frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 10 October 2025
DOI 10.3389/feduc.2025.1490875

OPEN ACCESS

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Leuphana University Lüneburg, Germany

*CORRESPONDENCE
Doris Neubauer-Hametner
✉ doris.neubauer@ph-linz.at

RECEIVED 03 September 2024
ACCEPTED 05 September 2025
PUBLISHED 10 October 2025

CITATION
Neubauer-Hametner D, Wendt H and Kasper D (2025) Teacher perceptions of classroom composition and instructional strategies in primary school science education.
Front. Educ. 10:1490875.
doi: 10.3389/feduc.2025.1490875

Teacher perceptions of classroom composition and instructional strategies in primary school science education

Doris Neubauer-Hametner[1,2]*, Heike Wendt[2] and Daniel Kasper[3]

[1]Institute Knowledge Transfer, Private University of Education, Diocese of Linz, Linz, Austria,
[2]Department of Education Research and Teacher Education, University of Graz, Graz, Austria,
[3]Department of General, Intercultural and International Comparative Education Studies and Educational Psychology, Faculty of Education, University of Hamburg, Hamburg, Germany

Teachers constantly need to make decisions about which instructional strategies to apply in their classrooms, in particular in the context of so-called adaptive teaching. Research, therefore, needs to explore how such decisions are informed and chosen. Using teacher and student data from the Austrian 2019 TIMS study, the present cross-sectional empirical study addressed three issues. First, we explored the frequency of use of inquiry-based instructional strategies (IQIS) by Austrian primary school science teachers. Second, we asked whether there was a potential relationship between this frequency of use and science teachers' perceived challenges in terms of heterogeneity, achievement and motivation? Finally, we examined potential associations between the frequency of use of specific IQIS and science teachers' characteristics. Using an IRT-approach and multiple regressions we managed to identify the four inquiry-based instructional strategies: Demonstrating, Connecting, Involving and Cognitively Activating. Our results show a significant association between teachers' perceptions, teachers' characteristics and the frequency of use of IQIS. This suggests that primary school science teachers' perceptions of their class composition directly influence their choice of IQIS and that this perception is co-determined by certain teacher characteristics. The results are discussed in relation to educational equity, implications for pre-service training, and further training for primary school teachers but also regarding inquiry-based instruction, as our results contrast with numerous studies that examine student ratings as a basis for instructional quality.

KEYWORDS

TIMSS, primary school science, inquiry-based learning, instructional strategies, class perception, class composition, instructional quality

1 Introduction

1.1 Instructional quality in primary school science education

Numerous studies have examined various aspects of instructional quality, particularly in secondary school science and mathematics teaching (Baumert et al., 2010; Gustafsson and Nilsen, 2016; Nortvedt et al., 2016; Scherer and Nilsen, 2016). Recently, some studies have explored these in to primary school science education (Decristan et al., 2016; Fauth et al., 2014a, 2014b; Teig et al., 2018; Teig et al., 2019). The results of all these studies show that classroom management, a supportive environment and cognitively activating instruction, the basic dimensions of instructional quality, have a significant, albeit often indirect, influence on students' learning outcomes in science education (Fauth et al., 2019). These three dimensions of instructional quality have provided important insights into the field of instructional research, but from an educators' perspective, they do not seem to capture the whole scope of the issue. However, it remains certain that teachers play an important role and appear to have an influence on effective instruction (Blömeke et al., 2016; Blömeke et al., 2022; Nilsen and Gustafsson, 2016). Furthermore, although it is now generally accepted that teaching and learning processes depend primarily on the way relationships are structured, i.e., on the interactions within a learning group and on the reactions between teachers and learners, the interaction component has been neglected as a core issue of a pedagogical perspective in studies on instructional quality.

In the Austrian context, little is known about interaction and instructional quality in general (Itzlinger-Bruneforth et al., 2020). Although monitoring data on the frequency of experiments in science education are available (see TIMSS cycles since 1995), they provide little evidence for the design of inquiry-based educational processes in Austrian classrooms in terms of instructional quality. In addition, Austrian teacher and student ratings from large-scale assessments reveal a comparatively undifferentiated picture. The study addresses this research question, firstly with in-depth analyses by focusing on primary teachers in inquiry-based science teaching and initially identifying instructional strategies used by them. In a second step, the study examines relationships between teachers' perceptions of problematic characteristics of class composition and lesson design, and for the third step, we look at associations with professionalization characteristics as possible factors influencing lesson design. The study uses teacher and student questionnaire data from TIMSS 2019 and aims, on the one hand, to make a theoretical contribution by proposing a new, expanded theoretical model of inquiry-based learning in primary education and, secondly, to offer practical suggestions for pre-service training and further training with regard to improving the quality of inquiry-based teaching.

2 Conceptual framework

2.1 Inquiry-based approach in primary schools

Some researchers regard inquiry-based teaching elements as an appropriate basis for high-quality science education (Kahlert et al., 2015; Knörzer et al., 2019). Despite controversial debates around the role of inquiry-based teaching (Strat et al., 2024), there is broad consensus that this approach, when adapted to a target group and modeled in a didactically appropriate manner, encourages learners to systematically address life-world connecting issues (Carroll, 1989; Hartinger and Lange-Schubert, 2020) and engage with them in a critical and reflective manner (Anderson, 2002; Crawford, 2014; Furtak et al., 2012). Depending on the context, didactic orientation, and focus of the objectives, inquiry-based educational approaches are defined in a variety of ways (Minner et al., 2010; Rönnebeck et al., 2016). Anderson (2002) conceptualizes inquiry-based learning processes on three contextual levels: (1) profession-related in the research work of a person engaged in scientific activity, (2) learning process-related through active student participation, whereby learners acquire conceptual and procedural knowledge in the application of inquiry-based methods and understand the nature of science, and (3) the subject-specific teaching approach as a method in itself, which a teacher can use as a pedagogical tool to initiate learning processes. Due to the present study's primary school teacher focus, this study mainly refers to the third point.

2.2 Inquiry-based learning

Deepening understanding of scientific content and topics is the core idea behind the inquiry-based learning approach (Crawford, 2014; Kleickmann, 2012; Teig, 2022). According to Crawford (2014), science teachers are encouraged to arrange specific learning opportunities so that learners can practice various inquiry-based aspects. This includes asking research questions, planning and conducting investigations, or interpreting data as evidence. It also encompasses developing arguments, creating models, and communicating results, which in turn is supposed to improve their understanding of the natural world using logical reasoning and scientific evidence.

Multi-perspective approaches in science education also require that the focus is not merely on systematically and consistently going through idealized knowledge acquiring processes, but that interactive aspects play an equally important role (Möller, 2016; Steffensky and Neuhaus, 2018). Socially cooperative learning opportunities arise primarily in inquiry-based instruction through discursive exchange in varied social constellations and through the shared experience of project work (Hartinger and Lange-Schubert, 2020; Möller et al., 2006; National Research Council, 2000).

Inquiry-based science education in the primary school context, in the sense of an expanded understanding of subject didactics, thus encompasses both the repetition of cyclical inquiry phases and social-cooperative, metacognitive, and conceptual didactic design elements (Kahlert et al., 2015; Knörzer et al., 2019).

2.3 Primary school science teachers in inquiry-based teaching settings

When designing inquiry-based learning opportunities, both teachers and learners play an important role as interaction designers (Dobber et al., 2017; Furtak et al., 2012). Both of them being co-determining whether concepts are promoted and ultimately understood during a classroom inquiry-based intervention (Driver, 1995). In their meta-analyses, Dobber et al. (2017) show, however, that the type of teacher regulation contributes to the creation of a research attitude and is controlled within three levels of regulation, relating to a metacognitive, socio-cooperative, or conceptual level. Metacognition, in an inquiry-based context, is specifically understood as reflective thinking about one's own mental constructs. The extent of guidance and the degree of student involvement are regulated by the teacher in accordance with their learning group (Neubauer-Hametner et al., 2025; Dobber et al., 2017; Vorholzer and Von Aufschnaiter, 2019). For our study, we derive (and anticipate at this point) that the control levels, the degrees of teacher support, and the extent of student involvement are reflected in didactic instructional strategies that are used by science teachers consistently.

2.4 Inquiry-based instructional strategies

Inquiry-based instructional strategies (IQIS[1]) are evident in professional teaching through reflective, learning group- and goal-oriented lesson planning that aims to achieve the learning goals while taking into account the individual needs of the learners (Kahlert et al., 2015). According to Klauer and Leutner (2012), they are described as a meaningful combination of methods, techniques, and procedures that may be regarded as conscious design decisions made by teachers. The high degree of freedom in Austrian primary school science merits the use of diverse instructional strategies to adapt inquiry-based learning processes.

2.4.1 Demonstrating IQIS

Demonstrating IQIS focus on promoting conceptual knowledge and understanding and initiating metacognitive higher-order thinking processes (Baumert et al., 2010; Minner et al., 2010). They are characterized by transmissive teaching and learning beliefs, according to which the science teacher is the key figure in instruction. Due to the highly guided nature of the teaching activities, learning content is predominantly acquired through individual work. It is pre-structured and is preferably carried out by learners through cognitive activity. The teacher acts as a moderator and supports the inquiry-based learning. This is done by incorporating learning materials as teaching resources, guiding natural observations, demonstrating investigations, introducing new concepts, and summarizing acquired fact knowledge, and using in a learning opportunity to link conclusions from previous investigations. Demonstrating IQIS focuse on the acquisition of basic knowledge that may later be used for more demanding thinking and problem-solving processes (Mayer, 2004; Möller, 2016). Referring to Sweller's (1988) theory of cognitive load, Kirschner et al. (2006) argue that structured and guided teaching is particularly important in primary school science education. Their study shows that this type of IQIS can reduce high cognitive load and boost student performance. Furthermore, findings from instructional quality research report positive learning effects related to demonstrating IQIS, especially for learners with unfavorable learning conditions (Decristan et al., 2016; Ewerhardy et al., 2012; Fauth et al., 2019).

2.4.2 Connecting IQIS

Connecting IQIS to the learners` realities is considered a central principle in primary school didactics and methodology (Nießeler, 2015; Schultheis, 2015). This principle is particularly salient in science education with regard to the selecting and prioritizing both content and learning goals. Strategies for applying this principle are characterized by how teachers view encountering the world and shared social experiences as constitutive elements, thereby enabling authentic learning about the world (Kahlert et al., 2015). Science Teachers would also activate prior knowledge, link it to new content, and include field work as well as materials. Diversity of perspectives and student participation are guiding principles for these strategies. Based on Carroll's (1989) conceptual model of lifeworld connecting instruction, studies show positive relationships with student performance, motivation, and engagement when authentic learning opportunities on topics relevant to the learners' life worlds are offered (Treviño and Carrasco, 2025).

2.4.3 Involving IQIS

In primary school, IQIS focusing on learner involvement are characterized by constructivist teaching and learning beliefs and by promoting scientific reasoning. Accordingly, the learners` engagement with knowledge acquisition is emphasized (Marquardt-Mau, 2011), and their metacognitive, socially cooperative and conceptual learning processes are facilitated, resulting in an authentic learning experience. Important phases in the learners` active involvement include designing, planning, conducting, and guiding experiments, as well as interpreting and presenting data, which the learners actively experience being part of a research team (National Research Council, 2000, 2012; Pedaste et al., 2015; Rönnebeck et al., 2016). A positive association with achievement and motivation, for instance, has been generally shown by Furtak et al. (2012), Minner et al. (2010), and Schroeder et al. (2007). It is suggested by Teig et al. (2018) that this is only the case when experiments are used with moderate frequency. According to Aditomo and Klieme (2020), however, these effects appear to be dependent on the context.

2.4.4 Cognitively activating IQIS

Instructional strategies that activate cognitive processes are based on constructivist and transmissive teaching approaches and strive at stimulating deeper understanding in order to promote higher-order thinking (Baumert et al., 2010; Sliwka et al., 2022). The focus is on engaging learners with challenging tasks, which encourage learners to go beyond what they have learned, find their own solutions to problems, and adopt a meta-level perspective. Individual solutions would then be discussed in the learners` own words in research teams. The science teacher guides such processes by alternating between metacognitive, social, and conceptual approaches (Brophy, 2000; Klieme et al., 2006; Mayer, 2004). Research findings suggest strong associations between cognitively activating IQIS and achievement as well as motivation (Baumert et al., 2010; Klieme et al., 2009; Lipowsky et al., 2009; Seidel and Shavelson, 2007).

2.5 Adaptability as a characteristic of professional lesson planning

For primary school teachers, adaptive instruction, tailored to individual learners` needs, is an indispensable professional competence (Brühwiler and Vogt, 2020; Corno, 2008). Adaptive instruction, both on the micro and macro level, requires structured planning and implementation, and it presupposes a professional diagnostic view of the learning group (Beck, 2008; Beck et al., 2008; Corno, 2008). Science classes at primary school level provide an ideal object of study for this. As a non-standardized subject in many primary school education contexts, science classes often favor adaptivity teaching (Hardy et al., 2011). The subject-specific nature of the primary school science classes allow teachers to exercise a high degree of freedom in selecting content, methods, and approaches, enabling them to set multi-perspective and interdisciplinary educational priorities (Beck et al., 2008; Einsiedler, 2015; Giest et al., 2017; Hardy et al., 2019; Klieme and Warwas, 2011; Knörzer et al.,

1 For simplicity, we will now apply the abbreviation IQIS for *InQuiry-based Instructional Strategies*.

2019). In addition, the Austrian context is characterized by the class teacher principle, according to which the teacher often provides instruction in all subjects in a class. However, there are only a few studies for this specific context that examine how science classes in primary schools are taught adaptively.

2.6 Perception in educational contexts

2.6.1 Perception of class characteristics

Teachers are faced with the daily challenge of adapting their instruction to the learning needs of their learning groups in order to make both anticipatory and situation-specific decisions (Borko et al., 2008; Escudero and Sánchez, 2007; Jacobs et al., 2011; Jacobs and Empson, 2016; Shavelson, 1983). The development of perceptual skills is essential in this regard (Santagata and Yeh, 2016). Perception is generally considered subjective, distortable, and influenceable, and it needs to be professionalized, especially in the educational context (Sherin et al., 2008; Sherin, 2007). On the one hand, perception is inevitably shaped by interindividual personality traits of the teacher themselves (Blömeke et al., 2022), and on the other hand, it may be determined by experience, professionalization measures, and external factors (Auwarter and Aruguete, 2008; Harfitt, 2012; Robinson-Cimpian et al., 2014). Studies on teachers' perceptions seem to use the term ´perception´ inconsistently, with perception and expectations used synonymously or diametrically, for instance (Brandmiller et al., 2020). Stahnke et al. (2016) provide a useful systematic overview of perception studies, drawing in particular on the PID model by Blömeke et al. (2015), some research conceptualizes perception as "teacher noticing" (Jacobs et al., 2011; Sherin et al., 2011), "responsive teaching" (Dyer and Sherin, 2016; Jacobs and Empson, 2016; Zimmerman, 2015) or "professional vision in action" (Sherin et al., 2008).

In our study, we go one step further and treat general perception as the teacher's current assessment and evaluation of specifically perceived learning group characteristics against the background of adaptive instruction that takes into account the interindividual learning needs of the entire learning group. In our study, we draw on characteristics of learners that are generally considered problematic by teachers, such as lack of prerequisite knowledge, classroom disruptions, lack of motivation, and limited language proficiency.

2.6.2 Perception as an empirical focus

The practice of using student ratings as a basis for measuring instructional quality is now well established (Fauth et al., 2014b; Finefter-Rosenbluh et al., 2021; Lüdtke et al., 2009; Oppermann and Lazarides, 2021). However, only a few studies focus on teachers' general perceptions of their learning group (Brandmiller et al., 2020; Ready and Chu, 2015; Ready and Wright, 2011; Robinson-Cimpian et al., 2014). Others suggest that teachers make situation-specific decisions in response to students' content-specific reasoning and thus continuously adapt instruction to students' needs (Jacobs et al., 2011; Jacobs and Ambrose, 2008; Sherin et al., 2008; Zimmerman, 2015). A quantitative study by Brandmiller et al. (2020) showed, however, that teachers are not unbiased toward students and that their perceptions of particular student characteristics, such as cognitive abilities, learning motivation, and behavior, vary depending on socioeconomic background, migration status, and gender. In a similar vein, other studies report teachers displaying a somewhat distorted perception of their learners, depending on social status, assessed abilities, and gender (Auwarter and Aruguete, 2008; Hamre and Pianta, 2005; Ready and Wright, 2011; Robinson-Cimpian et al., 2014; Timmermans et al., 2015) and class size (Harfitt, 2012). All in all, we could not find studies that relate instructional quality to characteristics of lesson design from the teachers' perspective. Based on the lack of research and the findings of these studies, it can be assumed that teachers design their instruction according to their perceptions of their learners' characteristics and use strategies that they consider useful for addressing perceived problems.

2.7 Challenges for science teachers in primary school

Although inquiry-based learning is considered a hallmark of high-quality science instruction, it is regarded as a challenging teaching principle, particularly in primary schools (Abd-El-Khalick et al., 2004; Crawford, 2000; Lee and Songer, 2003). Some studies show that teachers can find the preparation and implementation of inquiry-based learning challenging, overwhelming, and demanding (Appleton, 2007).

Empirical evidence shows that primary school teachers not only use constructive strategies but likewise resort to evasive or avoidance strategies (Appleton and Kindt, 2002; Harlen, 1997; Appleton, 2003). Potential reasons proposed for such a behavior are insufficient professional knowledge (Appleton and Kindt, 2002; Dunker, 2016; Mulholland and Wallace, 2000; Tosun, 2000), overly complex preparation and implementation of materials (Deters, 2004; Hogan and Berkowitz, 2000; Keys and Kennedy, 1999; Wallace and Kang, 2004), insufficient estimation of student abilities (Crawford, 2000; Jahnke-Klein and Busse, 2019; Windschitl, 2004), or explicit and implicit theories about the value of science (Appleton and Kindt, 1997; Harlen, 1997; Levitt, 2001) or the evaluation of the specific didactic teaching settings (Crawford, 2000; Deters, 2004; Keys and Kennedy, 1999).

Due to the high degree of freedom in science education in Austria, we assume that both constructive and avoidance strategies can be well observed empirically in this particular type of instructional setting.

2.8 Teacher characteristics as indicators of instructional quality

Empirical studies show that factors such as formal educational level, teaching experience, and willingness to participate in continuing further training may influence the quality of lesson design (Blömeke et al., 2016; Blömeke and Olsen, 2019; Darling-Hammond et al., 2017; Nilsen and Gustafsson, 2016). With regard to Austrian science teachers, Mistlberger (2023) was able to show that science teachers with more teaching experience use demonstrating IQIS significantly more often and that teachers willing to participate in continuing further trainings design involving and demonstrating lessons significantly more often. According to the study by Joffres and Haughey (2001), a decline in primary school teachers´ commitment can be explained by low self-efficacy or a lack of community spirit within the teaching team. Negative teaching experiences also influenced commitment depending on their perceived level of failure in the classroom.

Building on these empirical findings, we broaden the concept of inquiry-based learning in primary schools from a one-dimensional view on epistemological cyclical sequences to multi-perspective interaction processes. We integrate aspects of adaptive teaching concepts in conjunction with teacher perceptions, the challenges of inquiry-based instruction, and teacher characteristics, and examine their associations with a view to qualitative science teaching in primary school.

3 Research questions and hypotheses

The following research questions derived from this broadened theoretical framework, guide our empirical study:

> *RQ1:* Which IQIS are used by science teachers in Austria and how often are they applied?
>
> *RQ2:* (a) Is there a relationship between the frequency of inquiry-based instructional strategies and the perception of challenging characteristics of class composition, class performance, and motivation, and (b) is this related to teacher characteristics?

Based on teacher studies on avoidance behavior by Appleton (2003) and Harlen (1997) we expect that primary school teachers generally make little use of inquiry-based instructional strategies and that involving strategies are used the least (H1). Based on the results of perception studies by Brandmiller et al. (2020), Hamre and Pianta (2007), and Sherin et al. (2011), we hypothesize that the principle of adaptivity will be evident in the classes tested and that teachers will adapt their instruction to the characteristics of their classes (H2). We also expect that involving IQIS will be used more frequently in classes with high average achievement and high motivation, as this is a particularly cognitively demanding learning setting and teachers use it more frequently and in a more targeted manner in classes with better learning conditions (H3). Based on the findings of the study by Jahnke-Klein and Busse (2019), we further assume that perceived language proficiency deficits among students have a negative influence on the use of actively involving research strategies (H4). As Blömeke et al. (2016), Darling-Hammond et al. (2017), and Nilsen and Gustafsson (2016) found, we hypothesize that teachers who are willing to participate in continuing further training and have completed specific training in inquiry-based teaching use all four IQIS significantly more often, regardless of perceived problematic class characteristics, especially those that are involving (H5). Based on the study by Mistlberger (2023), we assume that experienced teachers who have been in the profession for longer tend to use demonstrating (teacher-centered) strategies (H6).

4 Methods

4.1 Data and sample

We analyzed data from the Austrian 4th grade teacher and student sample of the TIMS study in 2019. The Trends in International Mathematics and Science Study is an international large-scale assessment that measures and compares the mathematics and science achievement of fourth and eighth graders in a four-year cycle (Mullis and Martin, 2017; Martin et al., 2020). The sample we used comprises $n_s = 4{,}966$ fourth graders ($M_{age} = 10.4$ years) in 302 classes from 192 schools. To enable an analysis of nationally representative data at the student level, a two-stage sampling procedure was used. In the first step, all target schools were stratified according to the most important demographic variables and then randomly selected, with larger schools having a higher probability of selection. In the second step, at least one of the target classes in each selected school was randomly selected, with each class (within the same school) having the same probability of selection (see Martin et al., 2020/TIMSS 2019 Technical Report). The teacher who had provided science instruction for at least 1 year prior to the assessment was then asked to complete a questionnaire (Itzlinger-Bruneforth et al., 2020). All students and science teachers were intended to participate once their class had been selected. The selection of the sample was closely monitored to ensure high quality standards (Martin et al., 2020).

The teacher sample includes data from $n_t = 339$ science teachers in 302 classes. For the analysis, all data were weighted at the class level (SCIWGT). In the case of team teachers, both science teachers completed the questionnaire and their responses were averaged. However, the number of team teachers is so small ($n = 37$) that it has only a minor impact on the results presented. Since the teacher sample interrelates with the student sample, it is not representative of the population of science teachers in Austria. However, for the present study, it may be argued that representativeness is given because the student sample is representative and we can hardly imagine a plausible inducement why the teachers of these representative students should differ from teachers overall. Missing values were replaced by multiple imputation, resulting in five imputed data sets. For each analysis, the complete data sets were analyzed separately, and the results of the analysis were combined according to Rubin's (1987) formulas.

4.2 Material

4.2.1 Scaling IQIS

Four scales for measuring inquiry-based instructional strategies (IQIS) are used as dependent variables in our analysis: (1) demonstrating, (2) connecting, (3) involving, and (4) cognitively activating. Conceptually, we build on the classic "inquiry cycle" of Pedaste et al. (2015), and the meta-analyses of Rönnebeck et al. (2016), and expand the scope of other empirical studies that use TIMSS (Blömeke et al., 2016; Gustafsson and Nilsen, 2016; Scherer and Nilsen, 2016). Only those strategies that follow the classical epistemological inquiry process (Teig et al., 2019) were traditionally considered representative of scientific inquiry. Our "involving" scale represents this dimension. For our broadened approach, we apply 21 items from the *Sciences Teaching to the TIMSS Class* and *Teachers' Emphasis on Science Investigation* scales from the TIMSS questionnaire for science teachers (Mullis et al., 2020/TIMSS 2019 Context Q-Scales; Chap. 16), in which teachers could indicate the use of inquiry-based learning opportunities in various social forms according to their estimated frequency of use (never = 0, occasionally = 1, in half of the lessons = 2, in every or almost every lesson = 3).

As with other scales in TIMSS (e.g., Mullis et al., 2016), we constructed the scales using IRT scaling methods with the aim of measuring a single underlying latent construct. To this end, we applied the partial credit model (Masters, 1982, 1988) using the PROC-IRT procedure from SAS/STAT®Version 14.1 of the SAS system for

Windows (SAS Institute Inc., 2015). The fit values, as shown in Table 1, can be considered acceptable.

Table 2 shows the step parameters for all polytomous items. Most items in all four scales are evenly distributed in terms of their degree of difficulty. Overall, the dispersion of the items is good compared to the distribution of the person parameters, although a slightly denser indicatorization in the middle range and a better differentiation between the different categories of the respective scale would be desirable. For this scale, the threshold parameters for the categories "E" and "H" for the items "presenting data" and "conducting experiments" do not appear to be clear. This raises concerns about the validity of the assumption of stochastic independence, as this would also conceptually indicate a deviation from the research community itself.

The internal consistency for the present sample was Cronbach's $\alpha = 0.69$ for *demonstrating*, $\alpha = 0.64$ for *connecting*, $\alpha = 0.91$ for *involving*, and $\alpha = 0.79$ for *cognitively activating*, which is in the acceptable range and thus within the range of the reference studies (Wagner et al., 2016). Table 3 shows descriptive associations and intercorrelations for the IQIS scales.

4.2.2 Measurement of the perception of class characteristics

To measure teachers' perceptions, we apply four items from the scale "Classroom instruction restricted by students not ready to learn": *lack of prerequisite knowledge*, *classroom disruptions*, and perceived *lack of motivation* for which studies from other contexts (e.g., Bellens et al., 2019; Decristan et al., 2016) support the assumption that they are related to teaching adaptations. Given the high proportion of second language learners in the Austrian context (19%) (see BMBWF, 2024), we have also included *limited language proficiency*. We assigned dummy codes to the three different response categories to distinguish between teachers who stated that "some" or 'all' students had challenges and those who stated that "this was not a problem at all." Table 4 shows the descriptions for the four variables.

We have not summarized the responses further, as the perceptions of composition reported require, at least conceptually, different instructional measures, with "some" indicating heterogeneity in the classroom and 'all' and "not at all" indicating homogeneity with varying challenges. It should be noted, however, that these measurements are not objective measurements of class composition, but rather provide valid insights into teachers' subjective reflections on the characteristics of their students and their own competencies in promoting adaptive instruction.

4.2.3 Science achievement und students' motivation

In order to control for "objective" characteristics of class composition, we included four measures that indicate the level and heterogeneity of the classes in terms of both achievement in science and motivation. For achievement in science, we applied from the TIMSS scale Science ($M = 522.06$, $SE = 2.58$) as both the class average and the standard deviation. For motivation, we additionally applied the class average and standard deviation for the scale "Students like science" ($M = 9.85$, $SE = 0.05$; for the items, see Mullis et al., 2020). In TIMSS, the performance scales and motivation scales are constructed using IRT scaling methods with the aim of measuring a single underlying latent construct (Martin et al., 2020).

4.2.4 Teacher characteristics as covariates

For teacher characteristics, we applied four indicators based on Blömeke et al. (2016) and Teig et al. (2019): (a) formal educational level, (b) teaching experience, (c) further training in science, and (d) specific further training in critical thinking and inquiry skills. Since the formal educational level of teachers may range from a teaching academy diploma, a diploma in education from a teacher training college, a Bachelor of Education from a teacher training college or a university of applied sciences, to a Master of Education from a university or university of applied sciences and a doctorate from a university, we distinguish between teachers with a qualification at ISCED7 (master's or equivalent level, 10.3%) or higher and teachers with a lower level (ISCED 5, short-cycle tertiary education; 38.8% or ISCED 6: bachelor's or equivalent level, 50.9%). For teaching experience, we coded the open questions on years ($M = 19.2$; $SE = 0.75$) as less than 5 years of experience (15.2%) and more than 5 years of experience (84.8%) to distinguish between novice teachers and others. For further training in science, we recoded the open-ended questions on hours ($M = 2.04$; $SE = 0.07$) into less than 6 h (68.8%) and more than 6 h of further training in the last 2 years (31.3%) to distinguish between highly motivated teachers and others. In addition, we applied information on whether specific training programmes in critical thinking and inquiry skills had been completed in the last 2 years to distinguish better-prepared teachers (yes = 24.2%) from others (75.7%).

4.3 Analysis

In order to examine the frequency of use of different IQIS, we first calculate descriptive statistics using the sample weighting SCIWGT. We then examined the percentage of students for whom teachers reported that the strategies were never, occasionally, in half of the lessons, or in almost every lesson for all four scales. For these scales, mean values were calculated and mean values of $0 \leq M < 0.5$ were categorized as "never," mean values of $0.51 \leq M < 1.5$ as "occasionally," mean values of $1.5 \leq M < 2.5$ as "in half of the lessons," and mean values of $2.51 \leq M \leq 2.5$ as "in every lesson." To model the relationship between teachers' perceptions of classroom composition challenges and the IQIS, we applied multiple regression models for the four separate IRT scales of the IQIS as dependent variables. For each

TABLE 1 Model fit statistics for IQIS-scales.

Criteria for model selection	Demonstrating	Connecting	Involving	Cognitively activating
AIC	70089.2	68419.3	35683.1	54587.2
BIC	70156.0	68474.9	35727.6	4635.5
Log likelihood	−35026.6	−34194.6	−17834.0	−27280.6

TABLE 2 Step parameters for items according to the IQIS-scales.

Demonstrating				Connecting			
Item	Resp. Cat.	*b*	(SE)	Item	Resp. Cat.	*b*	(SE)
Have students memorize facts	E	2.89	(0.69)	Do field work outside class	E	3.43	(0.58)
Students watch me demonstrate an experiment	E	2.06	(0.09)	Work in same ability group	E	2.80	(0.43)
Students watch me demonstrate an experiment	H	1.90	(0.04)	Bring interesting materials into the class	H	2.00	(0.08)
Use evidence to support conclusions	E	1.88	(0.23)	Do field work outside class	H	1.93	(0.09)
Have students memorize facts	H	1.84	(0.10)	Work in mixed ability groups	E	1.59	(0.15)
Read textbooks/resource materials	E	1.61	(0.10)	Work in mixed ability groups	H	1.58	(0.06)
Use evidence to support conclusions	H	1.45	(0.07)	Work in same ability groups	H	1.39	(0.07)
Observe phenomena and describe	E	1.19	(0.05)	Relate lessons to daily lives	H	0.20	(0.04)
Observe phenomena and describe	H	0.43	(0.04)	Bring interesting materials into the class	O	−0.29	(0.05)
Read textbooks/resource materials	H	−0.08	(0.05)	Link new content to students level	H	−0.71	(0.04)
Have students memorize facts	O	−0.19	(0.04)	Work in mixed ability groups	O	−0.74	(0.07)
Listen to me explain new content	E	−0.27	(0.04)	Work in same ability group	O	−0.79	(0.06)
Listen to me explain new content	H	−0.40	(0.04)	Relate lessons to daily lives	O	−1.54	(0.05)
Use evidence to support conclusions	O	−2.21	(0.05)	Link new content to students level	O	−1.88	(0.09)
Students watch me demonstrate an experiment	O	−2.88	(0.06)	Do field work outside class	O	−2.13	(0.05)
Read textbooks/resource materials	O	−3.32	(0.11)				
Listen to me explain new content	O	−3.74	(0.20)				
Observe phenomena and describe	O	−4.72	(0.23)				

Involving				Co-activating			
Item	Resp. Cat.	*b*	(SE)	Item	Resp. Cat.	*b*	(SE)
Plan and design an experiment	E	2.84	(0.04)	Complete challenging excercises and go beyond it	E	2.21	(0.06)
Interpret data from experiments	H	2.71	(0.05)	Encourage class discussions	E	1.67	(0.05)
Present data from experiments	E	2.36	(0.13)	Decide own problem solving procedures	E	0.95	(0.05)
Present data from experiments	H	2.35	(0.06)	Complete challenging excercises and go beyond it	H	0.60	(0.05)
Interpret data from experiments	E	2.12	(0.04)	Encourage class discussions	H	0.38	(0.04)
Conduct an investigation	H	2.08	(0.07)	Ask students to explain their answers	H	0.21	(0.04)
Conduct an investigation	E	2.06	(0.04)	Encourage students to express own ideas	H	−0.09	(0.04)
Plan and design an experiment	H	2.05	(0.05)	Decide own problem solving procedures	H	−0.95	(0.04)

(Continued)

TABLE 2 (Continued)

Involving				Co-activating			
Item	Resp. Cat.	*b*	(SE)	Item	Resp. Cat.	*b*	(SE)
Plan and design an experiment	O	−1.08	(0.08)	Encourage students to express own ideas	O	−1.54	(0.08)
Interpret data from experiments	O	−2.21	(0.04)	Ask students to explain their answers	O	−1.65	(0.06)
Present data from experiments	O	−2.26	(0.05)	Encourage class discussions	O	−3.93	(0.22)
Conduct an investigation	O	−3.08	(0.09)	Decide own problem solving procedures	O	−4.47	(0.52)
				Complete challenging excercises and go beyond it	O	−5.54	(0.59)

Response Category: E=every or almost every lesson, H=half of the lessons, O=occasionally.

TABLE 3 Frequency descriptive statistics and intercorrelations for the IQIS-scales.

IQIS	*M*	(SE)	Demonstrating	Connecting	Involving
Demonstrating	1.43	(0.03)	–	–	–
Connecting	1.56	(0.03)	0.46	–	–
Involving	0.98	(0.04)	0.48	0.45	–
Cognitively activating	1.93	(0.04)	0.28	0.57	0.37

TABLE 4 Descriptive statistics and intercorrelations for the items “teachers’ perceptions of class composition”.

Class characteristics perceived as problematic	Not at all		Some		A lot	
	%	(SE)	%	(SE)	%	(SE)
Lack of prerequisite knowledge	18.1	(2.7)	62.6	(3.1)	19.3	(2.2)
Classroom disruptions	29.5	(3.2)	53.4	(3.6)	17.0	(2.4)
Lack of motivation	41.7	(3.6)	51.3	(3.6)	6.9	(1.6)
Limited language proficiency	50.2	(3.5)	37.6	(3.6)	10.0	(1.9)

composition dimension, we use two dummy-coded variables (some, all) with “not at all” as the reference group. We calculated multiple regression models using PROC SURVEYREG from SAS/STAT® Version 14.1 of the SAS System for Windows (SAS Institute Inc., 2015). We then controlled for achievement and motivation measures of class composition (models 2 and 3) and teacher characteristics (model 4).

5 Results

Table 5 shows the proportion of students in Austria who, according to their teachers, experience varied inquiry-based instructional strategies with varying frequency. It shows that involving IQIS are used least frequently: 17.2% of students never experience involving IQIS and 74.8% only occasionally. In contrast, cognitively activating IQIS are the most common and are used in (almost) every lesson by 18.7% of all Austrian fourth graders and in half of the lessons by 56.3%. According to teachers, demonstrating IQIS are less common (in half of the lessons: 35.5% and in every lesson: 1.3%) than connecting IQIS (in half of the lessons: 47.3% and in every lesson: 1.5%).

To model the relationship between teachers’ perceptions of challenges related to class composition and IQIS, we analyzed the effects of these variables as covariates separately for the four IRT scales of inquiry-based instructional strategies. For better readability, we have summarized model 4 of the respective IQIS scales in a final regression model in Table 6. The characteristic values of models 1 to 3 are described below and can be downloaded as Supplementary material for verification purposes, but are not visualised.

The models that included only teachers’ perceptions of class composition (models 1) explained a small proportion of the variation (between 2 and 12%), while the complete models (models 4) explained a moderate proportion of the variation (between 17 and 25%). For all

TABLE 5 Frequency of IQIS use according to science teachers (Austrian 4th graders).

IQIS	Never		Occasionally		Half of the lessons		(Almost) every lesson	
Demonstrating	0.8	(0.6)	62.4	(3.5)	35.5	(3.4)	1.3	(0.6)
Connecting	0.2	(0.2)	50.9	(3.6)	47.3	(3.5)	1.5	(0.6)
Involving	17.2	(2.6)	74.8	(3.0)	5.5	(1.4)	2.5	(0.8)
Cognitively activating	0.0	(0.0)	25.0	(2.8)	56.3	(3.1)	18.7	(2.5)

scales, models that only take into account the measured class composition (models 2) explain a slightly higher proportion of the variance (between 6 and 15%) than model 1. The combined models of perceived and measured class composition (models 3) explain a moderate proportion of the variance (between 10 and 20%), with the R^2 value for all four scales being higher than for the respective models 1 and 2.

Teachers' perceptions of the challenges related to composition explain between 2 and 12% of the total variance (model 1). Significant regression coefficients were found for demonstrating, connecting, and cognitive-activating strategies, but not for involving strategies, where the sum of the indicators explained the variance rather than a specific indicator. With regard to the specific challenges related to composition, we ascertained that the perception of learners' prior knowledge did not have a significant influence on the scales. However, teachers who reported a high level of disruption in instruction were less likely to use connecting, demonstrating, and cognitively activating strategies. Teachers who perceive the limited language proficiency of all learners as a challenge reported more frequent use of connecting strategies. Teachers who perceive some unmotivated learners as a challenge are more likely to use cognitively activating strategies.

The measured class composition did not differ in terms of demonstrating strategies but did include connecting and cognitively activating IQIS. Here, the average motivation of the learners did not have a significant influence on the scales. The use of connecting, involving, and cognitively activating strategies is more likely to be reported in classes with higher mean science achievement. When controlling for teacher qualifications, we also ascertained that performance-related heterogeneity is significantly associated with less frequent use of cognitive activation strategies, while motivation-related heterogeneity is associated with more frequent use of involving IQIS.

Furthermore, we find some significant effects for the covariates of teacher quality, but without a clear pattern across all scales. Experienced teachers are less active in applying connecting activities than inexperienced teachers (model 4). Teachers who report having participated in specific training programmes on critical thinking or inquiry-based skills report less frequent use of demonstrating and involving strategies. On the other hand, more frequent participation in further training in science is associated with a higher likelihood of using all four IQIS strategies more frequently.

6 Discussion

The present study examined inquiry-based classes in Austrian primary schools for the first time. Inquiry-based science classes are characterized by multi-perspective approaches resulting from an intentional combination of metacognitive, social-cooperative, and conceptual instructional strategies to design a qualitative inquiry-based learning environments (Hartinger and Lange-Schubert, 2020; Kahlert et al., 2015). Using TIMSS data, we identified four IQIS (demonstrating, connecting, involving, cognitively activating) using 21 items from the teacher questionnaire, and examined their frequency of use in Austrian primary schools. In addition, the associations between teachers' perceptions of problematic class characteristics and the use of varied instructional strategies was examined, too, controlling for teacher characteristics. Conceptually, our study is broader in scope than previous secondary analyses of TIMSS data, which primarily model inquiry-based learning as a sequence of cyclical inquiry phases (Teig and Nilsen, 2022; Teig et al., 2018, 2019). Descriptive analyses show that science teachers in Austria pursue involving strategies at most occasionally, whereas demonstrating, cognitively activating, and connecting IQIS are used significantly more frequently. For involving and demonstrating strategies, it appears that less than 50% of learners routinely experience these strategies. Primary school teachers in Austria seem to avoid these strategies in comparison to cognitively activating and connecting IQIS. This is not surprising, as Appleton and Kindt (2002) and Harlen (1997) show, these strategies are time-consuming to prepare and cognitively demanding to implement. Whether this is actually avoidance behavior in the sense of Appleton (2003) and Harlen (1997) can be merely suspected here. Further qualitative studies would be needed to learn more about the motives of teachers.

The multiple regression analyses show significant relationships between the frequency of IQIS use and perceived challenges in instruction resulting from class composition characteristics and teacher characteristics. For the scales *connecting*, *involving*, and *cognitively activating* significant positive associations with average class performance emerged with regard to frequency of use. Given the level of demand of the instructional strategies, it seems plausible that science teachers use them particularly in classes with a higher overall level of performance. Furthermore, studies in classroom show that there are significant associations between the cognitive level of instruction (cognitively activating IQIS) and average class performance (Baumert et al., 2010; Blömeke et al., 2016; Fauth et al., 2019; Nilsen and Gustafsson, 2016; Teig et al., 2019). With the exception of the involving scale, we did not observe any associations with motivation that can also be found in classroom teaching research. We, however, found a small but significant positive association with motivation, which also appears to be heterogenous in itself, as illustrated by its SD.

When looking at the perception of challenging characteristics of the class composition, the results show that, when controlling for other characteristics, a lack of prerequisite knowledge does not have a significant relationship with the frequency of use of instructional strategies. However, it is evident that teachers who perceive limited of language proficiency in their classes use IQIS that connect to the real world significantly more often (connecting IQIS). This seems plausible against the backdrop of the discourse on designing language-sensitive science education (Wildemann and Fornol, 2016). However, we found

TABLE 6 Final regression model for all IQIS scales, perceived class characteristics, mean achievement, motivation, and teacher characteristics.

Impact factors on lesson design	Demonstrating		Connecting		Involving		Cognitively activating	
	b	(SE)	b	(SE)	b	(SE)	b	(SE)
Intercept	−0.100	(1.373)	−2.442	(1.144)	−3.994	(1.544)	−2.514	(1.411)
Class characteristics								
Lack of prerequisite knowledge								
Some learners	−0.095	(0.168)	0.042	(0.313)	−0.099	(0.168)	0.050	(0.210)
All learners	−0.010	(0.145)	0.041	(0.130)	0.108	(0.191)	0.039	(0.155)
Classroom disruptions								
Some learners	−0.167	(0.145)	−0.013	(0.123)	−0.092	(0.155)	−0.185	(0.148)
All learners	**−0.302**	(0.149)	**−0.317**	(0.148)	−0.243	(0.193)	**−0.362**	(0.158)
Lack of motivation								
Some learners	0.717	(0.132)	0.172	(0.129)	0.048	(0.145)	**0.324**	(0.163)
All learners	0.326	(0.223)	0.226	(0.186)	−0.025	(0.280)	0.424	(0.294)
Limited language proficiency								
Some learners	0.097	(0.145)	−0.195	(0.139)	−0.102	(0.173)	−0.097	(0.148)
All learners	0.236	(0.180)	**0.317**	(0.166)	0.201	(0.239)	0.176	(0.213)
Science class								
Mean achievement	0.001	(0.002)	**0.004**	(0.002)	**0.007**	(0.002)	**0.004**	(0.001)
SD achievement	−0.001	(0.001)	0.000	(0.001)	−0.001	(0.001)	**−0.001**	(0.001)
Mean motivation	−0.071	(0.079)	0.106	(0.070)	0.006	(0.089)	0.040	(0.080)
SD motivation	0.009	(0.025)	0.003	(0.026)	**0.063**	(0.036)	0.029	(0.025)
Teacher characteristics								
Formal educational level[a]	0.122	(0.129)	−0.115	(0.092)	0.036	(0.107)	−0.065	(0.099)
Teaching experience[b]	−0.004	(0.005)	**−0.012**	(0.005)	−0.002	(0.006)	−0.007	(0.004)
Further training in science[c]	0.073	(0.060)	0.044	(0.056)	**0.159**	(0.071)	0.064	(0.054)
Specific further training[d]	**−0.106**	(0.145)	0.000	(0.050)	**−0.131**	(0.173)	0.013	(0.067)
R^2	0.17		0.20		0.25		0.17	

Bold print = regression coefficient ($p < 0.05$); * < 0.1; ** < 0.05; *** < 0.01.
[a]Master or higher (0 = lower degrees).
[b]Five or more years of teaching experience (0 = less than 5 years).
[c]Hours spent in further trainings for science.
[d]Participation in specific further training for critical thinking or inquiry skills (yes = 2; no = 1; 0 = no participation).

no evidence that when language deficits are perceived on the part of the learners, this leads to less demanding inquiry-based science education being designed. The extent to which multilingualism is used as a resource or perceived as a deficit and influences the use of instructional strategies cannot be investigated with the available data.

The regression analyses further showed that cognitively activating IQIS are used more frequently when teachers describe motivation as problematic. In classes where demonstrating, connecting, and cognitively activating IQIS are used less frequently, classroom management is also described as challenging in terms of problems with disruptive learners. Against the background of the findings on instructional quality, it seems plausible that teachers who have problems with classroom management work on these and have less capacity to plan and implement complex, multi-perspective classes. In general, it seems that the effects are very small overall and cannot be statistically corroborated, particularly for the involving IQIS, due to the low variance in frequency of use. It would be useful to replicate these findings using optimized scales or qualitative analyses. Nevertheless, we interpret the findings as empirical evidence that primary school teachers in Austria use their degrees of freedom and adapt strategies for their inquiry-based instruction in accordance with their perception of the learning group. Our study thus extends existing empirical findings by Brandmiller et al. (2020), Hamre and Pianta (2007), and Sherin et al. (2011), who have investigated the perceptions of external characteristics of learners for individual diagnostics, suggesting that these interpretations may also be effective for classroom practice with regard to learning groups.

With regard to equity issues, this is worrying in two respects. First, in the present study 17.2% of learners never experienced involving IQIS in primary school science education. Second, it is evident that not only involving strategies, but also strategies that connect to the real world (connecting IQIS) and activate cognitive processes (cognitively activating IQIS) are used more frequently in high-performing classes. The danger of a scissor effect is evident here, as cognitively activating instruction has been proven to promote learning (Baumert et al., 2010; Klieme et al., 2006; Lipowsky and Bleck, 2019).

Unlike studies by Blömeke et al. (2016) and Nilsen and Gustafsson (2016) we find no evidence of significant associations between teacher characteristics and the use of cognitively activating IQIS in the Austrian sample. Likewise, no significant relationships were found with regard to teachers' formal training. However, differential associations with other indicators of teacher professionalism can be demonstrated for the other instructional strategies. Participation in continuing further training proves to be significant for the use of involving IQIS, as confirmed by the study by Darling-Hammond et al. (2017). Teachers who participate in continuing training also provide involving IQIS in their instruction more frequently. However, participation in specific training programmes on critical thinking and inquiry skills shows a negative association with both involving and demonstrating IQIS. We suspect that teachers who are active in continuing further training do not use IQIS more frequently, but rather in a balanced and meaningful combination. Furthermore, the study by Teig et al. (2018) shows that too frequent use of involving strategies may have a negative effect on student performance.

In addition, we find a significant relationship between teaching experience and the use of connecting IQIS. Teachers with more job experience use these significantly less often, and since this also includes field work activities. Joffres and Haughey (2001) suggest that the willingness to include field work decreases with increasing job experience. This issue would need to be investigated in further studies. Further associations, such as those shown in the bivariate analysis in Mistlberger's (2023) study, cannot be replicated in our multiple regression analyses.

The results of our study can be interpreted as initial empirical evidence that the general perception of class composition determines the frequency with which instructional strategies are used. If further studies are able to replicate this finding, there will be a need for more intensive discussion about reflexivity in teacher training and support measures in school practice. Pedagogical reflection skills are already part of teacher training (Schön, 1983; Stîngu, 2012). At the beginning of their training, prospective teachers should be provided with spaces where implicit theories can be expressed and then professionally reflected upon and constructively questioned. This would enable them to better cope with the challenges of a demanding learning environment and create space for reservations, fears, and doubts. Teachers need practical models and examples in both initial and continuing training to gain an idea of what inquiry-based learning might look like in everyday teaching. The study by Pawelzik et al. (2016) indicates that the effectiveness of internships can contribute to an increase in self-efficacy experiences in teacher training through qualitative practical experiences. We conclude from our study that a wide range of practical learning opportunities are needed in teacher training, characterized by phases of personal experimentation and reflection, in order to enable a smooth transition from active learners at university to supportive, inquiry-based learning facilitators in the classroom.

Teacher training studies by Dunker (2016) and Lipowsky (2010) indicate, however, that training programs only have the potential to reach teachers under specific conditions. In particular, teachers with many years of teaching experience who feel that they have been insufficiently trained for qualitative inquiry-based educational processes should have more opportunities to participate in tailor-made subject-specific training courses. A study by Heinrich-Dönges (2016) tried to identify conditions for successful training. The author cites personal interests and the opportunity to contribute to individual and school development issues as potentially effective factors. They might contribute to changing and further developing one's own instruction in a sustainable manner after the training series. Incorporating these approaches into the planning of future training programmes in science could help to strengthen teachers' self-confidence and improve their science achievement in a quality- and interest-oriented framework. We also ascertain that a supportive professional school community can be beneficial for teachers. Furthermore, we see it as the responsibility of school leaders to explore organizational structures that support primary school teachers in preparing inquiry-based learning arrangements for their instruction in a more motivated, time- and resource-efficient manner, thereby strengthening primary school teachers' self-concept. This may be a viable way forward to gradually address concerns about educational equity and equality.

A particular added worth of this study lies in its multi-criteria consideration of instructional strategies that should be used in inquiry-based science education. Furthermore, although the broader conceptual version and approach to inquiry-based educational processes through IQIS proved fruitful, the fundamental question arises as to whether a more extensive and meaningful structure is needed, which was not possible to map using the available data. Following the argumentation of Praetorius et al. (2020) and Kleickmann et al. (2020), it would be worth considering, for instance, supplementing strategies for instructional reflection and quality improvement or even for adapting, individualizing, and differentiating instruction in future studies. Given the growing importance of inclusive education, further research would shed light on how teachers in inquiry-based learning settings respond to the learning needs of students with special educational needs.

It should also be taken into account that the operationalization was theory-based and post-hoc. This results in limitations with regard to both the validity and the measurement characteristics of the scales used. The standardized response categories, which generically ask about the overall frequency of use in a school year, proved to be a challenge for the consideration of teaching elements. It would be worth considering asking about the weighting of instructional elements in content-related units. Furthermore, our IRT analyses for the "involving" scale, which maps core phases of cyclical inquiry models in its four items, show in particular that the items are not logically independent. An extension of the scale to include further indicators of involving teaching elements for instance support measures when learners lack ideas or have difficulty developing and formulating a personally relevant research question would be recommended for future studies, too. It should be noted that the scale used here for cognitive activation (cognitively activating IQIS) reflects generic and non-specific aspects of science education. The use of subject-specific scales for primary schools, such as those developed by Pedaste et al. (2021) would be desirable for future studies. There are further avenues for research to be explored. Mixed hierarchical modeling should be used, for instance, to examine the four IQIS-scales.

Further limitations must be taken into account when interpreting the results. Although participation in the standardized survey was voluntary for teachers, the questionnaire was quite lengthy. As a result, a biased response pattern in the sense of a lack of differentiation cannot be completely ruled out. In addition, the cross-sectional data only allow for a reflexive snapshot, but not a causal interpretation. However, this means that any changes that may have occurred during the school year cannot be considered. It should also be borne in mind that, for reasons of economy, large-scale assessments can only provide a superficial picture of constructs. As a result, deeper insights into the quality of varied learning arrangements are not possible. A particular limitation certainly affects in the operationalization of teachers' perceptions with regard to characteristics of class composition that are perceived as problematic. Although we consider the items to be suitable for drawing conclusions about teacher perceptions, it remains problematic that perceptions cannot be related to more objective indicators. In addition, the present analyses assume that perceptions are relatively stable. Qualitative and longitudinal studies would be needed to test these assumptions.

Despite its limitations, this study provides insights into interactions and instructional quality, and offers initial findings on the design of inquiry-based learning opportunities in primary school science education in Austria. This is particularly important given the ongoing need for research in this area. These findings should stimulate further research projects that distinguish between varying types of high-quality interaction in inquiry-based learning and may serve as a basis for further secondary analyses comparing countries.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because this is a secondary analysis of the TIMS study. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DN-H: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing, Resources, Data curation, Validation. HW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. DK: Methodology, Software, Supervision, Conceptualization, Data curation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. Open access funding provided by the University of Graz.

Acknowledgments

The authors would like to express their sincere gratitude to the University of Graz for generously providing the financial support that made the open access publication of this article in Frontiers in Education possible. This support reflects the university's strong commitment to fostering high-quality research and its dissemination within the international academic community. We would furthermore like to mention how, in order to enhance certain passages of text, we utilised the AI writing assistant DeepL.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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