisen, 2017), involves addressing key questions related to their definition and quality criteria. This theoretical base enables (prospective) teachers to perceive instructional explanations as intentional, student-centered teaching practices in chemistry.

Practical application. Instructional explanations should be approached not only theoretically but also practically, engaging (prospective) teachers' personal experiences. Previous studies show that (prospective) teachers often find explaining to be one of the greatest challenges, especially prospective teachers in the final stages of training in Germany ("Referendare"; Merzyn, 2005). Thus, hands-on experience is crucial, as theoretical knowledge alone does not always align with teachers' beliefs (Nespor, 1987; Pajares, 1992).

To bridge theory and practice, pivotal moments in instructional explanations during chemistry lessons – such as particularly challenging topics or points where models and representations are especially useful – can be integrated into teacher preparation courses, enabling future teachers to practice explaining through concrete examples. For example, teacher trainees could engage in structured explaining exercises such as micro-teaching units in university-based labs or peer-teaching sessions (Boz *et al.*, 2019). Research supporting the "learnability" of explanatory skills underscores the value of this approach (Charalambous *et al.*, 2011). Kagan (1992, p. 75) noted that, "changes in teacher belief are generally not effected by reading and applying the findings of educational research. [...] Instead, teachers appear to obtain most of their ideas from actual practice, primarily from their own and then from the practice of fellow teachers". These exercises allow trainees to practice delivering explanations with a focus on quality criteria, supported by peer feedback and self-reflection. Specific chemistry topics, such as those requiring *Why*-explanations that clarify the underlying principles of abstract concepts, could serve as practice material to reinforce effective beliefs (Ehras *et al.*, 2021). The majority of the teachers interviewed expressed a transmissive belief that students are cognitively passive during instructional explanations. To address this, practical exercises on instructional explanations could include strategies for promoting cognitive activation.

Trainees could then further refine their skills by explaining chemistry concepts to school students, documenting their experiences, and reflecting on subject-content appropriate and audience-centered strategies.

Reflective practice. Given the established link between teachers' beliefs and instructional practices (*e.g.*, Hashweh, 1996; Richardson, 1996; Gess-Newsome, 1999; Gess-Newsome *et al.*, 2003; Cross, 2009), teacher education programs should incorporate mechanisms for making teacher candidates' beliefs about instructional explanations explicit and visible (Kagan, 1992), promoting critical reflection. Shulman (1986, p. 9) emphasized that, "The teacher need not only understand that something is so; the teacher must further understand why it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied". Reflective questions might include: What are the origins of my beliefs? Do these beliefs align with didactic research, or should they be reconsidered for improved student learning? How have my beliefs evolved through theoretical and practical training?

Reflective programs on (prospective) teachers' instructional explanations already exist in didactic education, demonstrating their benefits in helping (prospective) teachers understand their instructional choices and refine their approaches. For example, Ehras *et al.* (2021) developed a seminar concept promoting students' explanatory skills through multi-perspective feedback and video analysis (see also Charalambous *et al.*, 2011; Kobl, 2021).

Our findings suggest that these reflective phases should be introduced early in teacher education and revisited periodically, ensuring continuity and reinforcement. There is also other research that emphasizes the importance of identifying and addressing prospective teachers' beliefs early in their training, as these beliefs tend to be less stable and more fragmented than those of experienced teachers (*e.g.*, Simmons *et al.*, 1999; Fletcher and Luft, 2011). However, they are also more amenable to development and refinement (*e.g.*, Hancock and Gallard, 2004; Boz *et al.*, 2019). This highlights the crucial role of university teacher training, as it provides an excellent opportunity to align prospective teachers' beliefs with a deeper, research-based understanding of instructional explanations in science education. In this regard, we agree with Boz *et al.* (2019, p. 510), who emphasize the need to engage with novice teachers' beliefs during university teaching: "it must challenge the adequacy of those beliefs; and it must give novices extended opportunities to examine, elaborate, and integrate new information [here about the instructional explanation] into their existing belief systems". Therefore, it is essential that the beliefs of prospective teachers about instructional explanations are made visible and explicit as early as possible in university courses. These beliefs should then be addressed, categorized, and reflected upon to support meaningful development within a personalized teacher education framework.

Furthermore, theory, practice, and reflection on instructional explanations should be integrated not only during university training but also throughout the practical teacher training, (such as the "Referendariat" in Germany). Beliefs about instructional methods often solidify during hands-on teaching experiences, as noted by teachers 2B and 2C, who encountered a disconnect between the ideals of their training and the realities of the classroom. Aligning the objectives of teacher training with practical classroom demands can help bridge this gap, equipping teachers with a well-rounded understanding of effective instructional explanations in chemistry. While this approach does not guarantee high-quality, understanding-promoting instructional explanations, it increases the potential to enhance the likelihood of explanations that align with constructivist beliefs about teaching.

Since beliefs can be difficult to change (*e.g.*, Pajares, 1992), this open yet systematic approach may help cultivate a deeper appreciation for and recognition of the value of instructional explanations in chemistry lessons. Only when teachers recognize their potential to enhance learning will they actively integrate them into their teaching, ultimately laying the foundation for high-quality instructional explanations that support students' understanding of chemistry.

Implications for future research

The findings of our exploratory investigation provide a foundation for future research. One area to explore is the comparison between teachers' beliefs and their actual teaching practices, which could offer insights into how beliefs translate into practice (following the perspectives of, *e.g.*, Bandura, 1986; Hashweh, 1996; Richardson, 1996). This raises questions about the alignment and the extent to which teachers' stated beliefs about instructional explanations correspond to their actual implementation in chemistry lessons (*e.g.*, Simmons *et al.*, 1999; Savasci and Berlin, 2012). It would also be valuable to examine how effectively these teachers' explanations meet learning objectives.

Additionally, our findings suggest that chemistry teachers from different school types hold distinct beliefs about instructional explanations. Building on this, future studies could investigate variations in the implementation of instructional explanations across different school types (*e.g.*, primary, middle, and secondary schools) in greater depth, thereby contributing to a more nuanced understanding of instructional explanations in chemistry education.

Another essential area for research involves the beliefs of two other groups central to instructional explanations: students and prospective teachers. Understanding student perspectives could reveal what constitutes a "good" instructional explanation from their point of view. This area is especially significant as, aside from Wilson and Mant (2011a), there is limited research on students' perspectives and beliefs regarding instructional explanations. For example, it would be interesting to explore whether students agree with teacher 1A's observation that "students like to have things explained to them" (1A, pos. 16). This line of inquiry could clarify students' preferences and expectations for instructional explanations in chemistry, particularly in an era of readily available explanatory videos. Comparing beliefs across teachers and students would highlight similarities and differences, offering valuable insights for teacher education and practice.

Additionally, prospective teachers' beliefs are a promising area for further research. Previous studies have shown that the stability of beliefs evolves throughout a teacher's career, with varying degrees of consistency. Compared to experienced teachers, the beliefs of students and novice teachers tend to be less stable, more inconsistent, and often disconnected (*e.g.*, Simmons *et al.*, 1999; Fletcher and Luft, 2011). Consequently, their beliefs are more open to change and influence than those of experienced teachers (see studies on belief development and change in prospective teachers, *e.g.*, Hancock and Gallard, 2004; Boz *et al.*, 2019; and studies examining prospective teacher beliefs at specific stages, *e.g.*, Markic and Eilks, 2008; Kotul'áková, 2020). Documenting prospective teachers' beliefs about instructional explanations is crucial for developing university-level courses that align with these findings. Combined with our investigation's results, this would provide a comprehensive overview of current beliefs about instructional explanations among both prospective and in-service teachers. A comparative study of these groups could offer insights into how beliefs evolve from prospective to practicing teachers. For instance, statements from teachers 2B and 2C in our examination suggest a potential progression in beliefs from prospective to experienced teachers, implying that beliefs may develop with experience and education. Examining this evolution with a larger, cross-national sample – including countries with different teacher education systems – could reveal whether this progression truly is consistent across contexts. Integrating the beliefs of chemistry teachers, students, and prospective teachers about instructional explanations could create a multi-perspective view aligned with Calderhead's (1996, p. 722) vision to "contribute to a fuller recognition of what it means to teach and to learn, and how the quality of such processes might be improved".

As Treagust and Tsui (2014) have noted, further research on instructional explanations in science education is important "to further improve classroom learning in the 21st century", opening up a significant field of research (p. 307; see also Braaten and Windschitl, 2011). We agree with Treagust and Tsui (2014), considering our investigation as a glimpse into "the culture of explaining" (Kulgemeyer, 2019, p. 24) among chemistry teachers and a contribution to the broader, yet still evolving, field of (chemistry) teachers' beliefs about this instructional practice.

Limitations

While this research provides valuable insights, it is important to note the following limitations.

Due to the exploratory nature of our investigation and its limited sample size ($N = 13$), the generalizability of the results is constrained. As the study focuses on teachers from a specific region in Germany, the findings may be influenced by regional educational policies, cultural factors, and the structure of the German educational system (*e.g.*, *Gymnasium* vs. *Gesamtschule*; Risch, 2010). Teacher beliefs may vary significantly across countries or regions with different chemistry curricula, teacher training programs, and cultural attitudes toward instruction.

A further limitation of this investigation is the lack of specific data on the exact number of years of teaching experience among the participants. While all participants were in-service teachers with teaching experience, the lack of detailed information about their exact years of teaching experience limits the ability to analyze whether and how varying levels of teaching experience influenced their beliefs about instructional explanations. Future research could address this limitation by collecting more detailed demographic data to explore potential patterns or trends based on teaching experience. Another methodological limitation is the longer duration of the interview with teacher 1A compared to the relatively consistent lengths of the other interviews. The extended duration of teacher 1A's interview suggests that, with a deeper level of probing, it might have been possible to capture additional or more nuanced beliefs in the other interviews as well.

Additionally, considering the varied meanings of the study's key term "explanation" across contexts, it is essential to critically examine and contextualize the terminology used in relation to the responses. Thus, it remains uncertain whether alternative terminology, such as "classroom explanation" instead of "instructional explanation", would have elicited different responses. Finally, this investigation focused on beliefs about instructional explanations that teachers had consciously planned and delivered, excluding spontaneously given *ad hoc* explanations, which may occur more frequently in chemistry lessons than planned instructional explanations. Consequently, the results do not provide insights into the practical implementation of these beliefs, particularly in the context of *ad hoc* explanations. However, a comparable study on *ad hoc* explanations in chemistry classes could be valuable, allowing a comparison between planned and *ad hoc* explanations and examining, for instance, whether teachers' beliefs differ between the two types.

Data availbility

The data supporting the findings of this investigation are not publicly available due to data privacy laws protecting the personal information of the interviewees. However, anonymized data can be obtained from the authors upon reasonable request.

Conflicts of interest

There are no conflicts to declare.

Appendix

Table 6 Codebook for Data Coding. Teacher statements (anchor examples) have been translated by the authors

Category	Code	Code definition	Anchor example
K_1: *General beliefs*	$K_{1.1}$: *Definition*	Statements about the definition of an instructional explanation.	"Actually, almost everything is an instructional explanation" ($K_{1.1}$; 3C, pos. 2)
	$K_{1.2}$: *Prerequisites*	Statements about the prerequisites for providing an instructional explanation.	"If I create a plan for an [instructional] explanation that does not take into account the students' prior knowledge – especially if I have not analyzed the learning group – then it won't achieve much" ($K_{1.2}$; 4A, pos. 129)
	$K_{1.3}$: *Preparation*	Statements about the preparation required for delivering an instructional explanation.	"I notice that I need to prepare differently for [instructional explanations] compared to phases where students work independently" ($K_{1.3}$; 2C, pos. 16)
	$K_{1.4}$: *Types*	Statements about different types of instructional explanations, such as *How*-, *What*-, and *Why*-explanations.	[Referring to the *Why*-explanation:] "Let's take another look: Why is it [the chemical phenomenon] like this?" ($K_{1.4}$; 3A, pos. 82)
	$K_{1.5}$: *Importance*	Statements evaluating the importance and priority of instructional explanations.	"The explanation is indeed a very important aspect in chemistry. It's beneficial to delve into it: What actually constitutes a good explanation?" ($K_{1.5}$; 3B, pos. 85)
	$K_{1.6}$: *References to quality characteristics*	Statements referring to the quality characteristics (see Table 2).	"[...] because otherwise, it would not be possible to meet all the criteria [about the instructional explanation] I just mentioned" ($K_{1.6}$; 1C, pos. 16)
	$K_{1.6.1}$: *Subject-specific quality aspects*	Statements referring to the quality characteristic "Subject specific quality aspects" (see Table 2). This includes ensuring that instructional explanations accurately represent subject matter, adhere to chemical conventions and specialized terminology, and incorporate chemistry-specific representational forms such as Johnstone's (2000) macroscopic, submicroscopic, and symbolic levels.	"At which level [according to Johnstone] are we currently? Explain it again in that way. Are we at the submicroscopic level? And then again and again: What do the different levels [according to Johnstone] mean?" ($K_{1.6.1}$; 3B, pos. 45)
	$K_{1.6.2}$: *Linguistic clarity*	Statements referring to the quality characteristic "Linguistic clarity" (see Table 2). This includes ensuring that instructional explanations are communicated clearly and understandably, following semantic, syntactic, and idiomatic conventions. It also involves avoiding overly long sentences, using smooth transitions between concepts, and selecting precise terminology.	"You should carefully consider, for example, the vocabulary you use to explain a subject and ensure that you avoid using complicated sentences" ($K_{1.6.2}$; 1C, pos. 4)
	$K_{1.6.3}$: *Structural organization*	Statements referring to the quality characteristic "Structural organization" (see Table 2). This includes ensuring that instructional explanations are well-structured, logically coherent, and concisely presented to effectively convey essential information.	"I'm trying to do this [the instructional explanation] logically and in small steps. [...] There are these logical chains, and I try to map them out" ($K_{1.6.3}$; 2B, pos. 50)
	$K_{1.6.4}$: *Use of visual and verbal support methods*	Statements referring to the quality characteristic "Use of visual and verbal support methods" (see Table 2). This includes incorporating graphical aids (*e.g.*, drawings, animations) and/or verbal aids (*e.g.*, analogies, metaphors) to enhance comprehension and reinforce key concepts.	"[It is important] to use something like structural formulas, models, because they are simply more illustrative than if we talk about hypothetical things that they [the students] can't see" ($K_{1.6.4}$; 1B, pos. 45)
	$K_{1.6.5}$: *Student centration*	Statements referring to the quality characteristic "Student centration" (see Table 2). This includes ensuring that instructional explanations are tailored to students' volitional, motivational (*e.g.*, interests), and cognitive (*e.g.*, prior knowledge) characteristics.	"When I throw a bunch of technical terms at them [the students], I know that not all of them will understand them" ($K_{1.6.5}$; 1A, pos. 12)
	$K_{1.6.6}$: *Appropriate speech and physical expression*	Statements referring to the quality characteristic "Appropriate speech and physical expression" (see Table 2). This includes clear articulation and vocal quality, supported by gestures, effective prosody, and facial expressions during instructional explanations.	"[The instructional explanation is given] at a slow pace. Of course, always with eye contact" ($K_{1.6.6}$; 1A, pos. 7)
	$K_{1.7}$: *Shift in beliefs*	Statements addressing the shift in beliefs (*e.g.*, during teacher training) from negative to positive due to various factors.	"The very beginning [of the interview], when you mentioned the topic, I thought that during my Referendariat [teacher training] I tried to completely ban instructional explanations [...]. And

Table 6 (*continued*)

Category	Code	Code definition	Anchor example
			now I am gradually starting to reintroduce it [the instructional explanation] [...]'' ($K_{1.7}$; 2C, pos. 24)
K_2: *Reasons supporting the importance of instructional explanations in chemistry lessons*	$K_{2.1}$: *Practical and time-saving considerations*	Statements referring to the time saving and practical aspects of instructional explanations (*e.g.*, requiring less preparation time).	''Another advantage [of instructional explanations] is that they are simply very time efficient. If you explain something as a teacher compared to letting the students work on it independently, it is simply much faster. You just can't let everyone discover everything on their own in terms of time'' ($K_{2.1}$; 2C, pos. 20)
	$K_{2.2}$: *Complexity of chemical content and terminology*	Statements referring to the advantage and/or necessity of an instructional explanation due to the abstract and complex chemical content and/or chemical terminology.	''I believe that explaining in chemistry class generally plays a crucial role because it [the subject matter] is very abstract for the students'' ($K_{2.2}$; 1B, pos. 23)
	$K_{2.3}$: *Adaptivity*	Statements regarding the linguistic and content-based adaptivity of instructional explanations, ensuring they are tailored to students' individual prior knowledge, language proficiency, interests, learning challenges, and previous subject-related misconceptions.	''A [good instructional] explanation [is one] that presents a complex issue in simple terms so that students with minimal prior knowledge can understand it. It is important to engage everyone, even those with very different levels of background knowledge, in a way that allows the [chemistry] lesson to progress'' ($K_{2.3}$; 4A, pos. 102)
	$K_{2.4}$: *Personal teaching style*	Statements linking instructional explanations to personal teaching style.	''It's also a matter of style, what kind of teacher you are. I think that I am a rather teacher-centered teacher. [...] I think that I am rather unfashionable, preferring that students focus on me. [...] That's why I'm a fan of instructional explanations [...]'' ($K_{2.4}$; 3C, pos. 20)
K_3: *Reasons opposing the importance of instructional explanations in chemistry lessons*	$K_{3.1}$: *Negative connotation*	Statements that carry a negative connotation or association with instructional explanations.	''Such an instructional explanation is not state of the art in teaching'' ($K_{3.1}$; 1C, pos. 22)
	$K_{3.2}$: *Contradiction to constructivism*	Statements in which instructional explanations are linked to transmissive beliefs and/or perceived as incompatible with constructivist perspectives.	''If you were to teach just like that [exclusively with instructional explanations], there are numerous studies [in] constructivist learning theory that refuse the idea that you can impart content or knowledge, not to mention skills, just by explaining something'' ($K_{3.2}$; 2C, pos. 20)
	$K_{3.3}$: *Inversion of a quality characteristic*	Statements in which instructional explanations or any of their components are described as the opposite of a quality characteristic (see Table 2).	''The disadvantage [of the instructional explanation] is that it is totally unrealistic. It is entirely abstract, such an explanation'' ($K_{3.3}$; 1C, pos. 12)

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