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Studying the quality of inquiry-based teaching in science classrooms. A systematic video study of inquiry-based science teaching in primary and lower-secondary schools

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ABSTRACT
A large body of research has studied the role and potential of inquiry to increase the quality of teaching in science education. While much of this existing research is based on international large-scale assessment studies, we still lack a clear understanding of the factors that influence the quality of inquiry-based science teaching in actual classroom practices. In this paper, we operationalise teaching quality through an observation manual, and we drew on this manual to systematically analyse video data of instructional practices in 20 Norwegian science classrooms at the primary and lower-secondary school level (73 observed lessons and about 450 students). We identified varying quality in the individual inquiry phases and differences between primary and lower-secondary schools. We observed that primary-school students collected and documented data more systematically than lower-secondary students and that consolidations were slightly more emphasised and of higher quality at the lower-secondary than at the primary level. Moreover, our findings indicate that inquiry-based teaching gave students more freedom to make their own choices and increased the quality of student participation in the classroom. Based on our findings, we discuss how teachers can improve the quality of inquiry-based instruction and empower students in the classroom.

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Inquiry-based science teaching; video studies; teaching quality

Introduction

Inquiry-based teaching is ubiquitous in science education research and practice, with many national curricula promoting and implementing inquiry practices in the classroom. One reason for the broad adoption of inquiry practices is the belief that such practices can empower students and increase the quality of teaching – after all, inquiry

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practices in the classroom mirror those of working scientists (Bjønness & Kolstø, 2015; Cairns & Areepattamannil, 2019). Indeed, a large body of research has studied the role and potential of inquiry as a basis for quality teaching in science education (e.g. Estrella et al., 2018; Furtak et al., 2012; Teig, 2021). However, no agreement on what we mean by either inquiry or quality in science education has been reached yet (Crawford, 2014; Teig, 2021; Wittek & Kvernbekk, 2011).

Moreover, findings from international large-scale assessment studies, such as the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS), suggest that inquiry in the classroom has a curvilinear relationship with the science achievements of students: more inquiry does not necessarily lead to better achievements (Cairns & Areepattamannil, 2019; Chi et al., 2018; Teig, 2021; Teig et al., 2018). These findings point to the necessity of studying the *quality* of inquiry-based teaching since increasing the *frequency* of inquiry activities will not necessarily translate into better science achievements (Marshall et al., 2010).

However, studying the quality of inquiry-based teaching comes with methodological challenges (Teig et al., 2018). Many assessment systems build on the self-reporting of students and teachers whose perceptions of classroom practices can differ significantly (Fitzgerald et al., 2020). Moreover, not all international large-scale assessment studies focus on suitable units of analysis. For example, PISA looks at the student, school, and country levels rather than the classroom or teacher levels which are more appropriate units of analysis for studying the relationships between inquiry-based teaching and science achievement (Marsh et al., 2012; Teig et al., 2018). Not least, traditional standardised tests tend to focus on measuring student knowledge and meeting pre-defined criteria. However, such criteria often conflict with the broader aims of inquiry-based science, such as strengthening student participation, empowering students to take ownership of their learning or increasing students' understanding of the nature of science (Abd-El-Khalick et al., 2004; Erickson, 2015).

In response, researchers have called for a 'more qualitative perspective on these activities, such as through video observations [that] could provide deeper insights into the optimal quantity and quality of inquiry activities' (Teig et al., 2018, p. 28). Our study heeds this call and contributes to filling the gap: first, by suggesting a framework for quality teaching that operationalises critical – and observable – aspects of inquiry-based teaching through an observation manual. Second, by using this manual to present a thorough characterisation of inquiry-based instructional practices in 20 Norwegian classrooms at the primary- and lower-secondary-school levels. We aim to understand better the factors that influence the quality of inquiry-based teaching and use this knowledge to help teachers empower students in the science classroom.

Research questions

To guide our research, we pose the following questions:

RQ1. What characterises the quality of inquiry-based science teaching in the observed primary- and lower-secondary classrooms?

RQ2. What are the links between inquiry-based science teaching and the quality of student participation in the observed classrooms?

Based on the findings from these research questions, we wish to discuss how teachers can empower students through inquiry in the science classroom. We understand empowerment as the process by which students develop the skills, knowledge, and confidence to take ownership of their learning and engage actively in educational experiences (Erickson, 2015; Shor, 1992). In the next section, we link empowerment to our framework for quality teaching in science.

Educational background and theoretical framework

In the following, we briefly introduce the larger educational project in which this study is situated and present our framework for quality teaching. In this paper, we focus specifically on aspects of inquiry and student participation.

Linking instruction in science and student impact

The aim of the project Linking Instruction in Science and Student Impact[1] (LISSI) is to study how different forms of teaching may be related to how students learn science in primary and lower-secondary schools in Norway (Ødegaard, Kjærnsli, & Kersting, 2021). The background for the project was that the Norwegian Directorate for Education and Training wished to explore key findings and challenges identified by PISA and TIMSS in 2015 (Bergem et al., 2015; Kjærnsli & Jensen, 2016b). Among these findings were that students' competence and results in science, especially at the lower-secondary-school level, have not had as positive a development as reading and mathematics. Besides, teachers seemed to make little use of inquiry-based teaching. The studies also suggest that students' motivation decreases from primary to lower-secondary school. LISSI researchers wished to give context to these findings by studying the quality – as opposed to the mere frequency – of the instructional practices in science. The project's emphasis on inquiry was a deliberate choice because this form of teaching is central to instructional practices in the Norwegian and international contexts. In particular, the Norwegian curriculum invites teachers to use inquiry-based teaching across subjects.

A framework for quality teaching in science

Teaching quality is one of the most critical school variables that influence student performance and the success of educational systems (Hattie, 2009; Klette et al., 2017; OECD, 2005). Nevertheless, good science education comes in many forms. A framework for quality teaching in science needs to reflect the breadth and variety of good instructional practices in the science classroom. LISSI has chosen a framework for quality teaching with three fundamental pillars: **power to act**, **knowledge**, and **learning environment**. These pillars are divided into five teaching dimensions, each of which sheds light on essential aspects of good science teaching: *inquiry, facilitating student participation, content depth, cognitive activation,* and *classroom management* (Figure 1). Each dimension is further operationalised through observable indicators, which we present in detail in the next section.

We based the teaching dimensions and their respective categories on international research on what matters for student learning in science (e.g. Fauth et al., 2019;

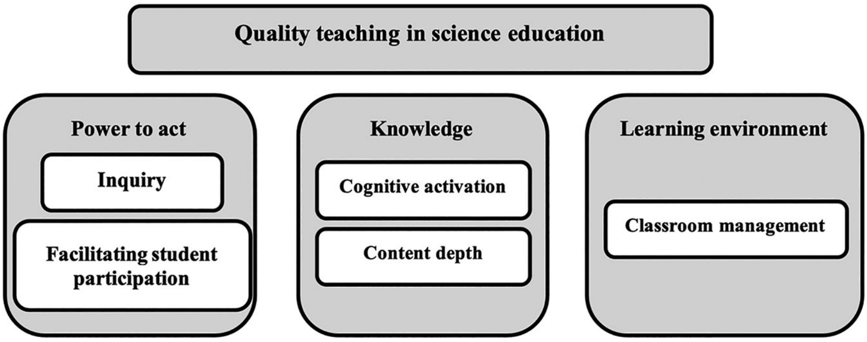

Figure 1. We conceptualise quality teaching in science education through three pillars: power to act, knowledge, and learning environment. The figure is adapted from (Ødegaard, Kjærnsli, & Kersting, 2021).

Neumann et al., 2012; Treagust & Tsui, 2014) and existing observation manuals for quality teaching (Grossman et al., 2013; Horton et al., 2009; Ødegaard et al., 2014). The overarching pillars build on a broad understanding of quality as transformation: 'the kind of transformative processes students (hopefully) go through in the course of their education,' (Wittek & Kvernbekk, 2011, p. 674). Such transformation can be brought about by empowering students (i.e. strengthening their **power to act**) and enhancing their **knowledge** (Wittek & Kvernbekk, 2011). A good **learning environment** is essential for empowering students and enhancing their knowledge. Together, the three pillars and five dimensions form a framework that suggests crucial factors for assessing the teaching quality in science education.

Since we are concerned with aspects of inquiry and student participation, we focus on the first pillar, power to act, for the rest of this study. Power to act is closely linked to our characterisation of empowerment[2] as a process that enhances students' participation and capacity for action: empowered students can take ownership of their actions, engage actively in educational experiences, and take responsibility for their learning (Erickson, 2015; Shor, 1992).

Inquiry-based teaching

Inquiry-based teaching has established itself as a broad tradition in science education, taking different forms in different contexts. Nevertheless, there are elements common to most inquiry models, including students wondering, asking questions, gathering information, investigating, observing, interpreting, discussing, and formulating explanations based on evidence (e.g. Barber, 2009; Bybee, 2000; Crawford, 2014; Keys & Bryan, 2001; Teig et al., 2018). Our framework compiles these elements into three distinct inquiry phases (*preparation, data collection, and consolidation*). It adds two more categories that capture science-specific aspects of inquiry: *nature of science* (NOS) and *degrees of freedom* (Figure 2). These last two categories focus on the extent to which teachers address NOS aspects explicitly and how much freedom and guidance the students receive.

Although 'inquiry has a decades-long and persistent history as the central word used to characterise good science teaching and learning' (Anderson, 2002, p. 1), research on

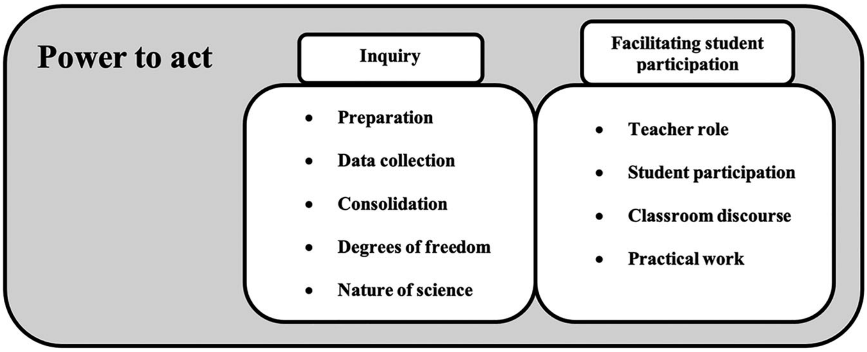

Figure 2. Our framework conceptualises inquiry and facilitating student participation as two dimensions of power to act (Ødegaard, Kjærnsli, & Kersting, 2021).

the relationship between inquiry-based teaching and science achievement has remained somewhat inconclusive. Some studies have demonstrated that inquiry activities positively affect science achievement and conceptual understanding (Hattie, 2009; Minner et al., 2010; Nilsen & Frøyland, 2016; Schroeder et al., 2007). Nevertheless, there is also evidence that frequent inquiry-based teaching can be negatively correlated with students' achievements (Cairns & Areepattamannil, 2019; Chi et al., 2018). This observation mirrors findings from research on experiments in science education. 'Student experiments per se do not result in better science performance (i.e. in better understanding of science concepts and principles), they do not incite a more pleasing development of interests in science and learning to understand science, and they do not support understanding science inquiry methods and views of the nature of science. It very much depends on how these experiments are staged' (Duit & Tesch, 2010, p. 23). Naturally, many factors have an impact on students' learning outcomes, including how teachers implement and structure inquiry activities, students' interests and their socio-economic backgrounds (e.g. Anderson, 2002; Bjønness & Kolstø, 2015; Hofstein, 2017; Teig et al., 2018).

Research design and methods

Data collection

LISSI followed a three-year mixed-methods research design to create a more comprehensive knowledge base for understanding the relationship between different types of instruction and the quality of science teaching (Ødegaard, Kjærnsli, Karlsen, et al., 2021; Ødegaard, Kjærnsli, & Kersting, 2021). In this paper, we focus on video data from the first round of classroom observations in which we recorded science lessons in ten primary and ten lower-secondary-school classrooms with about 450 students (circa 160 students in the 4th grade and 290 students in the 8th grade). Two video cameras were installed in each classroom, one aimed at the teacher and one at the students. Two microphones (one attached to the teacher, one positioned in the middle of the classroom) recorded the sound. We also installed two head cameras on students to capture group work. The observations lasted one to four weeks in each classroom, and in total, we observed 73 lessons. All students, their parents, and the teachers provided informed consent to participate in the research, and the Norwegian Centre for Research Data granted ethics approval.

Development of the observation manual

To operationalise quality teaching through observable categories, we developed an observation manual by combining three strategies from previous video studies (Neumann et al., 2012; Praetorius & Charalambous, 2018). First, we identified common features in existing observation manuals such as the Protocol for Language Arts Teaching Observation PLATO (Grossman et al., 2013) (PLATO; Grossman et al., 2013), the Electronic Quality of Inquiry Protocol EQUIP (Marshall et al., 2010), and the observation manual of the Budding Science and Literacy project (Ødegaard et al., 2014). Second, we selected relevant categories and adapted them to science teaching in line with the research literature on quality in science education (Fauth et al., 2019; Neumann et al., 2012; Treagust & Tsui, 2014). Third, we piloted and refined the categories over several cycles to improve the validity and reliability of the observation manual and ensure that it captures what we considered to be central characteristics of science teaching. At the start of the project, all LISSI researchers took a certification course in PLATO and became certified as reliable raters of the PLATO categories (Grossman et al., 2013). We coded video data separately as we added or created more categories and discussed our understanding of the new categories and subsequently coding thereof.

Since each category of the observation manual focuses on individual elements of teaching quality, we cannot expect that every lesson will achieve high codes in all categories. For example, a lesson focusing on consolidation will not achieve high codes in the data-collection category. Thus, it is essential to emphasise that good teaching comes in different forms, depending on the specific context.

Data analysis

We used the Mangold INTERACT software to analyse the video observations and took the recordings from the two stationary cameras as our starting point. Recordings from the students' head cameras were used where necessary to observe students' participation relevant to the coding. In the first step of the analysis, all teaching was divided into 15-minute segments that we coded with the observation manual. Each segment was assigned scores from 1 to 4 for each category, where a score of 1 indicates almost no evidence of the specific teaching practice, a score of 2 indicates limited evidence, a score of 3 indicates evidence with weaknesses, and a score of 4 indicates consistently strong evidence. Seven LISSI researchers coded the video data, and 20 per cent of the coded video material was coded independently by two researchers. Reliability was tested through percentage agreement between coders and by calculating Cohen's kappa. Reliability was generally satisfactory, with a kappa value above 0.6 (Ødegaard, Kjærnsli, Karlsen, et al., 2021). Tables 1 and 2 briefly summarise the observable indicators corresponding to lower or higher scores indicating lower or higher teaching quality for *inquiry* and *facilitating student participation*. We provide more detailed descriptions of each category when presenting our findings in the next section.

Table 1. The teaching dimension inquiry is operationalised through observable indicators corresponding to lower or higher scores indicating lower or higher teaching quality. Table adapted from (Ødegaard, Kjærnsli, & Kersting, 2021; Sæleset et al., 2022).

Inquiry categories	Scores 1–2	Scores 3–4
Preparation	No researchable questions, hypotheses, or predictions are developed. However, the teacher may activate students' prior knowledge or invite them to wonder about science.	A researchable question, hypothesis, or prediction is developed. The teacher or students may plan further inquiries.
Data collection	Students may perform observations or investigations with or without addressing a researchable question, hypothesis, or prediction. Data are not documented.	Students perform investigations to address a researchable question, hypothesis, or prediction. Data are documented and may be systemised.
Consolidation[4]	Students may discuss observations or data. However, while they may draw simple descriptions from them, no conclusions are made.	Students draw conclusions from observations or data. They may connect these to scientific theoretical knowledge and discuss the implications.
Degrees of freedom	The teaching only allows students to make up to one free choice regarding the formulation of questions, use of methods or interpretation of results.	The students make free choices regarding two or three of the following activities: formulation of questions, use of methods or interpretation of results.
Nature of Science	The teacher does not include NOS aspects or does not refer to these aspects explicitly.	The teacher explicitly refers to at least one aspect of NOS in the teaching. Connections between NOS and the lesson's content are clear enough to provide an understanding of NOS.

Since we aimed to study the quality of inquiry-based teaching, we took the coding of the 15-min segments as our starting point to identify those lessons that included inquiry activities. It usually takes at least one complete lesson to conduct inquiry activities that contain all three inquiry phases (preparation, data collection, and consolidation). Therefore, we chose lessons rather than the 15-minute segments as our unit for further analysis. We looked at all scores in the three inquiry phases for each lesson and selected the highest scores for preparation, data collection, and consolidation. Based on these three scores, we divided the lessons into three types: lessons with no inquiry, elements of

Table 2. The teaching dimension *facilitating student participation* is operationalised through observable indicators corresponding to lower or higher scores indicating lower or higher teaching quality. Table adapted from (Ødegaard, Kjærnsli, & Kersting, 2021; Sæleset et al., 2022).

Facilitating student participation categories	Codes 1–2 (low quality)	Codes 3–4 (high quality)
Teacher role	The teacher is the centre of the lesson or only occasionally facilitates student-student talk.	The teacher facilitates student-student talk rather than being the centre of the lesson.
Classroom discourse	If opportunities for student talk arise, science-related discussions are short or characterised by recitation. Teacher and student responses usually do not elaborate on or help develop students' ideas.	Open-ended science-related questions are discussed at some length. The teacher and students carefully listen to each other and elaborate on or help develop science ideas.
Practical work	If students interact with objects beyond materials for reading or writing, these practical activities are not tied to learning science concepts.	Students interact with objects beyond materials for reading or writing. Practical activities are connected to learning science concepts.
Student participation	Students are passive (e.g. take notes, read) or only to a small extent/for short periods active in their learning.	Students are involved in discussions, investigations, and other activities, and they may have a clear focus on the task at hand.

inquiry, and inquiry. Figure 3 presents the three steps of our data analysis that subsequently reduce the complexity of the data.

Findings

RQ1: What characterises the quality of inquiry-based science teaching in the observed primary- and lower-secondary classrooms?

To broadly characterise the inquiry practices in the observed classrooms, we divided the lessons into lessons with no inquiry, elements of inquiry and inquiry (Figure 4). In the

Step 1: coding 15-min segments of each lesson

Segment	0-15 min	15-30 min	30-45 min
Preparation	2	2	1
Data collection	1	3	2
Consolidation	1	2	3

Step 2: choosing the highest score in each inquiry phase

Lesson	Score
Preparation	2
Data collection	3
Consolidation	3

Step 3: dividing the lessons into those without inquiry, with elements of inquiry and inquiry

No inquiry	Elements of inquiry	Inquiry
All three phases have scores of 1 or 2.	One or two phases have scores of 3 or 4. The other phases have a score of 1.	One, two or three phases have a score of 3 or 4. The other phases have a score of 2.
Example: Preparation: 2 Data collection: 2 Consolidation: 1	**Example:** Preparation: 3 Data collection: 4 Consolidation: 1	**Example:** Preparation: 2 Data collection: 3 Consolidation: 3

Figure 3. We distinguish between lessons with no inquiry, elements of inquiry, and inquiry. This division is based on the lesson's highest-scoring segment for the three inquiry phases.

4th grade, we found 23 lessons with no inquiry, five with elements of inquiry, and nine with inquiry; in the 8th grade, we identified 18 lessons without inquiry, nine with elements of inquiry, and nine with inquiry. Figure 4 shows that about 25% of the 4th and 8th-grade lessons are inquiry lessons. In addition, the same number of lower-secondary school lessons has inquiry elements. In primary school, about half as many lessons have inquiry elements. This difference indicates that lower-secondary students have engaged in somewhat longer inquiry activities lasting for more than one lesson than students at the primary level. The number of lessons with no inquiry is relatively high and higher at the primary level than at the lower-secondary school level.

To obtain a more detailed picture of the quality of the different inquiry phases, we calculated the percentage distribution of the scores 1–4 for preparation, data collection, and consolidation in the lessons with inquiry and elements of inquiry (Figure 5).

The quality of preparation phases

Figure 5 shows that most inquiry lessons (with both inquiry and elements of inquiry) are coded 2 for the preparation phase. Score 2 implies that the teacher has invited the students to wonder about science phenomena or activated the students' prior knowledge. These are lessons where the students are active but not necessarily involved in inquiry-based activities. There were fewer lessons where students or the teacher developed questions, hypotheses, or a procedure for data collection (score 3). None of the lessons got a score of 4, in which students plan investigations based on their own questions or predictions. In summary, our analyses show that both primary- and lower-secondary-school students barely developed their own questions and hypotheses or planned their own investigations.

The quality of data collection phases

Figure 5 shows that the observed data collection phases were of good quality in both grade levels. Primary-school students engaged in higher-quality data collection (i.e. documenting and systemising data) more often than lower-secondary-school students.

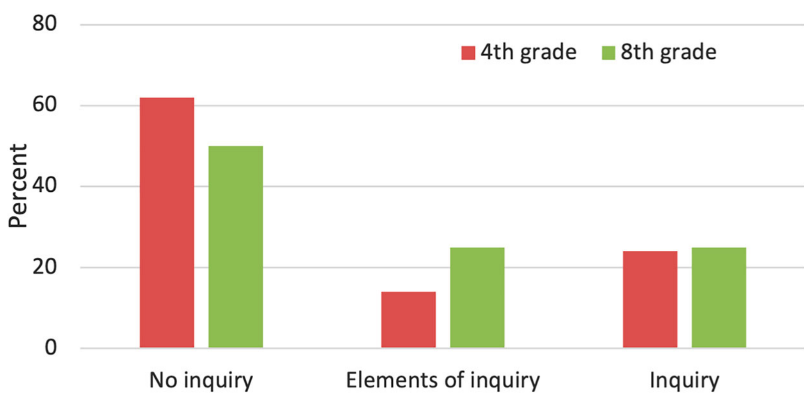

Figure 4. Percentages of lessons with or without inquiries or elements of inquiries for the 4th grade (37 lessons, red colour) and 8th grade (36 lessons, green colour).

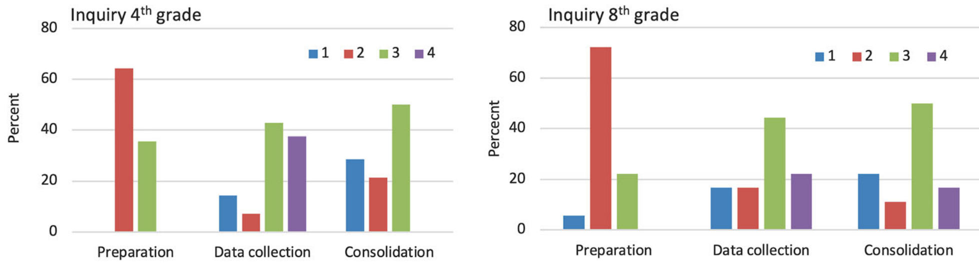

Figure 5. Percentage distribution of scores 1–4 in the lessons with inquiry and elements of inquiry for 4th grade (left, based on 14 lessons) and for 8th grade (right, based on 18 lessons) for the categories preparation, data collection and consolidation. Lower or higher scores correspond to observable indicators of lower or higher teaching quality.

Primary and lower-secondary-school students collected data in most of the lessons with inquiry and elements of inquiry (more than 80% scores of 2, 3 or 4 for the data collection phase). The data collected by the students came from both primary sources (observations and measurements) and secondary sources (books and the internet). About half of these lessons in the 4th and 8th grades were coded 3 for the data collection phase, corresponding to data collection based on a research question that is also documented appropriately. Further, our analyses show that almost the same amount of the 4th-grade lessons are coded 4 for the data collection, which implies that primary-school students systematised and categorised data quite regularly. Fewer lessons are coded 4 in the 8th grade.

The quality of consolidation phases

Figure 5 shows that consolidations[3] were slightly more emphasised and of higher quality at the lower secondary school than at the primary-school level. Two-thirds of the lessons with inquiry and elements of inquiry in the 8th grade have high-quality consolidations (score 3 or 4), where students draw conclusions from observations or data, may connect these to scientific knowledge, and discuss implications. In 4th grade, only about half of the lessons showed students that drew conclusions from data (score 3), but the conclusions were not related to scientific knowledge or implications (score 4). In primary school, half of the lessons were of low quality, meaning that students either did not discuss observations and data at all (score 1) or only provided simple descriptions of their observations and data without drawing conclusions from them (score 2). For students in lower-secondary school, the consolidation pattern is similar to that in primary school, except that fewer lessons got scores of 2, indicating that when consolidating activities took place, they were of higher quality.

Degrees of freedom in inquiry

Degree of freedom describes how many choices students can make during the inquiry activity. Formulating questions and hypotheses, using methods, or interpreting results each counts as one degree of freedom. Figure 6 shows that in a significant part of the lessons with inquiry and elements of inquiry, the students only had one degree of freedom (score 2). In such lessons, the teachers told the students what to do most of the time, and the students were involved in developing questions or planning investigations only to a small extent. In only a few lessons, the students were responsible for developing two inquiry activities (questions, methods or interpretations) that correspond to two degrees of freedom (score 3). We did not observe any lessons where the students had complete freedom of all the inquiry activities (score 4). We found that students had more freedom when acquiring information from secondary sources, such as books and the internet, than from collecting data during practical activities. Primary data was often collected according to a given recipe when students did practical work.

Interestingly, when it comes to the distribution of teaching where students have no freedom to make their own choices (score 1), we see a marked difference between lessons without inquiry and lessons with inquiry or elements of inquiry (Figure 6). Our analysis of the lessons with no inquiry showed that almost half had no *degree of freedom* in both the 4th and 8th grades, indicating that inquiry-based teaching gave students more freedom to make their own choices in the classroom.

Nature of science related to inquiry

Figure 7 shows that for lessons without inquiry, more than 90% of the teaching got low-quality scores (1 and 2) for NOS. In this type of instruction, the teacher does not include NOS aspects or refer to these aspects explicitly. In contrast, we observed that teachers emphasised different aspects of the nature of science in lessons with inquiry or elements of inquiry, such as the distinction between observations and inferences or that science is empirically grounded and tentative. Our analyses show that in more than a third of all lessons, the teachers were not explicit about these aspects in their teaching (score 2). However, in about a third of the lessons with inquiry and elements of inquiry, the teachers referred explicitly to at least one aspect of NOS and made a connection to the lesson content that was clear enough to provide an understanding of NOS (code 3). For example, the teachers explicitly mentioned and discussed with students that scientific models build on observations and that researchers must conduct investigations to obtain evidence and build scientific knowledge. Finally, we did not observe any lesson in which

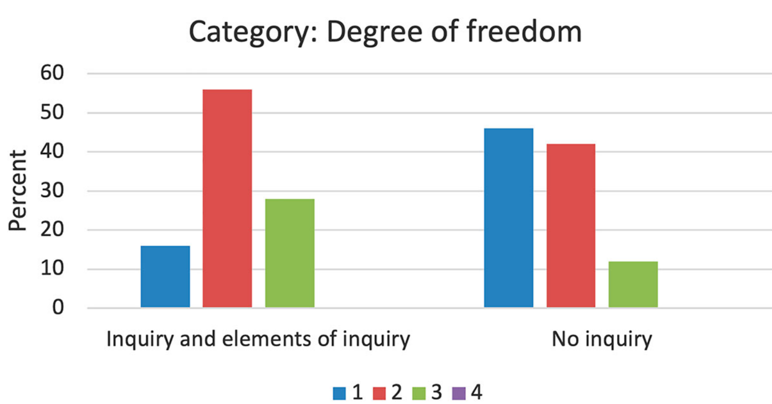

Figure 6. Percentage distribution of scores 1–4 for the lessons with inquiry and elements of inquiry (14 lessons for 4th and 18 lessons for 8th grade) and lessons without inquiry (23 lessons for 4th and 18 lessons for 8th grade) for the category degree of freedom.

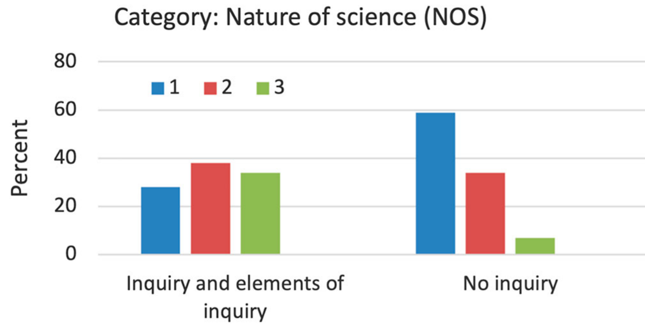

Figure 7. Percentage distribution of scores 1–4 for the category nature of science (NOS) in the lessons with inquiry and elements of inquiry (14 lessons for 4th and 18 lessons for 8th grade) and lessons without inquiry (23 lessons for 4th and 18 lessons for 8th grade).

teachers facilitated a deeper understanding of NOS (score 4). Such deeper understanding is characterised by both teachers and students explicitly referring to aspects of NOS. For example, students might reflect on how their inquiry activities resemble research-like activities, comparing their data collection with actual scientific exploration, or recognising the distinctions between observation and inference in their own arguments.

RQ2: What are the links between inquiry-based science teaching and the quality of student participation in the observed classroom?

Our study aimed to investigate whether and how inquiry-based teaching can lead to a higher quality of student participation in the classroom. Therefore, we turned our attention to the dimension *facilitating student participation* (Table 2) and compared the coding of each category in this dimension for lessons with no inquiry, elements of inquiry and inquiry. Figures 8 shows that, by and large, lessons with inquiry or elements of inquiry had higher quality for the categories of *classroom conversations*, *teacher role*, *student participation*, and *practical activity* than teaching with no inquiry. Thus, inquiry-based teaching increased the students' participation in the observed classrooms.

Figure 8 shows that inquiry teaching and teaching with elements of inquiry have classroom discourses of higher quality (i.e. more scores of 3 and 4) than teaching without inquiry. This observation implies that the students in lessons with inquiry and elements of inquiry were more involved in open-ended science-related questions and discussions. In these lessons, teachers and students also encouraged each other to explain, argue for and develop their ideas.

Likewise, our analyses of the teacher role show that teachers facilitated more joint activities or talk between students in lessons with inquiry and elements of inquiry than in lessons without inquiry. Figure 8 shows that almost all lessons with inquiry scored 4 for this category, indicating that the teachers consistently and effectively facilitated activities and conversations between the students. For lessons with no inquiry or elements of inquiries, we have lower scores for this category. Broadly, lower scores for the category teacher role denote instruction in which the teacher often is the centre of the lesson or only occasionally facilitates activities and student-student talks.

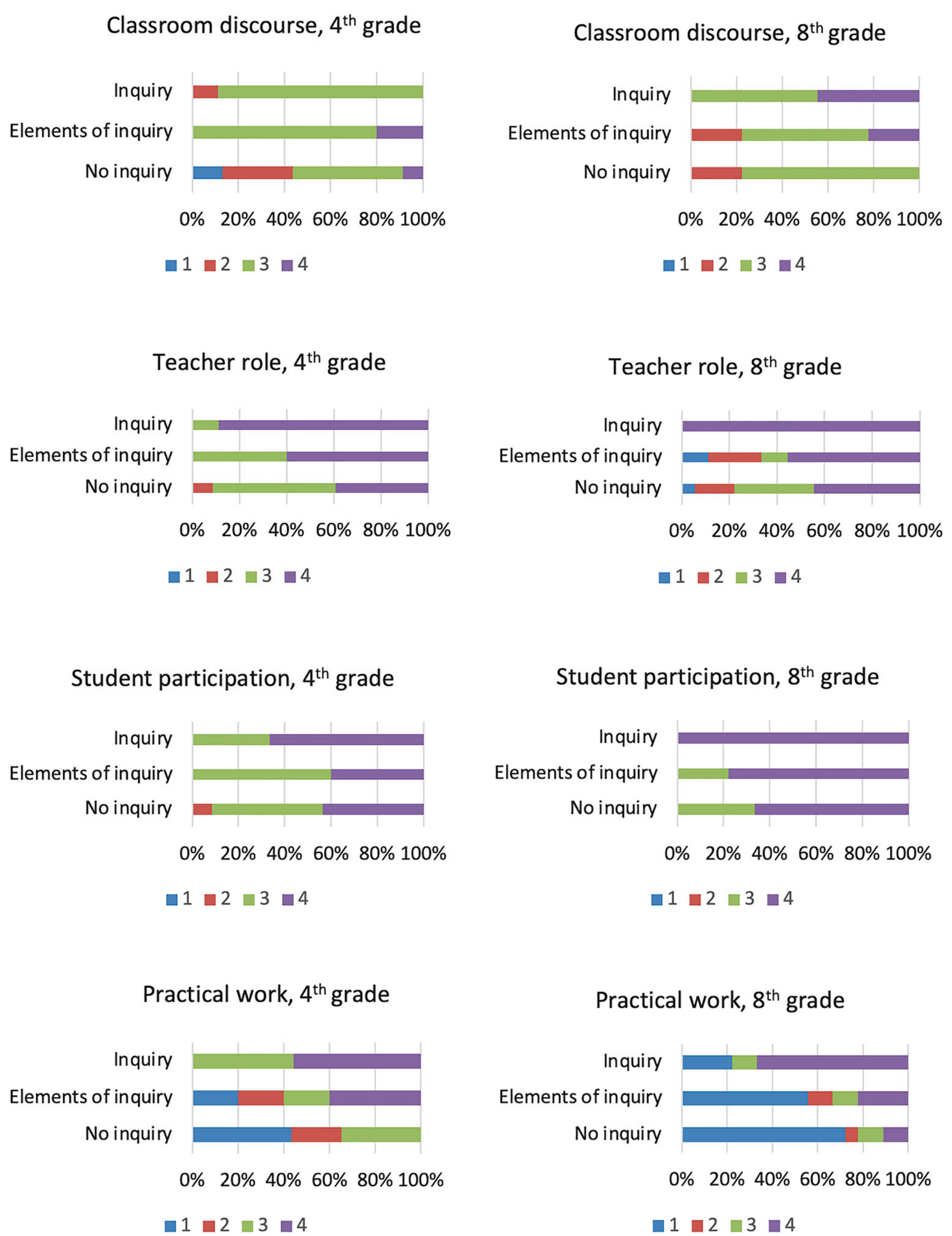

Figure 8. Percentage distribution of code 1–4 in the lessons with no inquiry (23 for 4th and 18 for 8th grade), elements of inquiry (5 for 4th and 9 for 8th grade) and inquiry (9 for 4th and 9 for 8th grade) for the category classroom discourse, teacher role, student participation and practical work.

Furthermore, we see an increasing quality of student participation in lessons with an increasing degree of inquiry. In the category student participation, more inquiry lessons got high scores of 4 than lessons with elements of inquiry or without inquiry. This observation implies that the students were more often involved in discussions, investigations, and other activities in inquiry lessons than in lessons with elements of inquiry or without inquiry. This finding is consistent with our analysis showing that the students engaged in practical work more often during lessons with inquiries than lessons without inquiries. More scores of 3 and 4 for inquiry lessons show that the practical work was more often linked explicitly to learning science concepts. Thus, our findings indicate that the quality of student participation in practical work increases with an increasing degree of inquiry.

Discussion

Against the backdrop of conflicting evidence of the links between inquiry-based teaching and student achievement (e.g. Cairns & Areepattamannil, 2019; Chi et al., 2018; Hattie, 2009; Minner et al., 2010; Teig, 2021) and growing consensus that 'more isn't always better (Teig et al., 2018), our study has heeded calls for investigating the quality, rather than the quantity, of inquiry practices in science classrooms. By observing 20 Norwegian science classrooms at the primary- and lower-secondary level, we have provided a thorough characterisation of what inquiry-based teaching looked like in the observed classrooms – and which factors influenced the teaching quality. We have operationalised quality teaching with the help of an observation manual that consists of observable aspects of science teaching. This manual has allowed us to study the quality of inquiry practices (RQ1) and the links between inquiry and student participation (RQ2). Although we saw that inquiry played a central role in the observed classrooms, we identified varying quality in the individual inquiry phases and differences between primary and lower-secondary schools. For example, we observed that primary-school students collected and documented data more systematically than lower-secondary students and that consolidations were slightly more emphasised and of higher quality at the lower-secondary than at the primary level. Moreover, our findings indicate that inquiry-based teaching gave students more freedom to make their own choices and increased the quality of student participation in the classroom in several ways, including classroom discourse and practical work.

In our framework, *inquiry* and *facilitating student participation* are two dimensions of teaching quality that make up the overarching pillar of **power to act**. We now combine and synthesise our findings to discuss how teachers can empower students through inquiry in the science classroom. Towards that end, we discuss similarities and differences to previous research before discussing practical implications for raising the quality of inquiry-based teaching. Here, the observation manual and its differentiation between scores 1–4 provide valuable information about the adjustments teachers can make to raise the quality of inquiry-based teaching.

Preparing inquiries

The observed preparation phases were characterised by teachers asking questions or stimulating students' curiosity. Exploring student-generated questions or letting students create their own hypotheses and approaches to investigate questions appeared to be an aspect of inquiry-based teaching that was not widespread among teachers. Thus, our study confirms previous findings from TIMSS (Bergem et al., 2015) and PISA (Kjærnsli

& Jensen, 2016b), where students answered that they rarely were involved in planning their own experiments. Our findings also support and complement existing research that suggests that teachers have a much greater focus on structuring their instructing around students' personal experiences or a given problem than helping students ask and answer their own questions (Ireland et al., 2012). One reason the observed teachers rarely invited students to generate questions for inquiry may be that models for inquiry, such as the 5E model (Bybee, 2009), seldom emphasise the role of questions in guiding and structuring inquiry-based teaching (Ireland et al., 2012).

In the lessons that received low scores in preparation, we observed many curiosity-stimulating activities and students discussing what they thought would happen based on previous experiences and prior knowledge. Here, we see a potential to raise the quality of teaching by supporting students to take the next step from wondering to creating questions and hypotheses (Chin & Brown, 2002). We saw that teachers facilitated more student discussions in lessons with inquiry or elements of inquiry and encouraged students to explain, argue and develop scientific ideas more often in inquiry lessons than in lessons without inquiry. Thus, inviting students to pursue their ideas seems a feasible instructional adjustment to strengthen students' power to act. When students are free to wonder about a phenomenon and become curious, they actively participate and direct their learning.

Additionally, encouraging students to ask questions and involving them more directly in generating researchable questions and formulating hypotheses can be an excellent way to increase students' awareness of the nature of science. In fact, our findings suggest that inquiry teaching provided teachers with more opportunities to address NOS aspects than other forms of teaching. Suppose the teacher explicitly communicates that coming up with questions and hypotheses is essential to creating new knowledge in science. In that case, there is a greater chance that students become aware of the extent to which they engage in practices that mirror those of scientists. Incidentally, such an instructional approach would give students more room to feel ownership of their inquiries. The students could experience that there is something they do not know (yet) but that they have the means to investigate and explore, i.e. that they can do something themselves to understand the world better (Chin & Brown, 2002). In other words, good inquiry-based teaching can empower students by instilling trust in their power to act.

Conducting inquiries

Our results show that the observed data collection phases were generally of high quality in primary and lower-secondary schools. In science education, we ask students to understand scientific theories in light of observations and observations in light of theories. Thus, being able to systemise observations and classify collected data is a crucial step towards building such a scientific understanding. As Ødegaard and colleagues noted, 'the data phase of inquiry seems essential as a driving force for engaging in science learning in consolidating situations.' (Ødegaard et al., 2014, p. 2997). In other words, raising the quality of data collection phases can also increase the quality of consolidations. Therefore, we see an excellent opportunity for improving the quality of data collection by encouraging students to document observations systematically and pointing out how such documentation can become the first step of scientific analysis. Besides, we saw a tendency for students to have greater freedom (i.e. a larger number of choices) when using secondary sources (e.g. books or the internet) than when engaging in practical activities and experiments. Hence, it is a helpful reminder that inquiry activities need not necessarily centre on primary sources (i.e. observations and measurements) to be of high quality. Finally, we saw that the quality of practical work was higher for lessons with than without inquiry. Direct links between practical work and learning science concepts characterise high-quality practical work. Thus, increasing the quality of data collection is an excellent way of showing students that they can acquire scientific knowledge, thereby strengthening students' agency.

Concluding inquiries

Our analyses show that consolidations were more emphasised and of higher quality at the lower-secondary school than at the primary-school level. At both levels, the observed consolidation phases were often short and descriptive. In these lessons, students came up with simple descriptions of their observations. Often, they did not draw any conclusions, discuss implications, or connect their empirical findings to scientific knowledge. These findings align with previous research that found that 'in the context of scientific inquiry, teachers seem to focus more on procedures rather than on the process of knowledge generation' (Ruiz-Primo & Furtak, 2007, p. 78). It is a known problem that teachers often set aside too little time for discussions that can consolidate students' data collection and experimental work (Klette, 2013; Ødegaard et al., 2014). Finally, teachers might find it challenging to initiate consolidation phases in which students discuss actively. After all, science teaching has a long tradition of authoritative rather than dialogic discourse, which can passivise many students rather than encourage them to inquire (Scott et al., 2006). Teachers need to be comfortable giving away some of their instructional control when allowing dialogic discourse (Ødegaard, Kjærnsli, & Kersting, 2021).

Our findings suggest that teachers can lift the quality of consolidations by connecting collected data and observations more closely to scientific theories. Especially at the primary level, such connections were largely missing. Here, the full potential of using dialogue to scaffold students' learning can be fully realised (Kolstø, 2018), not the least because our findings show that the teachers' role in facilitating student-student talk becomes more critical in inquiry lessons. During consolidations, teachers have excellent opportunities to make disciplinary thinking and scientific reasoning strategies explicit to students (Hmelo-Silver et al., 2007). Therefore, improving the quality of consolidations can go hand in hand with adopting a more direct approach to teaching NOS, namely by increasing students' awareness of the differences and similarities between inquiries in the classroom and professional science research activities (Lederman & Lederman, 2014).

Degrees of freedom and nature of science

Looking at quality features of inquiry that cut across the three inquiry phases, we found that most inquiry activities only offered a low degree of freedom for the students. Students are more likely to engage in activities if they can make choices themselves (Ryan & Deci, 2000). Besides, 'too much guidance can interfere with students' thought processes, act to frustrate problem-solving and lead to premature closure' (Hodson, 2009,

p. 213). Hence, we hope our findings encourage teachers to give students more room to explore and pursue their questions, approaches, and interpretations during inquiry activities. Nevertheless, we acknowledge that giving students too much freedom during inquiry activities is not beneficial either: teachers must treat a fine line between providing students structure and space (Bjønness & Kolstø, 2015). We hope our findings provide a more nuanced view of the possibilities and limitations of letting students make their own choices during inquiry-based teaching.

Although we saw that teachers included nature-of-science aspects more often in lessons with inquiry and elements of inquiry than in lessons without inquiry, an explicit treatment of NOS was generally rare. This finding agrees with previous research, for example, with results from PISA 2015 in Norway, where almost 30% of students said that the class never or rarely discussed scientific questions (F. Jensen & Kjærnsli, 2016). PISA 2015 also showed that Norwegian students performed somewhat weaker on science tasks that involved evaluating and planning scientific methods than on tasks that asked to use scientific theories, concepts and facts (Kjærnsli & Jensen, 2016a). One reason for such findings might be that teachers take for granted that students learn about and understand the nature of science when engaging in inquiry activities (Lederman & Lederman, 2014, 2019). Another cause might be the general conflation of NOS with scientific inquiry and a lack of awareness among teachers of what NOS perspectives entail (Farmer, 2020).

Limitations of our study

Our study aims to complement findings from international large-scale assessment studies with rich video observations from science teaching practices. Inevitably, the scope of qualitative video studies is smaller than those of large-scale studies. For example, we did not select schools randomly but recruited those in the vicinity of our universities that had previously participated in development projects. Thus, we cannot generalise our findings to larger populations. Moreover, the number of observed inquiry lessons and lessons with elements of inquiry is relatively low. Therefore, we must treat the scores' distribution in these lessons with caution. Although we often present these distributions as percentages of lessons, we want to emphasise that the results cannot be generalised directly. Our analyses are qualitative interpretations of classroom activities. We have chosen to quantify our findings to provide an overview of our data and illustrate patterns of observable quality signs of inquiry-based teaching (Ødegaard et al., 2014). Finally, we adopted a teacher-oriented perspective on science learning, thereby not fully considering that students have personal motivations, abilities, and values that also influence the learning and teaching of science in the classroom. Nevertheless, we believe that our findings provide vital insights into the quality of inquiry practices in primary and lower-secondary schools. Not least, our study highlights the breadth and diversity of inquiry practices and the many opportunities inherent in good science teaching.

Conclusion

In conclusion, the contribution of this paper is, first, an overview of the quality of inquiry practices in 20 Norwegian primary- and lower-secondary classrooms, and second, a description of the links between inquiry-based teaching and the quality of student participation. Heeding calls for a better understanding of the factors that influence the quality of inquiry-based teaching, our study has substantial implications for teacher education and professional development. Research has shown that science teachers often encounter challenges when teaching inquiry in their classrooms (e.g. Chichekian & Shore, 2016; Crawford, 2014). Moreover, there is little consistency in how science teachers implement inquiry-based instruction (Marshall et al., 2010). Our findings point to specific opportunities for improving the quality of instructional practices in different inquiry phases, which, in turn, can increase student participation and empower students in the classroom. For us, empowering means strengthening students' participation, their power to act, and, ultimately, their agency, i.e. their will and ability to play an active role in their education by setting goals, using their knowledge to effect change, and influence positively their own lives and the world around them (OECD, 2019). Empowering students leads to a transformative process of growth, and such transformation is one quality sign of good education (Wittek & Kvernbekk, 2011). Through detailed descriptions of observable characteristics of good science teaching, this study can help teachers and teacher educators reflect on their inquiry practices and suggest how to vary them in line with students' needs.

Notes

1. https://www.uv.uio.no/ils/english/research/projects/lissi-science-instruction/index.html
2. Empowerment overlaps with 'action competence', which is often connected with environmental and sustainability education (B. B. Jensen & Schnack, 1997; Mogensen & Schnack, 2010). Since action competence is a multifaceted concept that includes attitudes, skills, and knowledge, we have chosen the notions of empowerment and power to act to help us distinguish more clearly between aspects of knowledge and aspects of participation, action, and agency.
3. We were interested in consolidation phases that were part of inquiry-based teaching. Therefore, general classroom consolidation practices not connected to previous inquiry activities (e.g., data collection) do not get high scores in the consolidation category of our framework.
4. In our framework, we understand consolidation in a narrow sense as one of three inquiry phases. Thus, general classroom consolidation practices that are not connected to inquiry activities (e.g., previous data collection) do not get high scores in the consolidation category.

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