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Teachers' Questioning Practices in Chinese Secondary Biology Classrooms

Zhongyan Zhang[1] · **Martin Lamb**[1]

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Abstract

Across the curriculum, the questions that teachers ask in class direct learners' attention to key subject matter, and shape what they learn. This paper examines the types of questions that Chinese school Biology teachers ask, and considers how and why they vary their questioning in the context of scientific practices. Six teachers from four schools in Xi'an City in mainland China took part. Three lessons were observed for each teacher, followed by interviews in which teachers were asked to focus on specific teaching episodes and explain their questioning. Findings reveal that teachers' questions were mostly closed-ended, but in certain types of lessons their questions were more open and they used questions to manage class discussion. Teacher questioning is affected by personal beliefs, institutional working practices, and external policy shift, and teachers experienced tension in navigating between these factors. The results have important implications for policy and practice; for example, teacher educators need to recognize the complexity of teacher questioning and encourage teachers to discuss the challenges associated with asking more open questions, while policy-makers need to acknowledge the impact their decisions can have at the classroom level.

Keywords Scientific Practices · Teacher Questioning · Teacher Tension

Empirical evidence is increasingly supporting a positive association between teachers' questioning practices and student learning (Nawani et al., 2018; Vrikki & Evagorou, 2023). Achieving curriculum standards and enacting scientific practices rely on "the teacher's ability to stimulate critical thinking skills through effective questioning behaviours" in the classroom (Wilen, 1991, p. 7).

However, teacher questioning is not a simple practice; it is not just about pedagogy but involves social and management challenges and requires teachers to make in-the-moment decisions based on student responses and teaching priorities. So far,

✉ Zhongyan Zhang
ZhongyanZhang@outlook.com

[1] University of Leeds School of Education, Leeds LS2 9JT, United Kingdom

research has focused much less on factors which may constrain the way teachers ask questions and which may give rise to feelings of tension as they manage their classes. Such a focus is crucial in exam-oriented educational contexts such as China, where teachers may feel pressured to use closed questions to guide students to specific answers at the expense of students' active engagement in scientific practices (Pei & Liu, 2018). X. Chen et al. (2017) point out that Chinese teachers face dilemmas in their decision-making between their personal belief systems, the test-focused school governance, and the national policies advocating for student-oriented reform.

This paper aims to examine the extent to which teachers pose different types of questions and to understand their accounts of the factors that influence their questioning in secondary biology classes in the context of scientific practices. It contributes significantly to the literature by examining teachers' questioning practices from a novel perspective that encompasses personal, institutional and also broader contexts.

Literature Review

Importance of Teacher Questioning Practices

From the era of Socrates onwards, teacher questioning has been a core element in guiding students in various educational directions: facilitating conceptual understanding, engaging in classroom dialogue, cultivating deep learning, and developing critical inquiry skills. Early research tried to provide evidence through quantitative explorations of the impact that teachers' questioning practices have on student academic achievement (e.g., Riley, 1986; Samson et al., 1987; Winne, 1979). Wilen and Clegg (1986) reviewed correlational and experimental studies and concluded that eleven questioning practices (e.g., probing students' responses and clearly phrasing questions) positively impact student learning outcomes. Research has shown that higher cognitive questions, which require application, synthesis, and evaluation, are more effective for student achievement compared to lower cognitive questions focused on knowledge recall (Redfield & Rousseau, 1981). However, research findings are mixed, with some studies showing no significant differences in student achievement when comparing higher and lower cognitive questioning (e.g., Winne, 1979).

The reliance on quantitative methods fails to capture the nuances of classroom discourse and separates teacher questions from their context, such as the purposes of the questions and the interests or abilities of the learners. More recently, researchers have adopted a sociolinguistic approach that pays attention to "the role of social context in the interpretation of spoken language" (Carlsen, 1991, p. 158) and focuses on the relationship between teachers' questioning practices and students' responses (e.g., Lee & Kinzie, 2012; Y. Chen et al., 2017). This reflects the increasing recognition of the importance of student engagement in productive dialogues during classroom interactions (Vrikki & Evagorou, 2023). It is now seen that higher cognitive questions can enhance students' elaboration and reasoning skills (Soysal & Soysal, 2022; Vrikki & Evagorou, 2023). Teacher questioning also plays a crucial

role in facilitating argumentation in elementary science classrooms (McNeill & Pimentel, 2010). Shifting the pattern of questioning from yes/no and factual recall to a diverse range of probes enables students to engage more deeply in argumentation, such as articulating their own ideas and evaluating and refuting the claims of others (Martin & Hand, 2009). Key teacher questions (e.g., "Why can't they both be correct?") play a role in transitioning the classroom dialogue from an authoritative to a dialogic orientation by opening up classroom talk and giving space to student voices (Lehesvuori et al., 2019; Mortimer & Scott, 2003).

Typologies of Teacher Questions

Teacher questions have been classified in various ways, including by cognitive level (e.g., Bloom, 1956), purpose (e.g., Benedict-Chambers et al., 2017; Blosser, 1975), the degree of student-centeredness (e.g., Oliveira, 2010), authoritative-dialogic orientation (e.g., Van Booven, 2015), questioning strategies (e.g., Chin, 2007) and content (e.g., Roth, 1996). Among these classifications, Blosser (1975) detailed a specific system known as the Question-Category System for Science (QCSS), which has become widely used. This classification comprises closed and open questions, managerial questions that maintain classroom discipline, and rhetorical questions that emphasize statements rather than seeking answers. Using this framework can offer a comprehensive view of how teachers utilize questions and relates to their reflection on questioning; for instance, teachers might explain their use of closed questions, even when open questions could be employed to explore new ideas and perspectives.

The closed/open dichotomy has been the focus of most research, although some researchers criticize this simplistic dichotomy, arguing that narrowly defined categories overlook the complex, dynamic nature and multifaceted functions of communication (Ho, 2005; Y. Chen et al., 2017; Wang et al., 2023). Hardman (2019) found that closed questions, which have a pre-determined answer or a limited number of correct answers, often elicit short responses and provide less dialogic space. In contrast, open questions, which do not have fixed answers and can elicit two or more different responses, are strongly correlated with extended student contributions, indicating greater student participation in whole-class discussions (Hardman, 2019). Researchers continue to advocate for the increased use of open questions by teachers (Vrikki & Evagorou, 2023) and evidence shows that they enhance preschool children's mathematical learning (Trawick-Smith et al., 2016), promote argumentation, elicit higher-order thinking, and foster rich discourse (Lee & Kinzie, 2012; Lee et al., 2012; Martin & Hand, 2009; McNeill & Pimentel, 2010). However, Khoza and Msimanga (2021) have provided data to support the view that closed questions do not always lead to triadic initiation-response-evaluation interactions and that open questions may sometimes limit students' thinking and do not always lead to long, multiple-perspective responses. It is recognized that a balance between open and closed questions is necessary (Hardman, 2019).

Research has found that teachers vary their use of different types of questions according to the science activities (e.g., small group science experiments versus

whole class book readings) (Lee & Kinzie, 2012). Questions also vary in different modes of teaching, specifically in low-level didactic teaching and high-level teaching practices that emphasize students' own knowledge construction (Erdogan & Campbell, 2008). It might be expected that teachers' questioning will also differ between regular lessons and special lessons observed by colleagues (so-called 'polished lessons') as required of all teachers in Chinese state schools. The proportion of open and closed questions can be improved through teacher professional development programs (e.g., Lee et al., 2012; Wasik et al., 2006; Vrikki & Evagorou, 2023). For example, Hardman (2019) found that after 20 weeks of a school-based professional development intervention aimed at supporting the implementation of dialogic pedagogy, primary school teachers made significantly greater use of open questions and invited students to share, argue, and build on the ideas of other students in follow-up talk moves.

Teacher Tension

Previous studies have attempted to identify optimal questioning strategies (e.g., Chin, 2007; Soysal, 2022) that especially emphasize the value of open questions, which is also highlighted in teacher training practices across different subjects and countries (e.g., Hardman, 2019; Lee et al., 2012; Wasik et al., 2006). However, research shows that teacher questions are more commonly closed and knowledge-based (Eshach et al., 2014; Massey et al., 2008; Nehring et al., 2017). For example, Eliasson et al. (2017) used Blosser's framework to examine 953 questions posed by 14 secondary science teachers in Sweden and found that 87% of teacher questions were closed questions and only 13% open. This cannot be simply attributed to a deficiency in pedagogical skills, as previous research shows that teachers recognized the importance of higher cognitive questions, but they used them less frequently in the classroom (Sahin & Kulm, 2008; Yip, 2004). This contradiction between what teachers believe they should do, and what they actually do, suggests that teacher questioning is a complex issue, and always influenced by various factors, for instance, subject matter knowledge (e.g., Carlsen, 1987; Hashweh, 1987), students' socioeconomic backgrounds (da Silva & dos Santos, 2021), and teacher training (e.g., Joglar & Rojas, 2019; Oliveira, 2010).

The discrepancy between beliefs and practice has been noted in other areas of pedagogy. Some researchers have explained this by reference to the notion of *teacher tension*. This term refers to the situation where teachers encounter opposing forces or pairs of binary opposites in their practice (Berry, 2007; Liljedahl et al., 2023). According to Liljedahl et al. (2023), this tension can arise from conflicts within the teacher's own belief system, as built up through past experiences and values. It may also result from opposing forces in the environment, such as prevailing norms, educational values and stakeholder demands. In this paper, it describes a scenario where teachers are being pulled in different directions by multiple factors affecting their questioning practices and they have to negotiate these forces, which can make them feel tense and stressful, or give them positive, creative energy.

Previous studies have identified teachers' tensions in implementing scientific practices, for instance, between meeting students' interests and generating high academic performance, between developing inquiry skills (e.g., analysing and interpreting data) and delivering canonical science knowledge, and between giving students' freedom within an ideal inquiry lesson and providing guidance on what to do (Kim et al., 2013). Wallace and Kang (2004) investigated the tensions experienced by six secondary science teachers in scientific practices and found two major competing belief strands (see Fig. 1): teachers' personal interests and cultural constraints.

In order to fully comprehend these tensions, it is imperative to analyse teacher questions holistically, that is, to view them as the product of various influencing factors. A framework which could be useful here is that used by Ryder (2015) (following Goodson, 2003), who examined how teachers responded to externally driven curriculum reform. His research identified 27 different factors influencing teachers' responses and classified them into three groups: personal (e.g., a teacher's subject knowledge and pedagogical skills), internal (e.g., students' differing backgrounds and aspirations, and science department working practices), and external (e.g., national science curriculum reform). This framework allows for an exploration of the complex reasons behind behaviour and how the internal and external contexts interact with teachers' personal characteristics.

Research Focus

Despite the importance of teacher questioning demonstrated in this literature review, related research is still "scarce and relatively outdated" (Vrikki & Evagorou, 2023, p. 4). Most existing qualitative research on this topic focuses on Initiation-Response-Feedback [IRF] or questioning sequences. However, there is a lack of in-depth reflections from teachers on the reasons behind their questioning practices. Where studies have looked at this, they have tended to consider factors from one area only, such as teacher's subject matter knowledge (e.g., Carlsen, 1987), rather than acknowledging that teacher questions may be subject to multiple simultaneous influences, including institutional working practices and national policies. The present study addresses this gap by focusing on the institutional and broader context, and on teaching rather than student learning outcomes, with the aim of providing insights that can have practical value for teachers, teacher educators, and policymakers. The research questions are formulated as follows:

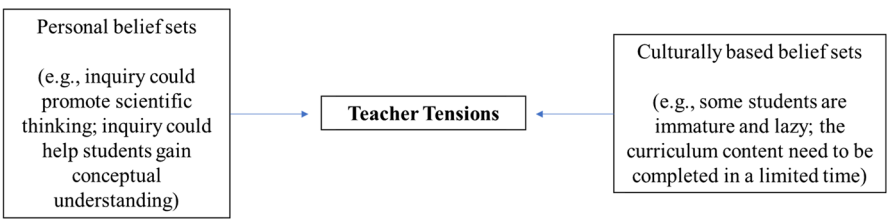

Fig. 1 Teacher Tensions from Two Competing Belief sets about Inquiry (Based on Wallace & Kang, 2004)

(1) To what extent do teachers show similarities or differences in their questioning practices?
(2) How are the teachers' questioning practices shaped by personal factors and broader social and cultural factors?

The first research question aims to map the similarities and differences in questioning practices that can be observed between teachers. The second one aims to explore how teachers reflect on factors that influence their questioning practices within the broad context surrounding their workplace and relevant policies.

Research Context

This study took place in the context of Chinese curriculum reform that places greater emphasis on scientific practices (Zhang, 2022), specifically the revision of the junior and senior secondary biology curriculum standards in 2017 and 2022, respectively. Activities such as the study of curriculum standards by teachers, expert lectures, in-service teacher training, and teaching competitions have been organized nationwide to facilitate the implementation of the revised standards in the classroom. Curriculum standards encourage teachers to conduct extracurricular activities (Ministry of Education [MOE], 2017), such as the so-called 'society class' (社团课) where students can meet once a week for approximately 100 minutes to pose their own scientifically oriented questions and plan and carry out investigations. The standards also provide numerous question examples in lesson plans to encourage teachers to plan a sequence of questions that activate student thinking and participation in scientific practices (MOE, 2017).

In addition, to implement the standards and improve teaching, all Chinese schools carry out a common working practice: what could be translated as 'polished lessons' (磨课) (Pang & Jiang, 2020). The term was first used in the official document "Sending Teaching to the Countryside Training Guide" released by the General Office of the MOE in January 2016. Here sending teachers to the countryside means urban teachers go to rural schools to help rural teachers improve teaching, for example by observing high-quality lessons and participating in post-lesson discussion (MOE, 2016). In this practice, one teacher chooses a lesson from the authorized textbook and designs a set of learning activities. They then teach the lesson to a class while being observed by several colleagues, who later critique the lesson and suggest how it could be improved. The teacher revises the lesson and teaches it to another class of learners, again observed by colleagues, who give their feedback and this process is repeated until the teacher feels they are fully satisfied with the lesson. Teachers form a community of practice where they learn through conversations about specific classroom contexts, by sharing knowledge and expertise, and through the negotiation of disagreements (Wenger, 1999). The polished lesson is usually shared among teachers in a department and may be posted online. Pang and Jiang (2020) argue that polished lessons help to optimize classroom teaching and learning and encourage a spirit of collaboration in schools.

The increasing popularity of polished lessons is rooted in Chinese traditional culture. The classroom has long been regarded as a public open space (Yang & Yan, 2020), unlike in many western contexts where the classroom door is firmly closed and teachers "are sometimes reluctant to allow colleagues into their classrooms" (Richards & Lockhart, 1991, p. 1). Chinese educational culture puts high importance on teachers observing and learning from each other, and in particular the emulation of role models (Yang & Yan, 2020).

Evidence indicates that teachers devote significant time to discussing and refining their questions when they polish a lesson (Zhu & Qin, 2008), so they are a potentially useful source of evidence for their thinking in this aspect of practice. Polished lessons may also be a significant influence on how teachers in a school develop their questioning techniques.

Research Methods

Sampling and Data Collection

The data for the present study was generated in a project looking at how teachers in Xi'an City in mainland China use questions in secondary biology classrooms to engage students in scientific practices. Purposive sampling was undertaken to gain access to teachers who were likely to use a relatively large number of dialogic and interactive questioning sequences (Mortimer & Scott, 2003). We believed that such teachers would be able to describe the nature of their questioning and articulate the reasons for it (Berliner, 1988).

Accordingly, the selection criteria for the study were: (1) many years (e.g., at least five) of classroom experience in secondary biology teaching; (2) a reputation of excellence in teaching (e.g., recognition as an expert teacher), from which we could assume that their discursive moves were not limited to IRF (Tytler & Aranda, 2015), and that they would have a high degree of conscious awareness of their teaching behaviour (Berliner, 1988); and (3) strong willingness to collaborate in this study. Table 1 provides a summary of the characteristics of six participant teachers who not only met these criteria, but also displayed a variety of teaching experience levels, grade levels and school types.

The original intention was for the first author to visit schools and observe and audio-record lessons herself. However, due to the restrictions imposed on schools by the Covid pandemic, in-person observation of lessons became impossible. Instead, each teacher was asked to audio-record three lessons which would showcase their teaching, and to include polished lessons if they had created them. Allowing teachers to select the lessons heightened their willingness to provide feedback during interviews. Two specific requirements were emphasized in their selection: they should record lessons (1) which highlight students' participation in scientific practices; and (2) where teachers thought carefully about teaching details and refined their teacher questions based on collective lesson observation and lesson discussion, as they regularly did in polished lessons. The audio-recordings, which captured all voices when the lesson was in whole-class mode (i.e. not when students were working in

Table 1 Details of the six biology teachers involved in the study

Teacher pseudonym	Gender	Years in teaching	Grade	Award	School type	The three lessons selected by each teacher
Ziv	M	21	7	National award winner	Private school A	Investigate the role of saliva, teeth, and tongue in digesting starch I&II; ***Healthy diet and food safety***
Sue	F	10	7	Provincial expert teacher	Private school A	***Explore the roles of animals in the biosphere***; The structure of the respiratory system and the functions of the respiratory tract; Components of the nerve system and the structure and function of a nerve cell
Zachary	M	26	7	Provincial expert teacher	University-affiliated school B	Blood transfusion and blood types; Amphibians and reptiles; Characteristics of mammals
Wynne	F	10	7,8	National award winner	University-affiliated school B	***Characteristics of reptiles; The bones, joints, and muscles, and how they fulfil their function in the movement of animals; The four main components of an ecosystem***
Simon	M	23	10	City-level expert teacher	University-affiliated school C	Genes are located on chromosomes I & II; DNA is the main genetic material
Helen	F	12	10	Provincial expert teacher	Public school D	***Explore what happens to homologous chromosomes during meiosis***; Genes are located on chromosomes; DNA is the main genetic material

[a] Grades 7–9 constitute junior secondary school for ages 12–15. Grades 10–12 make up senior secondary school for ages 15–18.

[b] Provincial expert teachers have a higher reputation than those at the city level. These titles are awarded after teachers successfully participate in teaching competitions. In these competitions, teachers create a lesson plan on the spot within a limited time frame, present the plan to a panel of judges within 10 min, and then teach a 15-minute lesson to a classroom of unfamiliar students

[c] The public school was funded by the government, and the private school was mainly funded by student tuition fees and owned and managed by a company. The university-affiliated school was run by a university and recruited many students whose parents were working at this university or whose grandparents had retired from it

[d] The lesson styled in bold and italics represents a polished lesson

groups), were transcribed and analysed in Mandarin. In addition, the biology textbooks, slides, videos shown, lesson plans, physical models, handouts and students' produced work were all collected and analysed for the information they could provide about the pedagogic context of the questioning.

Data was collected according to the sequence shown in Fig. 2. Each interview was conducted online and lasted about one hour. They were semi-structured, with a schedule of prepared topics but allowing for some flexibility based on the teachers' responses. The first interview was aimed at gaining information about the school, their work experience, previous experience with polished lessons and beliefs about good teaching; it was also a chance to develop a trusting relationship with the teachers. During the second and third interviews, the teacher was asked to comment on the teaching and specifically the teacher questions in three or four episodes which the first author selected from lesson transcriptions. A teaching episode refers to a roughly 5-minute classroom teaching/learning sequence containing intense verbal exchanges between the teacher and learners. This approach helped teachers to focus on specific moments of the lesson where they asked questions, allowing us both to recognize the precise context of the exchanges and interpret them accordingly.

During the interviews, questions were posed to elicit deep reflection from teachers, for example: "What do you think about your questioning in this episode?" "Why did you ask this question?" "You mentioned… Could you please give me an example?". Leading questions were avoided as far as possible, and the teachers were interviewed in a friendly manner to encourage them to share their expertise. These teachers turned out to be confident, purposeful, and articulate. They could fluently describe what they did in the classroom, explain why they asked a particular question or sequence of questions, and adeptly use examples to support their explanations.

Data Analysis

All lessons and interviews were audio-recorded and transcribed for analysis. To address research question one, Blosser's (1975) QCSS (see Table 2) was used to categorize teacher questions because it classifies them according to the function – e.g., whether questions can open up student thinking and discussion – which is

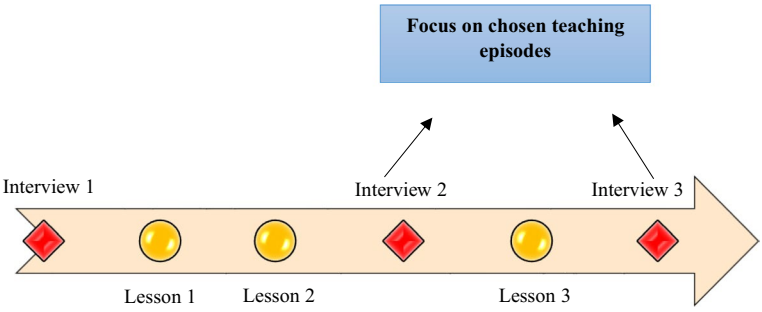

Fig. 2 A data Collection Sequence for each Teacher

Table 2 Analytical framework for the analysis of teacher question type, adapted from Blosser (1975)

Question type		*Description*	*Example*
Questioning subject knowledge	Closed questions	Has a pre-determined answer or a limited number of correct answers	1. Does it have ribosomes? 2. Why was an equal mass of steamed buns added to each test tube?
	Open questions	Has a wide range of possible answers	1. Why can't frogs survive in water-scarce terrestrial environments? 2. Why do you think its skin has this function?
Questioning for class management	Rhetorical questions	Used to emphasize an idea, to attract students' attention	1. Lack of water, isn't it? 2. S strain bacteria killed mice, right?
	Managing discussion questions	Used to check consensus, to probe	1. Anything to add? 2. Does everyone agree with his idea?

an important part of science teaching and learning. One modification was made to the framework: closed/open questions and rhetorical/managing discussion questions were placed under the higher categories of questioning subject knowledge and questioning for class management, respectively, because all questions can be broadly categorized as either open or closed. Additionally, the label *managerial questions* was changed to *managing discussion questions*. Managerial questions (e.g., "Could you please turn to page 30?") were transcribed, but they did not focus on teaching and learning and therefore were not analysed in this study. However, managing discussion questions used to check consensus in the class or to encourage students to elaborate further on the topic were included because they play a crucial role in inviting students to consider multiple ideas and build on their own and their peers' contributions (Lim et al., 2020). This category of questions was used, for example, when the teacher asked what conclusions students could draw. After one student answered, the teacher followed up by asking if this student or others had anything to add, or if other students agreed with what was said. Another researcher was asked to code two lessons and his analysis compared with the first author's. This approach not only represented a good reliability check but also an opportunity to gain peer insights and refine definitions. He coded lesson 1 of Ziv alone, and afterwards the coding results were compared and discussed, for example, slightly redefining the category of open questions. He then coded lesson 2 of Ziv, and there was roughly 92% reliability.

The study compared the types of teacher questions used in regular lessons with those in polished lessons, a topic rarely reported in the literature. This comparison lays the foundation for understanding both why and how polished lessons influence teachers' questioning practices.

To address research question 2, the coding was framed in terms of personal, institutional and external influences, in order to gain a holistic view of teacher questions and aid the identification of the often complex reasons behind teachers' questioning practices. Ryder's (2015) label *internal* was changed to *institutional* to represent the influential factors surrounding the school. There are some overlaps among personal/institutional/external factors, for example, teachers sometimes gave more than one reason for their choice of questions and their strong personal motivation can be partly supported and reinforced by external validation. All codes were developed based on the analysis of the data, involving familiarizing oneself with the data, generating initial codes, refining codes, and reviewing all the codes and data (Cohen et al., 2018). The interview data was paired with the lesson episodes to develop familiarity with the teaching and understand teachers' perceptions. After repeatedly reading the text, NVivo 12 was utilized for coding the interview transcriptions. The unit of analysis for coding was the entire segment of the interview transcript where teachers described their feelings about a specific teacher question, a sequence of their questioning, or a teaching episode. Attention was paid to transcripts where teachers mentioned changes or influences in their questioning or teaching in aspects such as the openness, content, and sequence of questions, along with the reasons behind these changes. For example, the following interview transcript was coded as *students*, which showed the impact of students' experiences on the teacher's use of a question that was changed from "Why do you like eating instant noodles?" to "Why do you like eating crispy noodles?".

> The textbook used instant noodles, but I used crispy noodles because most students had the experience of buying a pack of crispy noodles when they didn't have lunch at the school restaurant. I wasn't aware of this initially, but I later found out that students enjoyed eating crispy noodles. Therefore, when I taught this lesson for the third time, I changed my question accordingly. (Ziv_IV3)[1]

Initial coding, the number of teachers who mentioned a particular code, and the number of selected sections for each code were recorded, so that their relative influence could be tabulated. Subsequently, discussions with two experienced researchers were conducted to refine the codes, which included clarifying the meanings of the codes, merging similar codes into one, and splitting codes. All interview transcriptions were re-examined to ensure that that the data fit the codes and all relevant data had been included. Appendix A provides a summary of the personal, institutional, and external factors identified as influencing teacher questioning practices.

Findings

This section first presents the questioning practices of six teachers and then proceeds to provide their accounts of these practices within a broader social and cultural context.

A Quantitative Overview of Teacher Questions

Table 3 summarizes the percentages of different types of questions used by each teacher. The number of teacher questions in each teacher's three lessons varies, with Helen using the most. Closed questions were significantly more prevalent than the other three types, while open and managing discussion questions were used less frequently. Wynne used a higher proportion of both open and managing discussion questions compared to the other teachers and all her lessons were polished lessons. In contrast, two senior secondary school teachers, Simon and Helen, utilized a very low proportion of these two types of questions. For example, only 0.7% of Simon's questions were open, and merely 2.5% were for managing discussion.

The percentages of open questions within the 6 polished lessons and 12 non-polished lessons were 7.0% and 1.9%, respectively (see Table 4). Managing discussion questions were also used more in polished lessons, indicating that teachers encouraged students to share their ideas, contribute to classroom discussions, and participate in knowledge construction. A lower percentage of rhetorical questions (e.g., "After adding iodine solution, starch turns blue, right?"), which were mainly used to elicit simple answers, was used in polished lessons. The potential reasons behind

[1] Some conventions were used in the extracts from the transcriptions: "Sue_IV1" refers to Sue's first interview; "[]" means an insertion was added to clarify meaning; and "(…)" refers to the deletion of a brief segment of text from the transcript. Quotations are translated from the original Chinese transcripts.

Table 3 The number and percentage of types of teacher questions in three lessons per teacher

Question type	Ziv	Sue	Zachary	Wynne	Helen	Simon	Total
Closed questions	125 (55.1%)	328 (74.7%)	250 (64.3%)	162 (64.0%)	332 (71.1%)	178 (64.7%)	1375 (67.1%)
Open questions	16 (7.0%)	16 (3.6%)	17 (4.4%)	23 (9.1%)	3 (0.6%)	2 (0.7%)	77 (3.8%)
Rhetorical questions	67 (29.5%)	69 (15.7%)	110 (28.3%)	44 (17.4%)	121 (25.9%)	88 (32%)	499 (24.3%)
Managing discussion questions	19 (8.4%)	26 (5.9%)	12 (3.1%)	24 (9.5%)	11 (2.4%)	7 (2.5%)	99 (4.8%)
Total	227	439	389	253	467	275	

Table 4 A comparison of question types between polished lessons and non-polished lessons

	6 Polished lessons	12 Non-polished lessons
Closed questions	481(63.8%)	891(69.0%)
Open questions	53(7.0%)	24(1.9%)
Rhetorical questions	164(21.6%)	335(25.9%)
Managing discussion	58(7.6%)	41(3.2%)

Percentage = 100 ╳ the number of a certain type of question in 6 polished lessons or 12 non-polished lessons/total number of teacher questions

the pattern of teacher questioning, including the teachers' experiences with polished lessons, will be examined in the next section.

Teachers' Explanations for Their Questioning Practices

Personal Beliefs about Learning

All teachers in their interviews expressed a belief in the value of open questions for promoting students' scientific thinking, though not all used the term *open*. However, their actual use of questions in class reflected broader pedagogical beliefs and often they had to balance conflicting priorities. The following teacher is discussing the reasons for using fewer open questions – for example, going off track and curriculum time constraints:

> If I want to encourage divergent thinking by asking broad questions, it will be very likely to get off the track. (…) I cannot digress from my lesson because you know that there are teaching schedule requirements for teachers. (Sue_IV1)

Sue captured the struggle she faced when deciding openness of teacher questions and viewed asking open questions as a way of making students' thinking more divergent. However, she recognized that she would probably digress from her lesson. Her questions could not be too open due to time constraints and her teaching requirements. In her interview, Sue mentioned that her use of open questions and managing discussion questions are linked to the type and difficulty level of the lesson's content. For example, she used more open and managing discussion questions in her first lesson, where the subject matter was easier for students to understand and this provided time and opportunities for students to broaden their thinking. Additionally, this lesson involved socio-scientific issues, which lend themselves to open questions because these topics often do not have definitive right or wrong answers, e.g., discussing the advantages and disadvantages of burning straw and whether it is justifiable to kill wolves to protect sheep.

A similar tension was evident in Simon's lesson on Griffith's experiment suggesting that bacteria can transfer genetic information. In this experiment, mice were divided into four groups, with each group being injected with a different substance: living type S virulent bacteria, living type R bacteria, heat-killed type S bacteria,

and a combination of living type R bacteria and heat-killed type S bacteria, respectively. Simon stated he aimed to engage students in scientific practices, focusing on data analysis and the formulation of explanations from evidence. Consequently, he posed this question: "What was the conclusion of Griffith's experiment?" Yet, he felt this was compromised by time constraints:

> One student stood up and spent some time thinking. You know, a lesson is only 40 min now. After I asked a few students in a class, I was in a hurry because if I kept doing this, my teaching tasks would not be completed. (Simon_IV3)

Ultimately, Simon directed students to find the conclusion in the textbook, rather than allowing them time to discuss and reach a conclusion. He emphasized the importance of making the textbook's conclusion explicit to students, particularly those prone to a common misconception in students' exam answers. This misconception is that Griffith's experiment indicated DNA was the genetic material. It seems that Simon was feeling a tension between his belief in the value of open questions and the need to present the right answer effectively. During his interviews, Simon repeatedly emphasized, "the school is very concerned about test scores" (Simon_IV1). His school had a policy of separating teaching and examining, namely the examiners should be teachers teaching the same subject but not in the same grade. Following school exams, the school compared the average scores of each class to assess performance. To some extent, Simon experienced exam and accountability stress, which conflicted with his personal goal of developing students' inquiry skills.

The following example showed how a question was changed from an open question to a closed one when Wynne wanted the students to focus on specific subject knowledge:

> When I taught birds a few years ago, I asked such a question, (…) 'What do you think are the characteristics of bird bones?' In fact, my question was to make them notice the size of the sternum. Yet, my question was not specific; so, the students didn't know how to answer it (…) A brave child answered: 'I find that its skull is very small, compared to other animals.' (…) Later, I asked: 'What is the shape of a bird's sternum compared with a reptile's sternum?' (Wynne_IV1).

For the same subject knowledge, teachers might ask questions with different degrees of openness. A question can be located on a continuum between closed on the one hand and open on the other (see Fig. 3). The teachers controlled and balanced the openness of their questions. When they made decisions, they negotiated the tension between time constraints and the development of students' divergent thinking, between their desire to ask more open questions and the need to ensure that all learners in this large class had got the correct answer, for example.

Ziv explained the reasons for using more open questions in his society class as compared to regular lessons:

> I don't have curriculum standards for my society class. I only have an objective that is to instruct students to make movies. I can use more open questions to achieve this goal because everyone's task is different, although they have the

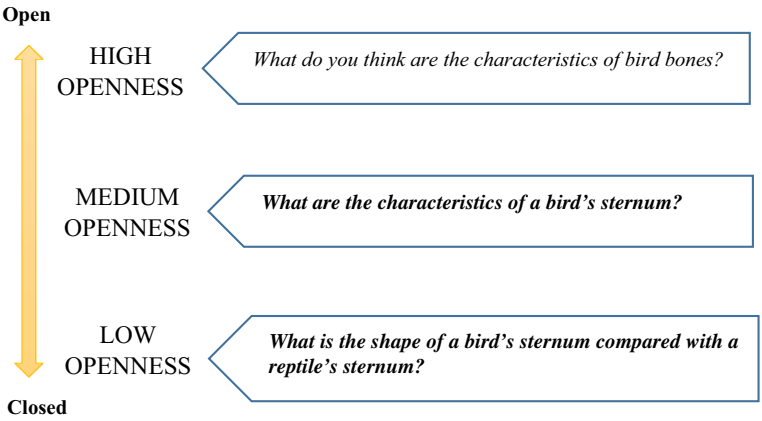

Fig. 3 Degree of Openness of Teacher Questions

same objective. Also, fewer students. If I have fewer students, I can use more open questions. (Ziv_IV2)

Ziv was the only teacher who had the experience of teaching in all three different contexts: regular classes, polished classes and society classes. In his society class, about four students formed a small group. Ziv encouraged each group to pose inquiry questions they were interested in (e.g., Are your water bottles clean?) and facilitated students' engagement in open inquiry that involved planning and conducting experiments, analysing and interpreting data, and communicating the results. Students used cameras to record their inquiry processes and ultimately created a short movie to showcase their questions, methods, and results. The society class was approximately 100 min each week and one inquiry project could last several months. Ziv modified his questioning practices and used more open questions in the society class because there were fewer students (36), no specific learning objectives for subject matter knowledge and no pressure of completing teaching tasks on time. In the regular class, his desire to use more open questions conflicted with his duty to support 56 students in acquiring prescribed subject knowledge.

Institutional Working Practices

Working together to polish a lesson in weekly group meetings, along with lesson preparation meetings, clearly had an impact on the teachers' questioning practices. For example, in a weekly group meeting, biology teachers in Ziv's school collectively discussed a lesson plan that scheduled specific plans for what and how to teach according to the learning objectives set out. They discussed which question to pose during a lesson on a healthy diet: whether to ask students to design lunch recipes or to order a meal. Ziv stated that they had considered the drawbacks of asking students to create lunch recipes. They concluded that asking them to order a meal was more effective, as students had more relevant experience:

> If I ask students to design lunch recipes, they need to know what kind of dishes they want to cook and their ingredients. They lack this kind of cooking experience but have more life experience related to dining at restaurants. (Ziv_IV3)

They considered the difficulties and life experiences of students when discussing the effectiveness or suitability of a teacher question during a collegial lesson preparation. As an expert teacher, Ziv had an obligation to showcase his polished lesson with many significant strengths. He tried his lesson plan in some classes, gathered feedback from other biology teachers, and refined his teaching accordingly. He stated that the final lesson was presented to an audience of about 25 people, including school leaders and teachers from various disciplines and schools. They sat at the back of the classroom, observing Ziv's teaching carefully. An essential cultural feature in this context was the practice of teachers being observed, modelling, and actively participating in institutional work to refine lessons with peers. Such involvement can potentially motivate teachers to craft questions and dedicate more effort to enhancing their lesson quality.

In addition to the influence on specific teacher questions, polished lessons and resources (e.g., slides and teaching materials) have the potential to affect the question sequences or even the whole question framework in a lesson. Zachary stated that he used slides that his colleague shared in the department when his colleague had a polished lesson on earthworm observation. He thus used sequences of questions and teaching ideas in the slides:

> She [Zachary's colleague] planned several activities in advance, such as observing, touching and measuring [earthworms]. Isn't there an activity called measuring the crawling speed? She listed the related questions and asked students to think, think about these questions before doing. In the past, I overlooked these things. (Zachary_IV2)

Zachary commented that his lesson was improved significantly – for instance, using questions to support students in scientific practices. Overall, it appears that the careful planning and preparation of resources entailed by polished lessons can help individual teachers to improve their questioning techniques.

External Policy Shift

This section examines how the external examination policy affected teacher questions in scientific practices. All participating teachers report integrating key points from public exams into their questioning. For example, Helen mentioned that her question about how to use radioactive isotopes to label a bacteriophage was influenced by the national college entrance exam:

> The national college entrance exams often test this: how to label bacteriophages. (…) In Jiangsu, Shandong, and Zhejiang province, they favor this type of question in the [college entrance] exams. (Helen_IV3)

The following example shows the impact of an external policy shift on teacher questioning. Biology was not part of the city's high school entrance exam until

2019, allowing teachers to design their own biology exam papers. Although the biology score was not included in the total for the high school entrance examination in 2021 when the data was collected, students still needed to pass this external exam to obtain their junior secondary school diploma. Zachary described how this change influenced his teaching attitudes and behaviours: "I felt that the teaching was very relaxing [before exam changes]. (…) We had the right to create test papers in terms of the [biology] exams, but it's different now. (Zachary_IV3)" Due to this policy change and assessment pressures, teachers sped up their lessons since they knew they had a limited time to cover four biology textbooks and prepare for the exam. Zachary stated that less time was given to carrying out scientific practices now, with fewer opportunities for making and recording observations, analysing data, and evaluating results. For example, in his amphibian lesson, the entire class briefly observed a single bullfrog at the front of the classroom, likely obscuring the view for those at the back. Yet he explained previously he had been able to organize classes differently:

> Two years ago, the students worked in in small groups to observe bullfrogs. A group of four students sitting in their seats carried out their investigation. They observed lots of things: for example, the triangular head, whether it has front and back legs, the role of the periosteum and the role of mucus in the skin. Yeah, anyway, they discussed a lot in detail in the past, while they do less now. (Zachary_IV3)

When the amount of time dedicated to scientific practices was drastically reduced, it became difficult for the teachers to enable students to engage in experimental design, observation and data records. This is required in the curriculum standards, but is not directly assessed.

Discussion

The findings of this study confirmed the findings of previous research that in regular lessons, teachers tend to use far more closed questions than open (e.g., Eliasson et al., 2017; Hsu et al., 2023; Lee & Kinzie, 2012). The evidence presented here suggests that time constraints, exam stress, and narrowed teaching objectives all contribute to the low percentage of open questions, and also possibly the frequency of rhetorical questions. This is problematic because the scarcity of open questions and those encouraging student engagement in classroom discussions could lead to excessive teacher control. This, in turn, can limit productive classroom dialogue and students' participation in knowledge construction.

However, this study also showed that teachers adapted their questioning practices to different class types, for example, polished lessons afforded more open questions. There are several explanations for this variation. First, these polished lessons have become a routine part of some institutions' working practices. As teachers become accustomed to this routine, they develop a sense of security and feel free to share disagreements and be critical of teacher questioning within this community (Uffen et al., 2022). Second, polished lessons are directly related to teachers' reputations,

their formal appraisal and chances of promotion (Yang & Yan, 2020). Consequently, teachers are often willing to invest significant amounts of time and energy into crafting these lessons, which involves refining and showcasing their advanced questioning strategies. Teachers also adapted their questioning practices in society classes, where they had the freedom to focus on developing students' thinking.

The use of teacher questions cannot be dissociated from other teacher practices; therefore, any consideration of influences on teacher questioning needs to consider other relevant factors. This paper has identified personal (e.g., teachers' beliefs about learning), institutional (e.g., schools' working practices), and external (e.g., exam policy shift) factors that feature in teachers' accounts of their experiences of teacher questioning. This extends beyond the literature, which has typically focused on factors from only one of these areas – for example, how teachers' questioning practices are shaped by personal knowledge (e.g., Carlsen, 1987; Hashweh, 1987), by anticipated student responses (e.g., Chin, 2006; Roth, 1996), and by experiences of teacher professional development (e.g., Oliveira, 2010) – rather than looking at other factors around the school and policy environments. The results are consistent with the findings of Ryder (2015), who identified how a range of personal/institutional/external contexts impacted on teachers' responses to curriculum reform. However, our data shows the local contexts, for example, how teachers collaborate to refine questions and how changes in local exam policies affect teacher questioning. Moreover, external factors appear to be influential on teachers' questioning practices. Changing an assessment method can increase pressure on teachers and reduce the time available for scientific learning. This confirms the findings of previous studies which have shown that assessment stress and time constraints can hinder the implementation of scientific practices (e.g., Kim et al., 2013; Ramnarain, 2016).

The holistic approach to examining teacher questioning enabled a deeper understanding of teachers' accounts of their tensions: for example, their desire to use more open questions conflicted with their task of supporting students in acquiring prescribed subject knowledge in large class settings. On the one hand, teachers had personal goals around promoting problem solving, fostering inquiry skills, and asking open questions to improve divergent thinking, while on the other, they faced institutional challenges (e.g., accountability) and external stress (e.g., exam assessment). This study aligns with Wallace and Kang's (2004) finding that personal belief sets supported teachers while public and culturally based belief sets (e.g., need for exam preparation) hindered the implementation of scientific practices. The study also illustrates the inconsistent relationship between teacher beliefs and actions, as shown in the literature (e.g., Kang & Wallace, 2005). Knowledge construction beliefs do not always lead to knowledge construction actions.

Literature shows that teachers might teach based on their beliefs, but these beliefs can also originate from their teaching practices (Dolphin & Tillotson, 2015; Lane & Ríordáin, 2020). This study demonstrates that strict accountability regimes and competition regarding exam scores may shift beliefs from knowledge construction to knowledge transfer, resulting in fewer questions being used to engage students in argument from evidence and to carry out investigations. More positively, when teachers follow the guidance offered in polished lessons and engage students in scientific practices – for example, when a teacher prioritized colleagues' feedback and

curriculum standards over time constraints and exam assessment – this might lead to gradual change in their beliefs. It is also true that tension does not always lead to stress but can generate positive and creative energy. In this study, teachers can be seen to respond to tension in different ways. For example, Ziv relieved his tension by carrying out open inquiry activities in the society class, where he can have more autonomy, offer students more opportunities to be active, and ask more open questions. This is similar to the research conducted by Wallace and Kang (2004), in which teachers resolved their tensions by conducting a few more open-ended inquiry-based laboratories (in addition to regular teacher-centred labs) to foster their personal goal of promoting scientific thinking. Teachers also moderated the openness of the questions, where they need to save time in regular classroom settings. This aligns with Van Booven (2015)'s research that focuses on the tension in teacher questioning between the authoritative and dialogic. He suggests that teachers in inquiry-based classrooms need to find a middle ground that is neither too authoritative nor too dialogic in order to meet their diverse learning objectives and students' needs.

Teachers may consider employing a ladder of questions with varying degrees of openness. For example, they could first ask, "What do you think are the characteristics of bird bones?" followed by, "What are the characteristics of a bird's sternum?" Using these follow-up questions can deepen students' understanding of the subject matter while keeping the discussion focused. Another aspect of questioning practices that helps mitigate the tension between personal beliefs, time constraints, and exam stress involves teachers posing more open questions and managing discussions during lessons where the subject matter is easy to learn and more time is available to develop students' thinking. Evidence shows that a socio-scientific context enables teachers to use genuine questions to which the teacher does not know the answer (e.g., How do you think?), opening up spaces for students' multiple voices (Bossér & Lindahl, 2021). Additionally, Ziv's engagement in scientific practices in the society class provides insights into how institutions can offer forums, separate from regular classes, where teachers and students can engage in scientific practices purely for the intellectual excitement of discovery, free from exam or time pressure. Helen demonstrated that she framed open questions that directly relate to exam questions. This approach legitimizes students' participation in classroom inquiries while also preparing them for exams.

Implications and Conclusion

The study has limitations that need to be addressed. First, our inability to observe lessons directly means we may have missed some important local contextual factors. Second, the sample of six expert teachers excluded those who have not received awards yet employ diverse questioning strategies. This focus on a specialized group of teachers narrows the broader applicability of the findings. For example, the questioning strategies used by these expert teachers may not be practical for other teachers in their everyday teaching. Third, while the study encompassed school policies and the broader context within which teacher questioning occurred, it did not

include interviews with school leaders. Consequently, the perspectives of school authorities were not captured, and the extent to which teaching and teacher questioning were influenced by these leaders remained unexplored. Finally, the concept of tacit knowledge, encapsulated in Polanyi's statement that "we can know more than we can tell" (Polanyi, 1983, p. 4), is acknowledged in the analysis. As Korthagen and Lagerwerf (1996) point out, teacher behaviour is not always guided by logical and rational thinking, and many actions are unconscious, spontaneous, automatic, and mechanical. Teachers may discuss their teaching extensively during interviews, but these conversations do not encompass everything they know about teaching.

Despite these limitations, the study has demonstrated that individual teachers' questioning practices vary according to the precise lesson context, and identified some of the factors that can explain such variance. It has also provided evidence of the tensions teachers feel as they design and conduct their science lessons while subject to diverse personal, institutional and external pressures. This evidence, which shows that teachers possess the pedagogical skills to ask open questions but are sometimes unable to apply them in teaching, should be highlighted in teacher professional development programs. This is crucial because previous literature tends to focus on the pedagogical skills related to open questions while neglecting the tensions teachers face in implementing these skills (e.g., de Boer et al., 2021; Lee et al., 2012). It is therefore suggested that teacher educators recognize this complex array of factors, understand teachers' difficulties and struggles, and help them negotiate tensions. A case study of how an expert teacher has negotiated these challenges positively could be used. For example, Ziv enjoyed engaging with students but was really struggling to use a variety of teacher questions in the classroom. However, in the society class, Ziv used more open questions and encouraged students to pose inquiry questions they were interested in. During teacher training sessions, the teacher educator could ask teachers if they see anything of their experience in Ziv's and give teachers opportunities to talk about their challenges and pressures in their own context and how they overcame these challenges.

Teachers used different words (e.g., "broad" and "divergent") to express the idea of open questions. One possible reason is that, although they were familiar with related pedagogic knowledge, they lacked understanding of the concepts of open and closed questions. Therefore, it is advisable to provide teachers with specific training on these types of questions. Teacher educators can introduce various types of teacher questions, accompanied by corresponding examples. They can ask, for example, "Can you give us an example of this type from your own teaching?" They can also introduce the concept of a spectrum for open and closed questions. A question can fall anywhere on the spectrum from open to closed, thereby enabling teachers to tailor the openness of their questions to suit specific teaching objectives and learning needs.

Making biology an exam subject for high-school entrance, which is a significant external factor here, changed teachers' classroom enactment of scientific practices significantly. For example, after this policy shift, Zachary did not allow students to observe in small groups how bullfrogs adapted to their environment. Crucially, the finding shows a tension around the interaction of two distinct

policies: the curriculum policy, and the assessment policy. The assessment policy emphasised biology subject knowledge, as this is what learners need to reproduce in the exam; by contrast, the curriculum policy stressed the need for learners to develop skills in scientific practices; the two policies were pushing in different directions. An implication is that policymakers need to consider how policies interact and potentially support each other, as well as how teaching, assessment, and external education policy (e.g., curriculum standards) can be aligned (Ryder & Banner, 2013).

Appendix A

Table 5 Factors influencing teacher questioning

Personal (teacher focus)
Subject knowledge
Pedagogical knowledge
Beliefs about learning
Views about teacher questioning
Beliefs about biology teaching and science teaching
Views about scientific practices
Years in teaching
Personal biography
Institutional (school focus)
Institutional working practices
Colleagues
Students (e.g., differing academic achievements)
Learning objectives
Textbooks
School ethos and priorities, student intake quality, and school policy on class grouping
Exams at school
Physical teaching spaces (e.g., laboratory and classroom)
Large class size
Resources (e.g., physical models, student drawings and experimental materials)
External (system focus)
External exam policy
Chinese culture (e.g., explain why a Chinese character is used to name a structure)
Curriculum standards
Requirements for completing teaching tasks on time and time constraints
The impact of teacher involvement in research on their questioning practices

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Declarations

Ethics Ethical approval was obtained from the Business, Environment and Social Sciences (AREA) Faculty Research Ethics Committee at University of Leeds. The approval number is AREA 19-176.

Declarations of originality The submitted work is original and has not been published elsewhere in any form or language.

Consent for publication Consent for publication was obtained for every individual person's data included in the study.

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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