Teacher Questions in Secondary Biology Classrooms: Making Scientific Practices Meaningful for Students

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

The purpose of this study is to explore how teachers use questions in secondary biology classrooms to engage students in scientific practices and how students perceive these questions. The focus is on teaching rather than learning outcomes. Six teachers from four schools in Xi’an City took part. A standard data collection sequence of three lessons and three interviews was conducted for each teacher. Eight students aged 12 to 16 were selected from these classes and interviewed one-to-one. The study found the following. First, polished lessons that referred to the teacher developing and repeatedly refining a lesson based on colleagues’ suggestions after live classroom observation enabled more open questions. Second, teacher questions were affected by personal (e.g., teacher knowledge), internal (to the school), and external (e.g., national curriculum policy) factors with external policy shift significantly affecting questioning practices. These factors aligned to support implementation of scientific practices or teachers working actively to negotiate tensions. Third, students demonstrated sophisticated and thoughtful reflections on, for instance, open and closed questions and scenario-based questions that asked them to think from the perspective of a scientist. This expands our knowledge of students’ views about teacher questions. The method of using episodes when interviewing teachers and students about teacher questions gave new insights into how teachers selected and adapted drawings, gestures, teaching materials and resources to support their questioning and scientific practices and the relationship between what students said and what their teachers said about teacher questions. The findings have important implications for policy and practice; for example, teacher trainers need to recognize the complexity of teacher questioning and how this is affected by multiple factors so that resources can be developed to help teachers negotiate these tensions.

Table of Contents

List of Tables

List of Figures

Abbreviations

DASTT-C	Draw-A-Science-Teacher-Test Checklist
IRF	Initiation-Response-Feedback
MOE	Ministry of Education
NGSS	Next Generation Science Standards
NRC	National Research Council
NSES	National Science Education Standards
QCSS	Question-Category System for Science
RQ	Research Question

Chapter 1 Introduction

Scientific practices have been given a great deal of attention by researchers, policymakers, and practitioners in the realm of science education (e.g., Erduran, 2015; Osborne, 2014). This study attempts to unpack how teachers in secondary biology classrooms in mainland China use questions to engage students in the practices that “scientists employ as they investigate and build models and theories about the world” (National Research Council [NRC], 2012, p.30). The reasons for this focus are outlined in the following paragraphs.

1.1 The focus of this study

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). Chin (2007) argues that the types of teacher questions and the way teachers ask these questions enable students to engage in high levels of cognitive thinking and knowledge construction. Considering the significance of teacher questions, the focus of this study is on their typologies, how teachers talk about their use of questions in the context of scientific practices, and students’ perceptions of teacher questions. I am not focusing on classroom dialogue or looking at teacher-student exchanges in detail, for the following reasons: (1) much of international research is about classroom discourse in science classrooms (Roth, 2014); and (2) student responses to teacher questions tend to be limited to odd words in some Chinese senior secondary schools, where many students prefer listening to speaking.

The study is not concerned with learning, but just with teaching. I am interested in teaching advocated in the curriculum standards, for example, how teachers use questions to stimulate thinking and promote inquiry skills. I do not base my judgements on empirical evidence regarding the impact of different types of teacher questions on student learning. Designing and collecting such data is time-consuming and challenging.

1.2 The significance of this study

Teachers have some control over their questions, and they can therefore plan them to some extent. As a result, focusing on teacher questions gives strength to the thesis in terms of its potential future impact. Existing evidence shows that Chinese secondary science teachers need detailed examples and illustrations of insights that can be applied to their practice (Pei and Liu, 2018): for instance, how to use questions to help learners argue scientifically. Teachers can use questioning examples in this thesis to improve their classroom questioning and enhance the enactment of scientific practices.

Previous studies tend to focus on types of teacher questions, question techniques and strategies (e.g., Blosser, 1975; Roth, 1996; Soysal, 2022). So far, however, there has been little mention of any controversy regarding teacher questioning. The effect of teacher training is likely to be limited if it primarily aims to increase teacher awareness of different types of teacher questions (e.g., open and closed questions) without considering the tensions teachers experience and the possible reasons they ask fewer open questions. This study provides an important opportunity to advance the understanding of a range of factors within school settings, for instance, policy shifts and teacher-teacher relations. This study also offers some important insights into what students notice about teacher questions, and it will provide recommendations for policy makers and teacher professional development.

1.3 Personal rationale

From 2008 to 2011, I studied Curriculum and Pedagogy for a research Master's degree at Shaanxi Normal University. During that time, the term 'scientific inquiry' appeared most frequently in science education literature, and therefore my postgraduate research was based on the review of published articles on scientific inquiry[1] in four Chinese biology journals from 2002 to 2009.

After completing a three-year Master's degree, I taught biology in a secondary school for eight years before studying for a PhD at the University of Leeds. When teaching I tried to help students make sense of what scientific inquiry involves and used scientific inquiry as a method of advancing students' understanding of scientific concepts and developing student interest in science. I also observed numerous science lessons taught by my colleagues. However, some teachers did not carry out activities that supported high levels of inquiry, in that students were provided with the questions, procedures and even conclusions of structured enquiries. Many such lessons used closed questions to assist students in constructing knowledge rather than building towards a deeper understanding of how scientists work and how scientific knowledge develops. For example, I remember a biology teacher once asking students in the class, "Could you please tell me the six steps of scientific inquiry?" This question may mislead students into memorizing a fixed set of inquiry steps, rather than helping them understand the iterative nature of scientific inquiry.

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[1] I used the term 'scientific inquiry' in my Master's study because it has been used with regards to Chinese national science curriculum standards since 2001. In the literature review chapter, I introduce and elaborate on the term 'scientific practices' as used in the literature and my title, and its relation to scientific inquiry.

Teacher questions are the basic unit underlying classroom teaching. As a teacher, I planned a sequence of well-crafted questions before class and refined my questions afterwards: for instance, adapting questions to help students think from different perspectives. Curiosity about how other teachers might use teacher questions in scientific inquiry, and my desire to improve teacher questioning led to me joining a PhD programme at University of Leeds.

Having reflected on my personal research and work experience related to the foci of the thesis, I will now describe my broad working environment and school policies in the following paragraphs because they are closely associated with my research questions [RQs].

When I was a secondary biology teacher, I was involved in three groups in my school: a collective lesson preparation group where biology teachers teaching the same grade discussed the teaching agenda and how to teach key teaching points and difficult teaching points every Monday afternoon; a biology teaching research group that was a collection of all biology teachers; and a grade group composed of all subject teachers teaching the same grade. The school had several policies to monitor and improve teaching. For example, it required teachers to have handwritten lesson plans that were checked regularly, and beginner teachers were expected to write detailed lesson plans. The school had two classrooms allowing teachers to easily record classroom-based teaching and asked each teacher to record at least four lessons every year. Teachers were encouraged to watch and reflect on videos of their own teaching, share their recordings on the internet and use these recordings to participate in competitions. For example, in 2019, teachers from different provinces shared classroom teaching videos on a national platform for educational resources, and the number of lessons reached more than one million, from which 10,000 exemplary lessons were selected.

There are two semesters in China every year. The first semester starts on September 1 and ends before the Chinese New Year that typically falls in either January or February. The second semester begins in spring, and the summer holiday begins in early July. In the first two weeks of each semester, the school leaders at my school selected lessons to observe, entering the classrooms without giving prior notice. The school also required teachers to observe at least 20 lessons over a semester and take down notes, including the introduction, teaching activities, teacher questions, and writing on the blackboard, and make comments. I observed hundreds of lessons in person while my lessons were observed many times during the eight years. I preferred to observe classrooms of expert teachers who had innovative ideas and motivated students to learn – for example, an English teacher dressed up as Charlie Chaplin and taught a lesson called A Master of Nonverbal Humour – because I could reflect on what I learned and how to improve my teaching.

One important yearly school event was a classroom teaching competition judged by a panel of experts (e.g., school leaders and university professors) because it affected teachers' teaching reputations and promotions. Before participating in this competition for the first time, I prepared a lesson about one month in advance. I invited several biology teachers to observe my lesson; they gave me many useful suggestions, and I repeated the process a few times before the competition. This process was a typical activity in the biology teaching research group. I used the term *polished lessons*, although it is a rarely used term in the international literature, because it is the language used by Chinese teachers, and its meaning represents Chinese culture; teaching is a craft and teachers can invest time and effort to hone a lesson into a masterpiece. I discuss polished lessons in more detail in the literature review chapter. As stated earlier, I also watched other teachers' polished lessons. Sometimes, in a teacher professional development programme, a teacher and a class of students were invited on a stage to present a lesson to a large audience. Therefore, it is quite common for teaching to be observed, appraised, shared, and modelled.

I worked in a school and in a teaching research system as detailed in Chapter 2, being involved in a variety of activities and affected by different levels of policies (e.g., biology curriculum standards and school-based policies). What I want to emphasize here is that my classroom practices, including questioning practices, were influenced by the working environment, policies, and culture. This led to me exploring how teacher questions were influenced by a range of factors.

1.4 Thesis structure

My thesis is composed of nine chapters, including this introduction. Chapter 2 introduces the context of the study in China: for instance, the context of scientific inquiry, the structure of the national science curriculum, and teacher development in China. Chapter 3 on literature review begins by defining key terms (scientific inquiry and scientific practices), looks at some seminal literature on teacher questions, and explores how factors influence teacher practices. The first three chapters therefore lay the foundations for RQs. I present my RQs here to provide a clear focus, but these specific questions and how they are informed by the literature review and research aims will be elaborated in more detail in the fourth chapter on methodology.

RQ 1 *What types of questions do teachers ask during teaching that encourages students' engagement in scientific practices?*

RQ 2 *What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?*

RQ 3 *What are teachers' reflections on factors influencing teacher questioning strategies?*

RQ 4 *How do students perceive their teachers' questioning in class?*

The first RQ is largely concerned with quantitative data on teacher questions. The second RQ qualitatively explores the purposes of teacher questions. RQs 3 and 4 are about teachers' and students' reflections on teacher questioning within a broad context surrounding teachers' workplace and policies. RQ 1 focuses on teacher questions, whereas the others involve teacher questioning that encompasses not only teacher questions but also their context and progression over time. Chapter 4 is also concerned with research philosophy, pilot studies, sampling strategy, formal data collection, data analysis, and ethical considerations. The fifth, sixth, seventh, and eighth chapters then present the findings for each RQ. The final chapter gives a summary of the findings for each RQ, discusses my original research contributions to the existing literature, provides the implications for policy and practice, and identifies future research study.

Chapter 2 Research Context

This study is closely related to curriculum reforms and policy implementation in science education. In this chapter, I first present the structure of the national science curriculum, then describe the context of scientific inquiry, and finally discuss teacher development in mainland China. Before proceeding to explore these topics, it will be necessary to give a brief overview of the implementation of the standards policy in China. Curriculum standards form the basis of the compilation of primary and secondary school textbooks, and provide guidelines for teachers' lesson plans, classroom practices and student assessment in mainland China (Zhang, 2022). They are the national key central documents referred to in the educational reforms, and there are no provincial or local curriculum standards. There are regional variations on issues of school curriculum, assessment, and textbooks, but they need to be aligned with the national standards. After the curriculum standards are released, local departments of educational administration and teaching research institutions are expected to organize various training activities in order to implement them (Ministry of Education [MOE], 2017a, 2017b, 2017c). Schools should then support and encourage teachers to learn curriculum standards in school-based teaching research groups, change the teaching methods, and carry out scientific practices in the classroom (MOE, 2017a, 2017b, 2017c).

2.1 Structure of the national science curriculum

The implementation of the full-time compulsory education in mainland China usually refers to six years of primary education (ages 6-12), which starts with Grade 1 and ends with Grade 6, and three years of junior secondary education, during which students (ages 12-15) complete Grades 7, 8 and 9. Senior secondary school education (ages 15-18) then lasts three years from Grades 10 to 12.

Students in primary schools are required to learn integrated science as a subject covering biology, chemistry, geology, and physics. In addition, they learn three separate science subjects – physics, chemistry, and biology – in junior and senior secondary schools. However, teaching integrated science for junior secondary students is only implemented in a small number of regions in China (Dan and Chen, 2011). For example, so far, Zhejiang has been the only province in which integrated science has been adopted and fully implemented in all junior secondary schools (Wang, 2018). Currently, the most widely adopted structure of the science curriculum can be seen in Table 2.1, which looks at the case of Shaanxi Province that has Xi'an as its capital city.

<table>
<tr><td rowspan="2"></td><td colspan="5">Grades</td></tr>
<tr><td>1-6</td><td>7</td><td>8</td><td>9</td><td>10-12</td></tr>
<tr><td>Educational Stage</td><td>Primary</td><td colspan="3">Junior secondary</td><td>Senior secondary</td></tr>
<tr><td>Ages</td><td>6-12</td><td colspan="3">12-15</td><td>15-18</td></tr>
<tr><td rowspan="3">Subjects</td><td rowspan="3">Science</td><td colspan="2">Biology</td><td></td><td>Biology</td></tr>
<tr><td></td><td colspan="2">Physics</td><td>Physics</td></tr>
<tr><td colspan="2"></td><td>Chemistry</td><td>Chemistry</td></tr>
</table>

Table 2. 1 Structure of the science curriculum from Grades 1 to 12 in Shaanxi Province in mainland China

2.2 The context of scientific inquiry in Mainland China

In this section, I use the term ‘scientific inquiry’ because it has been used in reference to Chinese national science curriculum standards since 2001. In the following paragraphs, I show how Chinese educational documents have given top priority to scientific inquiry, because this is related to the focus of my study and has had a significant influence on my research and teaching experiences.

Since 1949, mainland China has implemented reform to the basic education curriculum eight times. The eighth curriculum reform related to Grades 1-12 (ages 6-15) was initiated by the Outline of Basic Education Curriculum Reform that was released by the MOE in June 2001. In comparison with the former seven curriculum reforms, the eighth stressed the importance of students’ development and called for a transformation from rote learning to active participation in scientific inquiry (Liu et al., 2012; Zhong, 2006). Scientific inquiry has been defined as

> the abilities which are based on observation and experiments and include posing questions related to physics; formulating hypotheses and predictions; designing experiments and planning investigations; gathering and analysing data; making conclusions and explanations based on evidence; and communicating, evaluating, and reflecting the inquiry processes and results. (MOE, 2017a, p.5)

According to the *Biology Curriculum Standards for Compulsory Education (2011 Edition)*, the rationale for junior secondary biology teaching involves “advocating scientific inquiry”, “science for all” and “developing biological scientific literacy”. Here, biological scientific literacy refers to “biological scientific concepts and scientific inquiry skills required for personal decision making, participation in civic and cultural affairs, and economic productivity” (MOE, 2011, p.3). Hence, scientific inquiry was introduced in 2011 as one of the three core ideas of junior secondary biology curriculum in mainland China.

The MOE released the new editions of the national physics/chemistry/biology curriculum standards for senior secondary education in 2017. According to these revised editions, core literacies became the new rationale for teaching physics, chemistry, and biology, defined as the correct values, essential characteristics, and key abilities that students form through disciplinary learning to position for lifelong development (MOE, 2017a, 2017b, 2017c). In terms of biology, they consist of four dimensions: big ideas of biology, scientific thinking, scientific inquiry, and social responsibility (see Figure 2.1). These lay the foundations of the objectives of the senior secondary biology curriculum while also setting the criteria for textbook compilation, classroom teaching and academic assessment (MOE, 2017b). For example, the newly revised *General Senior Secondary School Biology Textbook* published by People's Education Press in 2019 added some *Inquiry·Practice*[2] activities to encourage students to learn by doing and think by doing (Zhao and Tan, 2020). As shown in this figure, scientific thinking is different from scientific inquiry and refers to (1) a way of thinking that emphasizes the importance of facts and evidence and might advocate a pragmatic attitude towards knowledge; (2) an ability to use scientific methods to understand things and solve practical problems; and (3) approaches that involve inductive generalization, deductive reason, modelling, critical thinking, innovative thinking, and so on (MOE, 2017b). In summary, the *Biology Curriculum Standards for Senior Secondary Education (2017 Edition)* supported a crucial role of scientific inquiry, one of the four constituents of biology core literacies, and highlighted an educational aim for students' development of core literacies.

[2] I translated *探究·实践* used in the textbook into *Inquiry·Practice*. So, there is a dot between inquiry and practice.

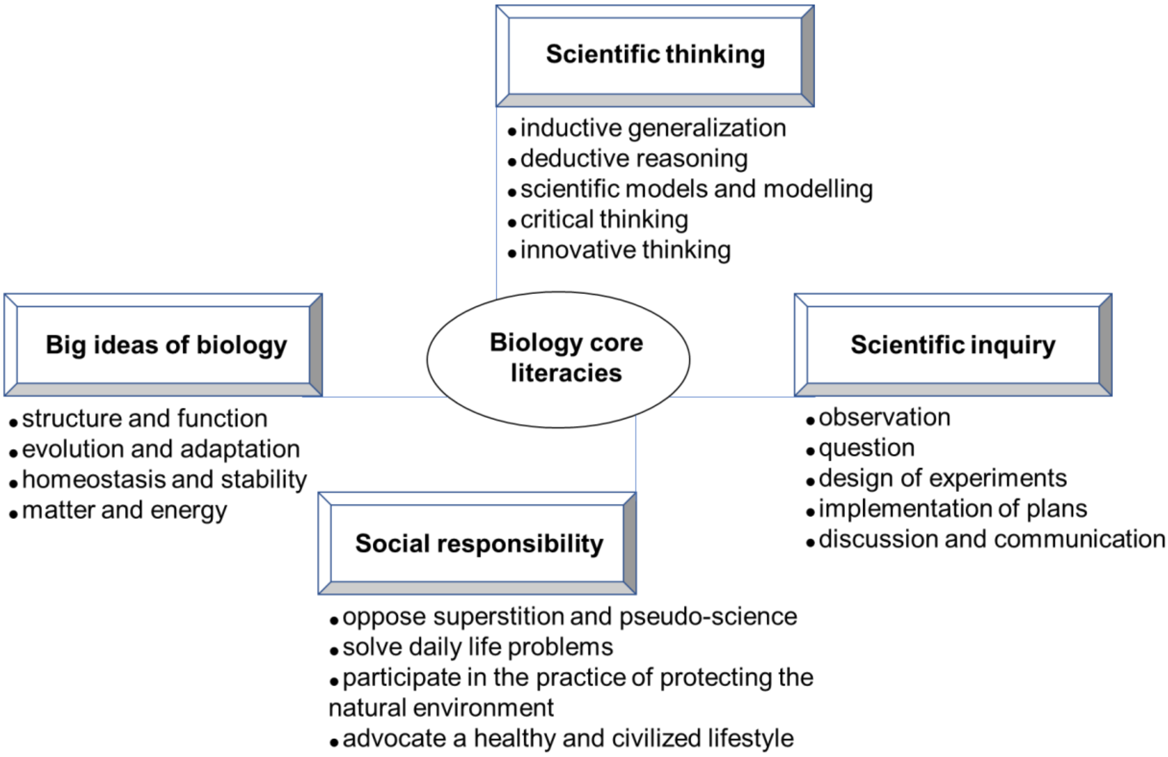


Figure 2.1 The biology core literacies

It is also clearly stated that scientific inquiry is not only a teaching and learning approach, but also a learning aim (MOE, 2011, 2017b). For example, when students learn through inquiry, they can learn about inquiry: for instance, “how to construct reliable, valid and accurate investigations” (Yeomans, 2011, p.3). Although people use scientific inquiry in different ways (see Table 2.2), in this thesis I tend to emphasize that using inquiry as a learning aim and using it as a pedagogical approach are intertwined.

Author	Argument	Use inquiry as a learning aim or a pedagogical approach
MOE (2017b)	Develop inquiry skills by teaching/ learning through inquiry	Learning aim and pedagogy (a teaching and learning approach)
Ryder (2011, p.6)	A scientific inquiry learning aim: "students should understand how scientists use theoretical models to explain phenomena"	Learning aim
Duran and Duran (2004); van Uum et al. (2016)	Support inquiry-based teaching by 5E instructional model: engagement, exploration, explanation, elaboration, and evaluation Seven inquiry phases: introduction, exploration, designing the investigation, conducting the investigation, conclusion, presentation/communication, and deepening/broadening	Pedagogy

Table 2. 2 Different uses of scientific inquiry

The MOE released the new editions of *Physics/Chemistry/Biology Curriculum Standards for Compulsory Education* in 2022 to highlight the importance of students' development of core literacies. The biology curriculum standards retained the essence (e.g., key concepts in biology) of the original 2011 biology curriculum standards and made developing core literacies a tenet of the biology curriculum (Zhang, 2022). Core literacies here include four elements: big ideas of biology, scientific thinking, inquiry practices, and attitudes and responsibilities. In terms of the meaning of inquiry practices, inquiry means scientific inquiry and practices refers to interdisciplinary practical activities: for example, students rear silkworms and collect data on the history of sericulture in China (MOE, 2022).

1. **Core literacies**: scientific inquiry is a key component of the core literacies of the biology curriculum and an important way of learning biology. (p.5)
2. **Curriculum objectives**: students need to develop inquiry skills: for example, asking questions, collecting and analysing data, and forming conclusions. (p.6)
3. **Teaching tips**: teachers should recognize the value of scientific inquiry in students' development of core literacies and use different ways of carrying out scientific inquiry: for instance, practical activities, data analysis, investigation, and measurement. Teachers may help students pose inquiry questions based on learning objectives and teaching content and encourage them to design experiments and collect data on their own initiative. Teachers need to place an emphasis on reports of inquiry activities and communication. (p.37)
4. **Assessment suggestions**: student assessment should be based on core literacies: big ideas of biology, scientific thinking, inquiry practices, and attitudes and responsibilities. (p.40)
5. **Textbook compiling suggestions**: textbooks should include a series of scientific practices. Through the process of asking questions, making hypotheses, collecting data, testing hypotheses, and drawing conclusions, constructing biological concepts, students can develop scientific thinking and have a better understanding of the nature of science. (p.45)
6. **Appendix**: some lesson plans on scientific inquiry are provided to capture the essential features of inquiry (e.g., posing questions, formulating hypotheses, and communicating) and to develop students' inquiry skills (see Appendix 1). (pp.53-69)

Table 2. 3 What the *Biology Curriculum Standards for Compulsory Education (2022 Edition)* say about scientific inquiry

Some major points about scientific inquiry in the latest biology curriculum standards for compulsory education are summarized in Table 2.3. It can be seen from the table that the biology curriculum standards directly affect curriculum objectives, lesson planning, classroom teaching, student assessment, and the compilation of textbooks. According to the teaching tips in the table, teachers cannot provide all the steps of the inquiry process and they need to give students opportunities to conduct a higher level of inquiry: for example, students can design procedures by themselves. I also present a sample lesson plan about an investigation into environment factors influencing the distribution of woodlice and an expert's comments in Appendix 1. From the expert's comments on the aspects that are emphasized in scientific inquiry and what students need to learn, I infer that scientific inquiry is more about the practices scientists do when they carry out research, rather than learning a concept. However, what is and what is not scientific inquiry is not clearly stated in the biology curriculum standards; therefore, teachers may have different understandings and interpretations of the concept.

There are various influential factors on the journey from national curriculum standards to the classroom teaching: for instance, policy enactment, teacher professional development, and teachers' personal understanding of scientific inquiry. Teachers' difficulties and dilemmas have been reported in previous studies (e.g., Zhang et al., 2005). For example, given the large class size (e.g., 50 students), time constraints to cover a prescribed biology curriculum content, and pressures from test-based accountability, the lecture method was adopted as the main teaching way (Cong, 2008). This was also greatly affected by Soviet educational theory that highlighted the teaching of systematic knowledge and the teacher's leading role (Gu, 2004). Furthermore, students were mostly engaged in inquiry questions posed by their teachers, and it was difficult to engage in open inquiry activities during the inflexible 45-minute class period. However, since the start of Chinese national curriculum reform and its stress on inquiry-based learning and opposition to rote learning, memorization and passive learning, it has been advocated that inquiry-based activities should be carried out on a regular basis.

2.3 Teacher development in China

Teacher development in this thesis can be defined as follows: “the process whereby teachers’ professionality and/or professionalism may be considered to be enhanced” (Evans, 2002, p.131). “Professionality” refers to “those elements of the job that constitute the knowledge, skills and procedures that teachers use”, and “professionalism” refers to “status-related elements of teachers’ work” (Evans, 2002, p.130), and Tsui and Wong (2009) argue that most teacher development happens in the workplace in China. This section focuses mainly on the policies, teaching research systems, and school practices that support teacher development in the workplace.

The educational administration structure (see Figure 2.2) is consistent with the administrative divisions of China that consist of several hierarchic levels, with education policies delivered from the MOE to schools in a top-down approach. China has more than 30 provincial-level regions (the highest level of administrative divisions) that are then divided into city-level areas, which are in turn subdivided into county-level divisions. For example, Shaanxi Province, which covers an area of over 200,000 km^2 with about 39 million people, is composed of 10 city-level divisions, including Xi’an City, the provincial capital, which covers an area of 10,000 km^2 with about 13 million people. The 10 cities of Shaanxi Province are subdivided into more than 100 county-level divisions.

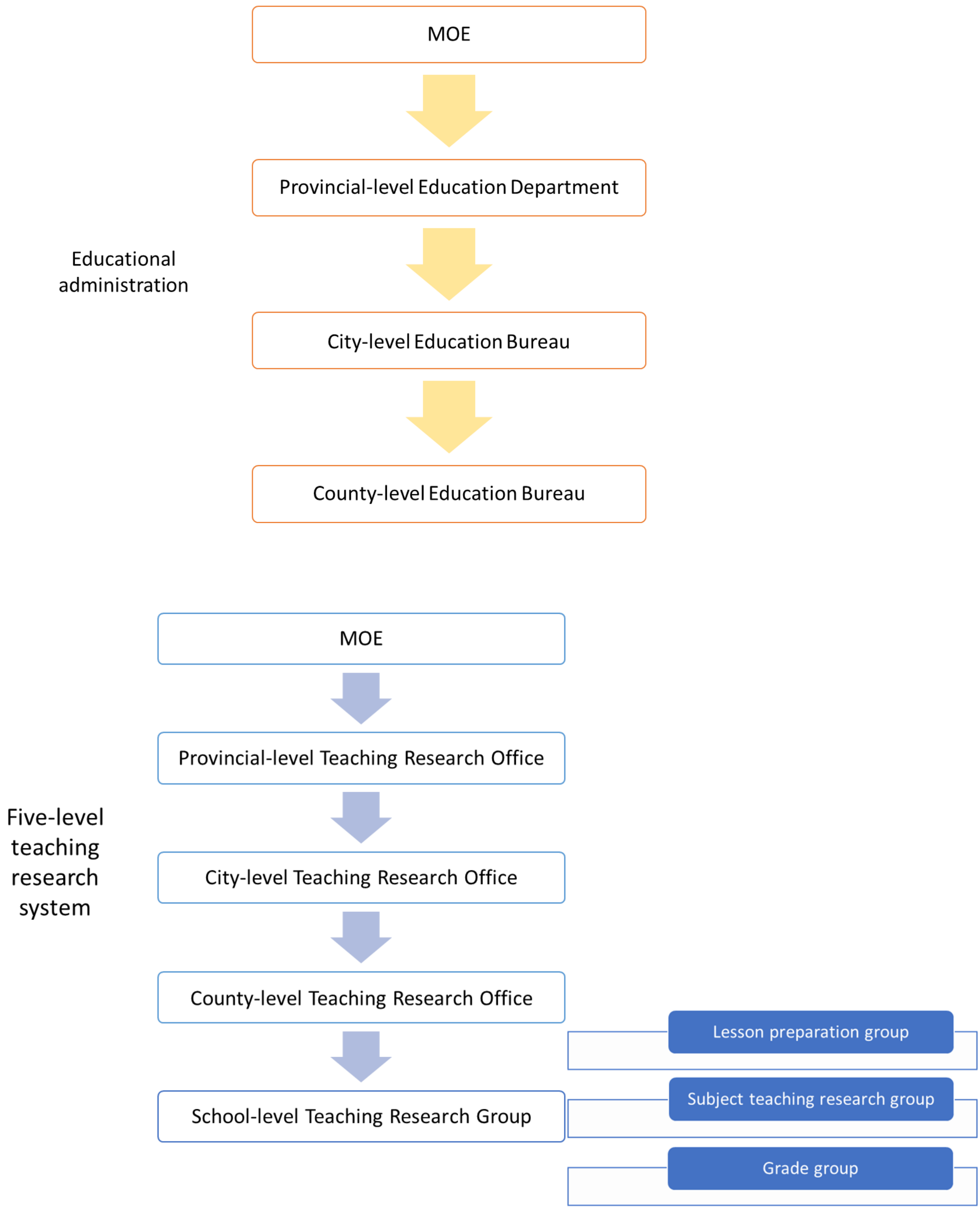


Figure 2.2 Educational administration and the teaching research system in China

In addition to this system, there is a five-level teaching research system that was set up in the 1950s (Yin et al., 2020). There are two possible explanations for the division into two separate systems (Cong, 2011). Firstly, China has a huge number of students, teachers and schools in primary and secondary education and a heavy educational administration workload. For example, the number of students enrolled in compulsory education was about 150 million, and there were about 10 million full-time teachers and about 207,000 schools for compulsory education in 2021 (MOE, 2022). Secondly, teaching and learning is at the core of school education and education specialists are needed to guide teachers and improve the quality of school education. However, education administrators may not possess such qualities.

The five-level teaching research system (see Figure 2.2) includes the National Centre for School Curriculum and Textbook Development, which is affiliated with the MOE, provincial-level, city-level, and county-level teaching research offices, and school-level teaching research groups (MOE, 2019). As explained in section 1.3 in the introduction chapter, there are three types of school-level teaching research groups: lesson preparation group, subject teaching research group, and grade group. This teaching research system builds a network covering all subjects, all teachers, and all grades in primary and secondary schools. It not only helps teachers get rid of professional loneliness (Dussault, 1997) but also connects a teacher’s individual professional development to the collective professional development. The details are described below.

In the teaching research groups, two common collective activities related to teacher development are collective lesson preparation, and lesson observation and lesson discussion (Cong, 2011). Firstly, the collective lesson preparation, which is usually organized once a week, can assume a typical form whereby a teacher talks about teaching ideas, what the key teaching points and difficult teaching points are, how to teach them, assignments, etc. Then, other teachers who teach the same subject and the same grade give their opinions and suggestions based on what the speaker said. Finally, the framework of the lesson plan is formed, and teachers can adjust it according to their students. Head teachers usually attach great importance to the collective lesson preparation and check and evaluate it regularly. Secondly, lesson observation and discussion are also commonplace. They are sometimes carried out in the lesson preparation group, sometimes in the teaching research group, and sometimes across the whole school. Generally, during the lesson discussion, the teacher who taught the lesson first talks about the learning objectives of the lesson, how to achieve them, how to identify teaching strategies according to students or educational theories, the confusion, etc. Then, teachers who have observed the lesson point out advantages and disadvantages. Lesson observation and lesson discussion are key components of polished lessons, as discussed in the literature review chapter. After completing polishing a lesson in a small group, the teacher then delivers a public lesson that refers to the fact the lesson is now open to a larger audience.

In terms of county-level or city-level teaching research offices, teacher developers in teaching research offices carry out online teaching research activities, go to schools to observe and make comments on lessons, organize open lessons of different levels, and help teachers to participate in teaching competitions at different levels (Cong, 2011). Throughout this thesis, the term *teacher developers* will refer to people who work in teaching research offices and have responsibility for guiding teaching and research in primary and secondary schools. According to the MOE (2019), teacher developers should possess great teaching and research skills, be familiar with educational theories, and have a wealth of teaching experience. In principle, they have more than six years of teaching experience and achieve excellent results in education (MOE, 2019). The National Centre for School Curriculum and Textbook Development affiliated with the MOE is responsible for provincial-level teaching research offices that assign tasks and provide guidance to lower-level teaching research offices. Provincial-level teacher developers may offer similar activities – for instance, giving lectures, organizing provincial-level open lessons, and guiding competitions – and because there are so many schools and teachers in a province, certain schools send a small proportion of teachers to attend these activities.

A well-known Chinese-language teacher stated that the beginning of her teacher professional development was to deliver public lessons: first to the whole school, then gradually to teachers who may be from different schools but work within a certain county-level area, and then to teachers in the city (Yu, 2006). In the process of polishing lessons and preparing for public lessons, teachers can get help from other teachers, colleagues, and teacher developers. Through constantly polishing teaching materials, refining lesson plans, improving teaching details, and reflecting on teaching, teacher professionality is well developed (Zhu and Qin, 2008).

Awarding an individual outstanding teacher an honorary title has long been a Chinese tradition, and there are different types (e.g., backbone teachers and expert teachers) and levels (e.g., national level, provincial level, and county-level) of teacher titles. Generally, educational administration departments use a series of procedures, select a certain number of famous subject teachers who have remarkable achievements in teaching and educational research from in-service teachers every year, and give them special treatment. This is supported by government policies. For example, the MOE released *Notice on the Implementation of the Training Plan for Famous Teachers and Headteachers of Primary and Secondary Schools in the New Era (2022-2025)* in 2022, through which 150 nationally known teachers from different regions were then selected to be trained regularly for three years to lead the reform and development of basic education (MOE, 2022). In addition, provincial governments have issued numerous policies and taken measures to support teacher development and select expert teachers. These expert teachers then have responsibility for helping other teachers' professional development. For example, a physical education expert teacher delivered over 300 lectures and went to undeveloped provinces many times to train rural teachers (MOE, 2021). In another example, a famous teacher polished her lessons and then make them openly available for beginner teachers. Through lesson demonstration and lesson discussion, the expert teacher could transmit the pedagogical knowledge she had accumulated over a long career to beginner teachers in only a short period, which saved beginner teachers a lot of time (Guo, 2008). Furthermore, she contributed to collective teacher professional development, rather than being satisfied with her own career success. Expert teachers may not have any legal authority (Paine and Ma, 1993), but they earn the respect of other teachers and might have celebrity effect. They demonstrate exemplary teaching and exemplify how to translate curriculum standards into classroom practices, and beginner teachers may imitate their heroes and learn.

Chapter 3 Literature Review

Conducting a literature review is standing on the shoulders of giants. I learn from the literature and draw upon it, but this literature review also presents critique of existing work. Because different reviewing processes may lead to different qualities and quantities in the literature and to different conclusions (Snyder, 2019), I start this chapter by explaining my review process in order to increase its transparency. I then go on in subsequent sections to present a wide variety of theoretical and empirical perspectives on scientific inquiry, scientific practices, teacher questions, factors influencing teacher practices, and students' views on different modes of interaction in the classroom.

3.1 The reviewing process

In this section, I first illustrate the scope of my review with a figure. I then describe the method I adopted to identify the relevant literature, including my search aim and methods.

3.1.1 The scope of this review

A literature review is "a foundation for all areas and stages of the research": for instance, RQs, methodology, data analysis, research findings, discussion, and conclusions (Cohen et al., 2018, p.181). It includes, but is not limited to, these points: defining key concepts; reporting related methodologies that need to be advanced or offer some insights into my research design; identifying landmark theories and ideas related to my research; and identifying potential research gaps. Based on these perspectives, I developed a literature map which shows the scope of my literature review (see Figure 3.1). There are two parts of the figure: topics of the review, and context of the review.

As can be seen in the figure, my review focuses more on teachers as that is the focus of my RQs. The key emphasis of this review is not on the empirical evidence of the impact of teacher questions on student learning outcomes. At a later stage, I will pay some attention to explore students' in-depth perceptions of different modes of interactions in the classroom as this is related to RQ 4. In the boxes in Figure 3.1, I list some key references that had impacted considerably on my study. As shown in the small box, I tried to perform a thorough search for issues around teacher questions, the core focus of the thesis. This includes types and purposes of teacher questions in accordance with my RQs. Teacher questions are worthy of focus in a thesis since they are identifiable and often the focus of teacher planning; however, they are not isolated form other aspects of teacher practice. Teacher questions are not "simply teacher behaviours but mutual constructions of teachers and students" (Carlsen, 1991, p.157). Thus, I was interested in issues around teacher practices more generally. In the larger box, I focused particularly on factors influencing teacher practices in relation to curriculum reform, while a sub-theme on differences in practices between beginner and expert teachers was reviewed because it was linked to the selection of teachers in the research design. The literature also identifies tensions between competing pressures or factors as a key theme in the work of the teachers. It involves the types of tensions teachers experience in the context of curriculum reform or scientific practices and how teachers negotiate these tensions. I also reviewed literature on polished lessons since they were highly relevant to current practices in China and set in a context that was significantly different from the context of the existing research.

The other part of the figure is the context. The literature I reviewed could be considered in the context of scientific inquiry or scientific practices, but it is not limited to them.

For example, the typologies of teacher questions could be in science, maths, or English lessons. Studies on teacher questioning or teacher practices have been conducted in multiple subject areas. I decided to look at broader themes, rather than only looking at the literature related to scientific practices or science teaching and learning. The literature that was written beyond the science curriculum context and relevant to my thesis might offer a fresh perspective on teacher questions in the science curriculum context.

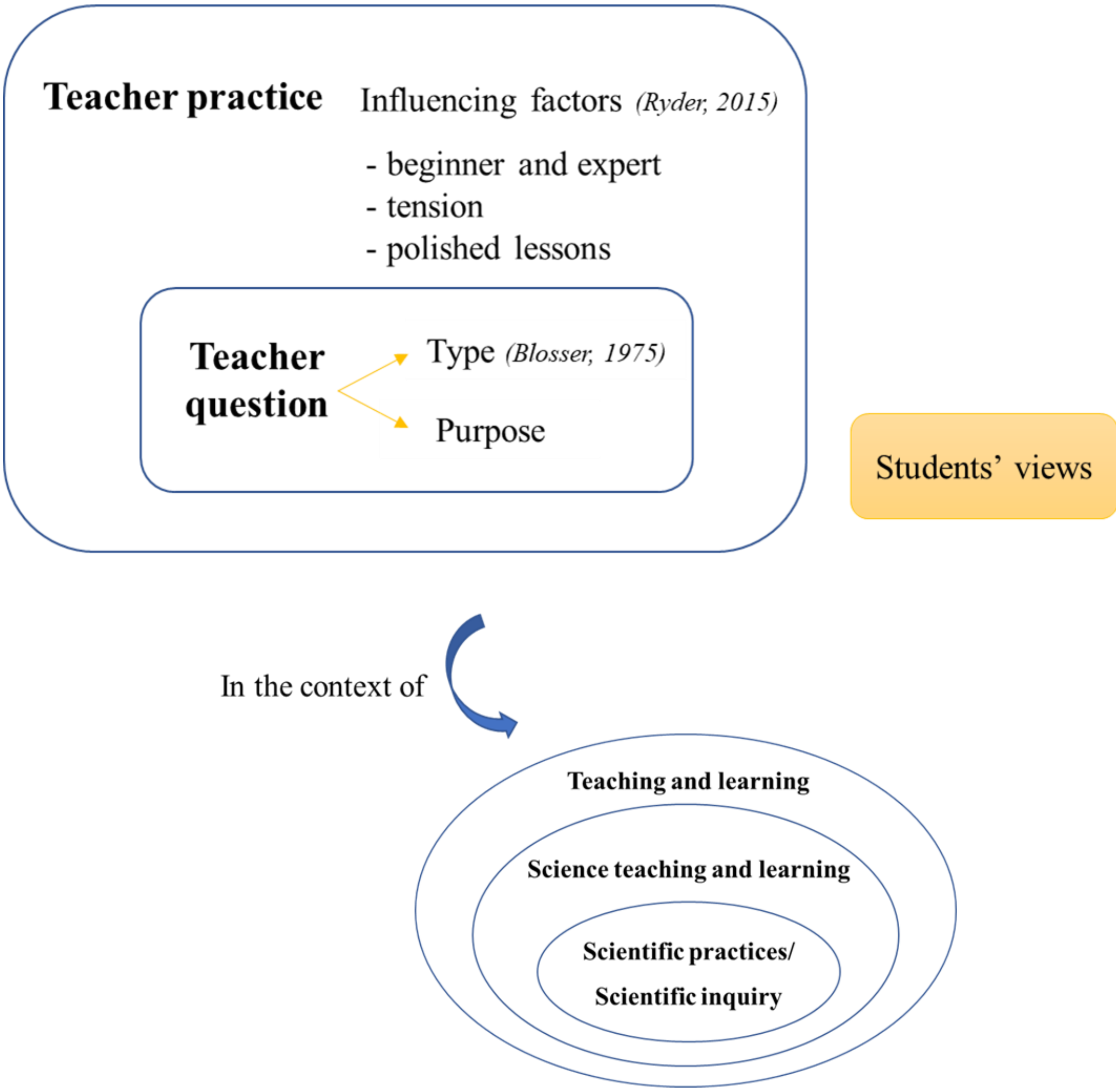


Figure 3.1 A literature review map

3.1.2 The search strategy for this review

My aim was to review relevant and high-quality literature that is published in peer review journals and widely cited by other researchers, rather than searching through all the relevant literature and immersing myself in a large sea of literature. Instead of undertaking a systematic review that focuses on a narrow topic and requires a stringent literature selection, I looked at some seminal research on the above topics to see how they informed my RQs.

There has been a huge body of research on scientific practices, teacher questions, or teacher practices over the past decade, and I needed to be selective. Therefore, I used several methods for collecting and identify literature. One method involved searching for the literature in four science education journals with high impact factors: *International Journal of Science Education, Journal of Research in Science Teaching, Science Education* and *Research in Science Education*. For example, when selecting studies related to teacher questions in these journals, I searched by title and used *teacher questioning*, *teachers' questions* or *teacher questions* as search terms via the Web of Science platform. The publication year was not restricted to after a certain year, but I tried to access more recent relevant and high-quality work that shows thorough critical thinking, presents convincing arguments, and offers original and insightful ideas that impact classroom practices and teacher professional development. Another search method meant I identified a few highly cited papers including, but not limited to, some that also included literature reviews (e.g., Carlsen, 1991; Kayima and Jakobsen, 2020; Ryder, 2015). I printed copies of the entire articles, and then manually searched references to identify additional articles relevant to my topic. The selection criteria were title, publication year, language, and research quality (e.g., highly cited papers and peer-reviewed journals). I read the abstract, then browsed through the article, read the most relevant part, and made my final decision. I also did literature searching by identifying important researchers who have published literature that has advanced the knowledge, methodologies or application in teaching and learning; for example, I searched on

Google Scholar for papers by William S. Carlsen, who published a seminal paper on teacher questioning from a sociolinguistic perspective in 1991, and I found another paper about the effect of science teacher subject-knowledge on teacher questioning.

3.2 From scientific inquiry to scientific practices

As stated in section 1.3, this study is concerned with teacher questioning in scientific practices rather than scientific inquiry. The definitions of the terms and their historical arguments, differences, and the reasons for the shift from scientific inquiry to scientific practices are explored in greater detail in the following sub-sections.

3.2.1 Scientific inquiry

According to some research, scientific inquiry tends to lack a consistent and explicit definition (Crawford, 2014; Herranen and Aksela, 2019; Minner et al., 2010). A widely quoted definition by National Science Education Standards [NSES] (National Research Council [NRC], 1996, p.23) emphasizes what scientists do: "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work". At the same time, the NSES (NRC, 1996, p.23) provides direction for teaching and learning and defines scientific inquiry as multiple specific things that scientists do, and students are also able to do, in the classroom:

> a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results.

However, the document fails to sufficiently distinguish between what scientists and students do in the classroom, which can lead to confusion and curriculum problems (Lederman et al., 2014; Ryder, 2011). For example, using inquiry as a learning aim and using inquiry as a pedagogical approach are intertwined. Teachers might possibly know inquiry as a teaching approach emphasized in the curriculum reform documents but then neglect what students should learn about inquiry (Lederman et al., 2014). As I mentioned before, scientific inquiry is used in my thesis both as a learning goal and a pedagogical approach, which is consistent with the MOE (2011).

A later document states inquiry has five essential features (NRC, 2000, p.29):

(1) Learner engages in scientifically oriented questions.

(2) Learner gives priority to evidence in responding to questions.

(3) Learner formulates explanations from evidence.

(4) Learner connects explanations to scientific knowledge.

(5) Learner communicates and justifies explanations.

Scientific inquiry is also highlighted in many other documents, though there is little consensus around the world regarding what constitutes inquiry and its critical features, because science curriculum standards, instructional documents and research articles have defined inquiry as different activities and strategies (Crawford, 2014; Rönnebeck et al., 2016; Wilson, 1976). For example, the Ministry of Education of Singapore (2013) states scientific inquiry has five essential factors: question, evidence, explanation, connections, and communication. White and Frederiksen (1998) create an inquiry cycle including five steps: question, predict, experiment, model and apply. Grangeat (2016) proposes a detailed model based on six essential features of scientific inquiry: the origin of questioning; the nature of the problem; students’ responsibility; the management of students’ diversity; the role of argumentation; and the explanation of teachers’ goals.

In addition, Crawford (2014) argues that scientific inquiry contains some different variations, including project-based science, problem-based learning, authentic science, and model-based inquiry. It is therefore even harder to guess the meaning in a speaker's mind when scientific inquiry is used. For example, Tal et al. (2006) emphasize four features of project-based science: a driving question, collaborative work, learning technologies, and the creation of artefacts. Rivera Maulucci et al. (2014) view authentic science inquiry as an active and generative process where students do actual scientific work by exploring their own questions, collaborating with scientists, and assisting with actual data collection.

Many studies on the openness of scientific inquiry focus on inquiry as a pedagogical approach. For example, Schwab (1962, p.55) first identifies three different degrees of openness in the inquiry process:

> At the simplest level, the manual can pose problems and describe ways and means by which the student can discover relations he does not already know from his books. At a second level, problems are posed by the manual but methods as well as answers are left open. At a third level, problems, as well as answer and method, are left open: the student is confronted with the raw phenomenon—let it be even as apparently simple a thing as a pendulum.

Based on Schwab's three levels of inquiry, Herron (1971) suggests adding a zero level in which investigation questions, procedures and conclusions are given (see Table 3.1). Osborne (2014) argues the lowest inquiry level shows teachers' misunderstanding of inquiry as a pedagogical approach, i.e., teachers equate inquiry to recipe-style practical work due to a lack of a generally accepted meaning of scientific inquiry. In this level, teachers might pay more attention to manipulative skills and canonical subject knowledge rather than an understanding more about the nature of scientific inquiry (Abrahams and Millar, 2008; Osborne, 2014).

Following the work of Herron (1971), Tafoya et al. (1980) rename four types of inquiry activities: confirmation, structured inquiry, guided inquiry, and open inquiry, which refer to levels 0, 1, 2 and 3, respectively. However, Sadeh and Zion (2012) define inquiry types in the following ways: structured inquiry (level 0), guided inquiry (level 1), coupled inquiry (level 2) and open inquiry (level 3). Furthermore, the NRC (2000) proposes more detailed inquiry levels based on the five essential features of inquiry, each of which can vary in the amount of learner autonomy. For example, in the process of posing questions, students can raise their own questions, choose alternatives, or sharpen the investigation questions provided by teachers. "The more responsibility learners have in the five features, the more open the inquiry. The more responsibility the teacher takes, the more guided the inquiry" (NRC, 2000, p.30). Together, there is a consensus among these categorizations that open inquiry features less teacher authority and more student autonomy.

Level of inquiry	Questions	Procedures	Conclusions
0	given	given	given
1	given	given	open
2	given	open	open
3	open	open	open

Table 3. 1 Herron's four inquiry levels

Kirschner et al. (2006) claim that open inquiry is less effective than guided inquiry because students may have insufficient prior knowledge and develop misconceptions, whereas a growing body of literature argues that open inquiry enables students to develop critical thinking, inquiry skills, and positive attitudes towards science (e.g., Berg, et al., 2003; Zion and Mendelovici, 2012). For example, Sadeh and Zion (2009) conducted a two-year longitude study and divide 50 high school students into two groups: an open inquiry group and a guided inquiry group. They conducted the quantitative content analysis and found that open inquiry students performed better in terms of two criteria: changes during the inquiry (e.g., making changes in the inquiry process) and procedural understanding (e.g., understanding the importance of controlling variables and using data). They suggest giving teachers an opportunity to experience an open inquiry project in which students are encouraged to pose inquiry questions, plan investigations, and carry out data collection and analysis.

There is a large volume of studies focusing on the nature of science that generally refers to “the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge” (Lederman et al., 2013, p.140). Schwartz et al. (2004) argue that teachers’ reflections on nature of science in an authentic inquiry context where they had an internship at universities and worked with scientists can promote understandings of the nature of science.

Some studies on scientific inquiry have paid particular attention to socio-scientific issues. For example, Lederman et al. (2014) illustrate that socio-scientific issues (e.g., genetically modified foods and genetic testing) are an important tool with which to develop students’ understanding of scientific inquiry. For example, students may play different roles (e.g., a scientist and a public health official), argue and make decisions based on controversial information, resembling what scientists are expected to do when they justify knowledge, according to Abd-El-Khalick (2003). Day and Bryce (2011) state socio-scientific issues enable teachers to pose open questions that allow students to consider an issue from multiple perspectives. However, Ryder and Banner (2013) find that several teachers mentioned they should focus on the teaching of traditional subject knowledge due to pressure of curriculum requirements, rather than the teaching of social-scientific issues.

3.2.2 Scientific practices

As described earlier, *Inquiry·Practice* is used in titles within *General Senior Secondary School Biology Textbook*, published by People's Education Press in 2019: for instance, *Inquiry·Practice An investigation of water uptake and loss in plant cells* and *Inquiry·Practice Factors affecting enzyme activity*. According to the *Biology Curriculum Standards for Compulsory Education (2022 Edition)*, inquiry practices represent one of the four elements of core literacy, by which it meant scientific inquiry and interdisciplinary practical activities (MOE, 2022). The use of these terms in recent Chinese textbooks and policy documents has demonstrated a tendency to highlight the role of practice in the biology curriculum.

A clear shift from scientific inquiry to scientific practices was seen in the following documents. The *Framework for K-12 Science Education* (NRC, 2012) and subsequent *Next Generation Science Standards* [NGSS] (NGSS Lead States, 2013) highlight the educational aim of student participation in eight scientific practices: (1) asking questions; (2) developing and using models; (3) planning and carrying out investigations; (4) analysing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations and designing solutions; (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information.

The term 'scientific practices' has been distinguished from 'scientific inquiry' in three ways. Firstly, the definition of scientific practices is less ambiguous than that of scientific inquiry. Secondly, scientific inquiry is implemented in a fixed order in many Chinese science classrooms (Tang and Ding, 2012). For example, the whole class tends to propose one inquiry question, generate one hypothesis, develop one experimental design, and draw one correct conclusion in inquiry-based science lessons (Pei and Liu, 2018). Conversely, scientific practices are "used iteratively and in combination", and they are not a linear set of "steps to be taken in the order presented" (NRC, 2012, p.49). I hope students can find more diverse ways of successfully learning and doing science, rather than having to follow step-by-step procedures (Mody, 2015). Finally, Crawford (2014) states that, when compared with inquiry in the NSES (NRC, 2000), scientific practices put greater emphasis on scientific modelling and argumentation. They capture the centrality of critique and argumentation, which is important for scientific learning (Ford, 2015; Osborne, 2014).

However, some researchers have argued the definition of scientific practices is narrow because it limits scientists' work to eight practices and it is unclear to what extent these practices can capture the crucial aspects of science (e.g., Ford, 2015; Tang, 2022). Collins (2015) questions if what students learn at school can really represent what science is like. The secondary classroom inquiry practices emphasize the importance of experimentation (Gray, 2014) but scientists from different disciplines use diverse science methods; for example, cosmologists might take the view that it is unnecessary to use experimentation methodology to justify scientific knowledge (Stroupe, 2015). In addition, scientists' daily routines may involve buying lab chemicals and tools, supervising, presenting reports, writing, publishing, and applying for funding (Mody, 2015); therefore, it is inappropriate to provide students with a neat and tidy model but neglect to include many of scientists' other regular tasks.

3.3 Typologies of teacher questions

A considerable amount of literature has been published on typologies of teacher questions, which is one of the foci of this thesis (see Figure 3.1). To capture a broader picture of question typologies in the literature and lay the foundations for section 3.5, which outlines the trends, a review of typologies of teacher questions based on different classification criteria (e.g., the cognitive level and content of teacher questions) is described in the following sections.

Blosser (1975) has developed a question classification hierarchy known as the Question-Category System for Science [QCSS], consisting of closed, open, managerial (e.g., questions that maintain classroom discipline) and rhetorical questions (questions that emphasize statements). Closed questions refer to questions that are often asked to obtain a limited number of “right answers” (Blosser, 1975). They can be further subdivided into two distinct categories: closed memory questions and closed convergent questions. Closed memory questions are used to recall factual knowledge and probably elicit one- or two-word answers: for instance, asking students to fill in the blank or give a yes-no response. Closed convergent questions are used to identify more complex operations encompassing predicting, comparing, explaining and higher cognitive levels. Open questions do not have fixed answers, and it is expected they will elicit two or more different answers. They can be further subdivided into open divergent and open evaluative questions. Open divergent questions can be answered with a whole range of possible answers and the teacher does not require any form of evaluative judgement (Blosser, 1975), while open evaluative questions highlight the students’ views and try to encourage them to express opinions from their own perspectives and understanding. Rhetorical questions are questions that teachers ask but do not anticipate getting answers. Questions like “Lack of water, isn’t it?” or “S strain bacteria killed mice, right?” are rhetorical. Managerial questions are those that address classroom management issues, for example, “Could you please turn to page 30?” and “Do you know the answer?” Eliasson et al. (2017) used this framework to examine 953 questions posed by 14 secondary science teachers in Sweden and found that 87 percent of teacher questions were closed questions and only 13 percent open.

Erdogan and Campbell (2008) present three broad categories of question: close-ended questions, open-ended questions, and task-oriented questions (questions that are used to manage or to understand previous statements). However, they classify close-ended and open-ended questions into further sub-categories. For example, closed-ended questions include verification (yes/no questions), disjunctive (choose between two alternatives), concept completion (fill in the blank), feature specification (ask for fixed and qualitative answers), and quantification (quantitative questions).

Numerous typologies have been based on the level of cognitive thinking required to answer the questions. For example, Bloom’s taxonomy introduces a hierarchy of six such levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. This taxonomy is widely applied across a range of contexts: for instance, teacher questions and student responses. Many taxonomies based on the cognitive dimension (e.g., Anderson et al., 2001; Krathwohl, 2002; Sanders, 1966) have been revised based on Bloom’s taxonomy and used as measurement tools to study the relationship between the cognitive levels of teacher questions and student learning outcomes (Carlsen, 1991; Winne, 1979).

Van Booven (2015) analysed approximately 10 hours of classroom discourse in elementary inquiry-based classrooms and classified a sequence of questions into two groups in terms of their dialogic orientation: authoritatively oriented questions, and dialogically oriented questions. The former focuses on only one point of view, while the latter accommodates non-fixed answers or multiple voices (Chin, 2006). The analysis revealed that authoritatively oriented questioning could obviously limit students’ higher-order scientific understanding, while dialogically oriented questioning could provide discourse opportunities for students to share their views from different perspectives and gain a deeper understanding of the knowledge. Van Booven also suggests that teachers should negotiate a tension between authoritatively and dialogically oriented questioning according to their learning objectives and employ some in-between questions. They suggest such questions can be effective in helping students to develop higher-order thinking.

Oliveira (2010) explores elementary teachers' perceptions and questioning practices before and after their participation in a summer institute designed to enhance teacher questioning skills in the context of scientific inquiry. He describes two types of teacher questions in the light of their degree of student-centredness. Student-centred questions emphasize the importance of what the students say or think: for instance, referential questions (requests for students to share what they think), confirmation checks (confirmation if what students said is understood correctly), and clarification requests (students clarify what they said). In contrast, teacher-centred questions primarily focus on the teachers' authoritative points: for instance, display questions (teachers test if students know the right answers), and comprehension checks (teachers check if students understand what the teachers said). The findings shows that teachers used more student-centred questions after the training programme, and that, compared with teacher-centred questions, students normally gave longer and more detailed responses to student-centred questions. Oliveira also highlights the importance of tentative questioning with hedges (e.g., "What do you think…?" (Oliveira, 2010, p. 440) and "What else can be fabric?" (Oliveira, 2010, p. 438)) because it conveys the teacher's expectation for an uncertain answer rather than a correct answer and, therefore, students feel safe to hypothesize, speculate and make mistakes in a nonthreatening learning atmosphere.

Roth (1996) classifies an expert teacher's questions into five groups in a Grade 4/5 classroom, according to their content in an open-ended engineering context in which students spent most of their time working in pairs and engaging in their bridge-building projects: questions about the natural world, questions about design practice, questions about the development and testing of design, questions about the final product, and questions about knowledge (e.g., the meaning of an important engineering concept). This typology is more closely related to engineering design and practices (e.g., purposes of designs and methods of testing stability) than engineering facts (e.g., the properties of materials). The teacher used questions to elicit students' explanations and ideas and seldom asked questions to assess whether students knew facts and knowledge.

These representative question-classification systems are compared in Table 3.2. In this table, teacher questions were classified according to function, cognitive level, teacher authority and content. The taxonomies of Blosser (1975) and Bloom (1956) are general and widely used classification systems of teacher questions and the other typologies were developed in the context of scientific practices.

Author	Focus	Classification
Benedict-Chambers et al. (2017)	Function	Explication questions, explanation questions, science concept questions, and scientific practice questions
Blosser (1975)		Closed cognitive memory, closed convergent thinking, open divergent thinking, open evaluative thinking, managerial questions, and rhetorical questions
Bloom (1956)	Cognitive level	Knowledge, comprehension, application, analysis, synthesis, and evaluation
Oliveira (2010)	Teacher authority	Student-centred and teacher-centred questions
Van Booven (2015)		Authoritatively oriented and dialogically oriented questions
Roth (1996)	Content	Questions about the natural world, questions about design practice, questions about the development and testing of design, questions about the final product, and questions about knowledge

Table 3. 2 Representative question-classification systems

Roth's (1996) typology of teacher questions sits within the context of open-inquiry engineering and is subject- and situation-specific. Such classifications provide concrete examples of teacher questioning in a specific domain, which is more likely to relate to engineering teachers and to encourage them to use these findings in their lesson preparation and classroom teaching. The question answer relationships (Raphael and Au, 2005) represent another subject- and situation-specific example and are designed for reading comprehension instruction, such as 'right there' (questions that ask students to find answers stated in the text) and 'author and me' (questions that ask students to consider the link between the text and what they already know). Another example is the nine different kinds of teacher questions identified by Hiebert and Wearne (1993) and grouped into four broad categories (see Table 3.3). For example, 'generate story' questions are used to encourage students to create a story about a number sentence during group discussion in the mathematics classroom.

recall	recall factual information
	recall procedures
	recall prior work
describe strategy	describe strategy
	describe alternative strategy
generate problem	generate story
	generate problem
examine underlying features	explain
	analysis

Table 3. 3 Types of teacher questions during group discussion

Erdogan and Campbell (2008) argue that intensive analysis is needed to uncover the details of purposes of teacher questions: for instance, the differences in the purposes of teacher questions between low-level didactic teaching and high-level teaching practices that highlight the knowledge construction students undertake using their own initiative. As can be seen in Table 3.2, Benedict-Chambers et al. (2017) have developed four question categories: explication questions that require students to describe their observation of phenomena; explanation questions that need students to explain why or how a phenomenon works; science concept questions that ask students to use scientific language to name a phenomenon; and scientific practice questions that encourage students to engage in scientific practices. However, most of the scientific practice questions guided students to design investigations and make predictions, with fewer focusing on, for example, observing and analysing and interpreting data. Collectively, these studies suggest the need for subject- and situation-specific classification focusing on the purposes of teacher questions in scientific practices.

3.4 Purposes of teacher questions

Teachers use different types of questions to address different purposes. For example, teachers could encourage students to express their own thoughts, views, and arguments by employing student-centred questioning, while they also use teacher-centred questioning to find out whether students know the right answer (Oliveira, 2010). Moreover, one type of question could be used for different purposes: for example, student-centred questioning can not only develop students' conceptual understanding but also serve an affective function (e.g., motivate students to learn science) (Oliveira, 2010). Thus, typologies of teacher questions are not the same as their purposes. The following studies outline the critical purposes of teacher questioning.

Previous studies on teacher questions have focused on scaffolding student thinking and helping students construct science knowledge (e.g., van Zee et al., 2001). For example, by asking 'what would happen to X if Y?' or 'how?' questions, teachers support students to examine different perspectives of scientific phenomena and move towards higher-order cognitive thinking (Van Booven, 2015). Teachers can induce 'conceptual-change' through specially designed questions which probe students' conceptions, challenge them to resolve inconsistent views, extend the knowledge base and help them apply learned concepts (Yip, 2004). Furthermore, Chin (2007, p.837) has provided evidence to support that teacher questions can be used as a "cognitive ladder" to help students to gradually go upwards towards a high cognitive level.

In addition, research on the role of teacher questions pays particular attention to teacher authority and the importance of student ideas. For example, Chen et al. (2017) analyses classroom observations and conceptualizes four critical roles of teacher questioning based on two dimensions (the ownership of activities, and the ownership of ideas): dispenser, moderator, coach, and participant (see Figure 3.2). The role of participant means students have the ownership of the activity and an idea when the teacher asks a question: for example, one student invited the teacher to a discussion, and the conversation between the student (Olivia) and the teacher (Brielle) is shown in the following (Chen et al., 2017, p.392):

> Olivia: I think rotation means like spinning, and orbit means to go around. Ms. Roberts, what do you think? Do you agree with me?
>
> Brielle: Okay. Could I have Olivia show me what you mean by going around?

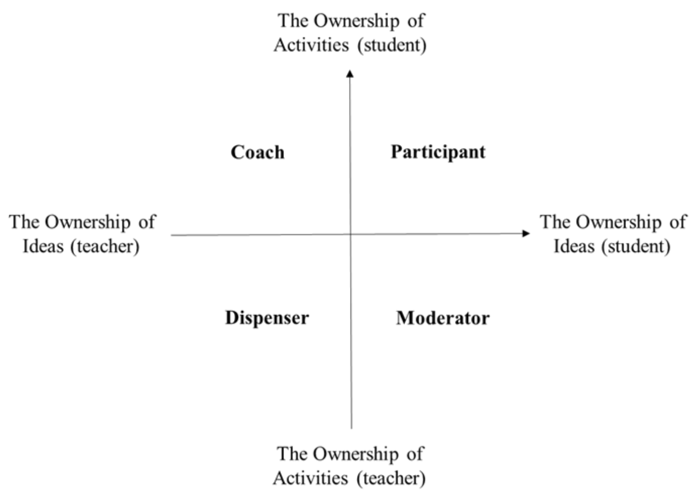


Figure 3.2 Four teacher questioning roles as developed by Chen et al. (2017)

This study has a striking methodological strategy. The participants were three US elementary teachers with over 20 years of science teaching experience but no experience of using an argument-based inquiry approach that encouraged students to use evidence to debate and support their claims. Thirty-one science lessons over four years were collected and analysed in order to capture changes in the teachers' questioning roles as they persistently implemented an argument-based inquiry approach, which made the study very strong methodologically. Chen et al. (2017) finds that teachers relied on the dispenser role in the first year but increasingly used multiple roles (e.g., moderator and coach) over time, which resulted in students demonstrating a high level of verbal argumentation performance.

In terms of teacher authority in the role of teacher questioning, Roth (1996) describes a case study of an expert teacher's questioning as part of an open-inquiry curriculum where the teacher's questions facilitated Grade 4/5 students' discursive activity and led to student-centred discussions. The teacher asked questions frequently to encourage students to talk about the bridges they made initially, which progressed to students offering explanations and justifications independent of the teacher's questioning and resulted in a student-led discussion where peers posed key questions in the domain of engineering. She usually asked questions to allow students to use their own language to construct their stories, rather than evaluating. She drew students' knowledge out, which was consistent with her belief that students knew canonical content knowledge: for instance, regarding materials and engineering techniques. Similarly, as noted by Oliveira (2010), teachers treated students as complementary experts, rather than novices, which led to students' engagement in classroom discussion and elicited long and complex answers.

In the same vein, Van Zee et al. (2001, p.177) conduct case studies involving elementary, high school and university science teachers and further highlight the importance of the use of teacher questions to draw out student ideas and find that teacher questions were typically asked to develop conceptual understanding by eliciting students' experiences (e.g., "Where did you see the moon?") and diagnosing and refining student ideas (e.g., "What do you think might happen?" and "What is your evidence for that idea?"). They also found that it was evident that teachers in their case studies used "reflective tosses" (Van Zee et al., 2001, p.178), questions employed to encourage students to reflect on what they had found confusing, rather than telling students the answers directly. Most important, when they explain how the teacher used questions to help students talk science, hear their thinking, and figure out the answers, they not only analyse a teaching episode, but also present the teacher's comments and two students' totally different views on this approach. This is an insightful and fruitful methodology worth pursuing in my thesis, not just because it has not been often employed, but also because it can provide distinctive insight. Thus, this informs my research design, which involves asking teachers and students to talk about their views about the same teaching episodes.

Chin (2006) observed 14 lessons taught by two teachers who asked many interactive questions in the classroom and identified purposes of utterances. She mentions two main purposes of teacher questions in the initiation model of Initiation-Response-Feedback (IRF): drawing out, which includes eliciting, probing, and extending; and cueing and provoking, including clarifying, prompting, and challenging. However, the results are based on different modes of teaching (e.g., lectures, teacher demonstrations, and whole class discussions) and not scientific practices.

Kawalkar and Vijapurkar (2013) analyse teachers' written reports about their motivations when questioning, examine all the teachers' questions for their intended purposes over 12 lessons, and compare the purposes of teacher questions in inquiry-based teaching and those in traditional teaching. Results indicate teacher questions had six purposes: exploring pre-requisites or setting the stage; generating ideas; probing further; refining conceptions; guiding the entire class; and classroom management. The progression of questioning in inquiry teaching was “from eliciting, diagnosing and probing students’ ideas to refining them and guiding the entire class towards accepted scientific knowledge” (Kawalkar and Vijapurkar, 2013, p.2019), whereas there were almost no questions to probe and refine students’ thinking in the traditional science classroom. Some possible limitations of their research design should be noted. For example, science lessons were carried out after school and one of the two participant teachers asked to teach science using inquiry had relatively little experience in inquiry-based teaching.

In terms of the purposes of teacher questions, these studies provide valuable insights into student cognitive development, teacher authority and pedagogical considerations. However, they tend to rely on classroom observations to access and interpret the purposes behind teacher questions. The limitation of this is they do not listen to teachers’ ideas regarding the complex, manifold and differently focused purposes of questions. A detailed account of teachers’ reflections on their question purposes is therefore missing.

3.5 Reflections on trends in the literature on teacher questions

Having reviewed literature on the typologies and purposes of teacher questions, I shall continue in this section to discuss three trends found in the literature on teacher questions. I selected the following themes because they are important in setting the context for my research.

Trend 1: As evidenced by the literature I have reviewed, there is a move away from a quantitative linguistic approach (e.g., Stevens, 1912; Dillon, 1985; Graesser and Person, 1994) towards a sociolinguistic approach that pays attention to “the role of social context in the interpretation of spoken language" (Carlsen, 1991, p.158). It is not, for example, a matter of counting the number of teacher questions and how much time a teacher spends asking questions during a lesson but a case of applying linguistics to analyse classroom discourse. It focuses more on how language is used in a specific context.

Researchers have studied teacher questions as part of a scrutiny of classroom discourse, and their discussion has raised many important issues. Firstly, regarding teacher authority, teachers adopt teacher-centred or student-centred questioning strategies and students are positioned as either novices or complementary experts, respectively (Oliveira, 2010). Secondly, regarding social interaction, teacher questions focus on students' engagement in classroom discussion (Oliveira, 2010). Thirdly, in terms of questioning strategies, Chin (2007), who conducted research in large classes in Singapore, identifies four approaches of teacher questioning that stimulated students' productive thinking, which include Socratic questioning (pumping, reflective toss, constructive challenge), verbal jigsaw questions (association of key words and phrases, verbal cloze), semantic tapestry (multi-pronged questioning, stimulating multimodal thinking, focusing and zooming), and framing (question-based prelude, question-based outline, question-based summary).

Trend 2: Wilen (1991) points out that, particularly during the period from the 1960s to the 1980s, much research on teacher questions focused on the process-product paradigm that refers to "the relationship between discrete observable teacher questioning practices and student outcomes" (Carlsen, 1991, p.157). Many studies have often attempted to explore the impact of a certain aspect of teacher questioning on student achievement, responses, or understanding of science: for instance, the frequency of teacher questions, the cognitive level of teacher questions (e.g., Samson et al., 1987; Winne, 1979), questioning techniques (e.g., Gall et al., 1978), wait time (e.g., Riley, 1986) and different types of teacher questions (e.g., Kleinman, 1965; Kruse et al., 2022).

These approaches use powerful statistics to reveal what needs to be improved in terms of teacher questioning, and findings can be translated into suggestions for teacher professional development programmes. However, as Carlsen (1991) points out, the striking weaknesses of this process-product research include the following: (1) it would be meaningless to adopt a questioning strategy that leads to higher academic achievement but discourages students' participation in classroom discourse; and (2) counting how many questions teachers pose in a lesson and how long they wait after posing a question, for instance, misses the point of classroom discourse and separates teachers' questions from their context (e.g., learning objectives, student ability and teacher-student relationship). This recognition of the broad role of classroom discourse in the analysis of teacher questions informs some crucial decisions about my design, particularly the use of episodes, as elaborated in the methodology chapter. I also argue that these studies tend to describe what teachers do, but they do not have much data about the reasons why a teacher asks a particular question or sequence of questions and what is driving those decisions.

Considering these issues, Kayima and Jakobsen (2020) argue for a question evaluation framework that not only uses predetermined question classification methods but also pays attention to the context of teacher questions. They develop a three-step methodological framework that brings qualitative and quantitative approaches together to explore the situational adequacy of teacher questions: (1) use an identification, interpretation-evaluation and response framework, as developed by Louca et al. (2012), in order to understand the context of teacher questions; (2) use a protocol to evaluate whether questions are relevant: for instance, focusing on the salient elements of the lesson; and (3) use Bloom's taxonomy to classify questions according to their cognitive levels. An important idea in this paper is that teacher questions are inextricably intertwined with their context and any single step is insufficient to understand how teacher questioning occurs. This is a trend advocated by Kayima and Jakobsen (2020), who have also demonstrated its value empirically; hence it is one that has influenced my study design. Moreover, their idea is in line with Carlsen's (1991) view that multi-methodological research approaches can complement and have teachings to offer each other.

Trend 3: Much of the research on teacher questions has focused on teacher-student classroom discourse (e.g., Chin, 2007; Khoza and Msimanga, 2021; Russell, 1983), but I did not find any examples of studies on teacher questions from a multimodal perspective. Although language is a key component in knowledge construction and meaning making, science teaching and learning is a multimodal process that draws on many representational and communicational resources: for instance, drawings, diagrams, gestures, body positions, teaching materials, and resources (Mortimer and Scott, 2003; Wilmes and Siry, 2021). Focusing solely on the sociolinguistic aspect results in the diverse dimensions of meaning making in scientific practices being overlooked. Taking gestures as an example, McNeill (1992) identifies four basic types of gesture: beats (e.g., tapping on the desk), deictic gestures (e.g., pointing), iconic gestures that show similarities with the phenomena being talked about (e.g., using a fist to represent a heart), and metaphoric gestures that represent abstract ideas. Roth (2001, p.366) presents a figure of deictic and iconic gestures a student used while talking to his peers in the physics classroom and claimed that: (1) these gestures performed the functions of telling an event and connecting the student' utterances to a monitor; and (2) gestures were not "merely ancillary, but central features of communication". Such analysis and perspectives could be used more reflectively to explore the role of gestures in teacher questioning. Broadly speaking, future research may contribute to how teachers select and adapt drawings, gestures, teaching materials or resources to support their questioning and scientific practices.

3.6 Factors influencing teacher practices

Having reviewed the literature on teacher questioning, including typology, purpose, and trend, as shown in Figure 3.1, I now continue by more broadly considering teacher practices the and factors influencing them. The purpose is to consider a wide variety of research in relation to factors influencing teacher practices and to use this broader approach to inform specifically insights on how teachers use questions in the classroom. It includes some key issues: for instance, teachers' responses to science curriculum reform, teacher tensions, the characteristics of expert teachers, and what teacher development activities might happen in schools.

Scientific practices and teacher questions are my key research foci, and science teachers should implement scientific practices in their classrooms according to the national curriculum standards. Therefore, in this section I mainly review studies that involve factors influencing teachers' responses to curriculum reform, factors influencing the implementation of scientific practices, and factors influencing teacher questions. I cannot separate the factors influencing teacher questions from those influencing teachers' classroom practices because they are interlinked. I also include factors influencing normal teaching because they are related to the enactment of scientific practices, and there are fewer studies about teacher questions. Factors influencing teachers of other subjects that contribute to related topics are also reviewed.

3.6.1 Factors influencing teachers' responses to curriculum reform, factors influencing the implementation of scientific practices, and factors influencing teacher questions

In the past two decades there have been significant developments in factors affecting teaching in the context of curriculum reform. Ryder (2015) provides 27 factors influencing teachers’ responses to externally driven curriculum reform, based on his review of 34 studies. These factors are classified 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 categorization originates from Goodson (2003). In the same vein, Ramnarain (2016) explores teachers’ views regarding factors influencing the implementation of inquiry-based science learning in an underdeveloped region of South Africa from two aspects: (1) intrinsic, which refers to the personal attributes of a teacher; and (2) extrinsic, which refers to the environment in which a teacher works; for example, there was insufficient time for teachers to prepare lessons and carry out inquiry activities. Comparing the two categorization schemes, the advantage of using Ryder’s (2015) framework can be discerned in that it contributes to an exploration of the complex reasons behind behaviour and the relationship between personal, internal, and external factors. For example, Ryder and Banner (2013) present how a teacher’s personal goal – teaching canonical science knowledge to prepare for post-compulsory science education – was aligned with the school’s priority but in conflict with the external goal of achieving scientific literacy for all, and this therefore resulted in the teacher’s reluctance to teach socio-scientific issues. Furthermore, it may be productive to use the person/internal/external framework to empirically explore factors within the context of science curriculum reform in different cultures, and some unique internal and external factors and interactions perhaps emerge in the Chinese context.

There is a scarcity of research focusing in particular on factors that influence teacher questions. Earlier research on teacher questions tends to consider factors in terms of only one of those personal, internal, and external areas. For example, regarding the personal factors influencing teacher questions, Carlsen (1987) studied the effect of subject-matter knowledge on teacher questioning, finding that teachers who had more subject knowledge asked fewer questions and teachers who taught unfamiliar subject knowledge asked more questions, especially low cognitive-level ones. He stated that one possible reason was that the low-knowledge teachers tried to avoid questions that they would be unable to answer by restricting student verbal participation. This is supported by Hashweh's (1987) claims that knowledgeable teachers asked high-order questions, asked students to synthesize textbook ideas, and used material not covered in the textbook, whereas unknowledgeable teachers asked questions to recall knowledge in the textbook.

Regarding the internal factors influencing teacher questions, da Silva and dos Santos (2021) studied the impact of students' socioeconomic backgrounds on the chemistry knowledge shown in teacher questions. They reported that a teacher in Brazil who taught chemistry in a public school where students' families got financial help from the government and a private school where students' parents had a good education, adopted different questioning strategies according to the students' socioeconomic context. The teacher asked the students from higher socioeconomic backgrounds in the private school more questions in relation to their theoretical understanding of a chemical phenomenon. However, the students from lower socioeconomic backgrounds in the public school were asked questions more about the symbolic form of knowledge (e.g., formulas and symbols).

Regarding the external factors influencing teacher questions, more recent attention has focused on the effect of teacher training on the use of teacher questions (e.g., Joglar and Rojas, 2019). Oliveira (2010) compares, both qualitatively and quantitatively, the differences in using teacher questions before and after participation in teacher training programmes. He shows that external teacher training was powerful in several ways: teachers' awareness of the social functions of teacher questions was increased; and teachers used more student-centred questions that emphasized the importance of what students said or what they thought after training. Wasik et al. (2006) conducted an intervention study in 10 Head Start classrooms where low-income children aged between 2 and 4 did book reading. Ten teachers were trained to ask open questions (e.g., “Why did you like the book?” (Wasik et al., 2006, p.67)) during book reading sessions, while another six teachers were given no such training. Wasil et al. concluded that teachers in the intervention group asked more open-ended questions than those in the control group. De Boer et al. (2021) also reports on an intervention study where 15 student teachers were asked to individually develop as many questions as possible in 15 minutes, first without using and then using perspective-based generic questions that prompted them to generate questions from a variety of domains (e.g., comparison, functional, and evolution). The results show that teachers generated more and higher quality questions while using this questioning tool. These studies focus on how teachers improve questioning through professional development programmes and do not take a detailed account of school organisational conditions (van Driel et al., 2012). This implies that how teachers talk about their teaching or questioning practices changes over time in the workplace context should be further explored.

Furthermore, these studies tend to consider factors from only one of those areas, with less attention given to examine in detail how questions are influenced by many different factors as part of a broad picture – for instance, teacher’s personal beliefs about teacher questions, institutional working practices, and national or provincial policies – and exploring the alignment or tension between these different levels of factors. In this way, they miss some important issues for teachers. Chin (2006) identifies many factors that influenced teachers’ feedback that sometimes include teacher questions (e.g., a teacher made a comment and then asked a question): the correctness or error of student responses; the nature or difficulty level of the topic; the ability levels of the students; the curriculum time available; teachers’ epistemology; and the preferred style of teaching. The study shows that teachers adopted different questioning strategies in response to students either responding with correct answers, a mixture of correct and incorrect answers, or incorrect answers. However, it does not elaborate further on the other elements.

It is worth noting that Roth's (1996) research design is impressive and convincing. The study shows that student gender is an internal factor that influenced the teacher's questioning strategies. The teacher nominated more boys to answer her questions during interactions with the whole class, and the proportion of boys to girls answering questions was about 2:1 in 12 samples over a 50-day period. She asked girls more close-ended and low-difficulty questions because she stated that open questions might make female students uncomfortable. Nevertheless, in small group discussions, the teacher gave the girls ample opportunity to answer questions (Roth, 1996, p.709):

> 1 want students to feel comfortable… but may be the boys are more comfortable speaking in front of a group than the girls. I do relate to a little girl, I feel uncomfortable, and 1 do jump in to help her more probably than I do with a boy.
>
> 1 tested out a couple of ideas. One is having a small group of all girls together and questioning that group. 1 find that the girls are more likely to speak up there.

This combination of micro analysis of individual interviews and macro analysis of quantitative issues around teacher questions at the classroom level has implications for developing my research design. For example, I may use lesson data to quantitatively present the use of teacher questions and use interview data to explore the reasons behind it.

3.6.2 Differences in practice between beginner and expert teachers

Expert teachers is a widely used term, and yet it is a concept difficult to define precisely. Researchers have used different selection criteria in terms of four categories: (1) years of teaching experience; (2) social nomination and recognition (e.g., highly regarded by head teachers, teacher educators, colleagues, parents, or students); (3) professional and group membership (e.g., a university degree or an experience of working as a teacher educator); and (4) teaching performance (Palmer et al., 2015). Previous studies have described different sets of attributes as factors in excellent teaching (Chen et al., 2012): for instance, student-teacher relationship, classroom climate, and knowledge delivery. Some studies equate expert teachers with experienced teachers (e.g., Housner and Griffey, 1985). However, in this thesis, the two terms differ because experienced teachers can show low levels of expertise, and expert teachers can have limited teaching experience (Palmer et al., 2015). Expert teachers here refer to those who have enough classroom experience in secondary biology and the reputation of being an exemplary teacher (e.g., recognition as a provincial expert teacher). However, this is not to suggest I did not consider professional membership and teaching performance, because they are embedded within the other two criteria in the Chinese context: for example, biology teachers should have a university degree and the approval of provincial expert teachers that judge teachers' classroom performances. More details are described in the methodology chapter.

The following studies reflect the differences between expert and beginner teachers in teaching or using questions, which not only show a pathway of teacher professional development from beginner to expert teacher, but also demonstrate the relevance to the selection of participant teachers in my research.

Berliner (1988) lists five stages in the development of expertise in pedagogy: novice, advanced beginner, competent, proficient, and expert. Novices have been defined as the level in which first-year teachers, generally, need to learn several context-free rules to make sense of teaching, which is like people who are learning to drive need to learn, for example, what traffic signs mean and what to do if someone is riding a horse in front of the car. Expert is the highest degree of proficiency in teaching, which is like a driver can not only make intuitive decisions in a situation but also become one with the car (Berliner, 1988). This classification does not refer to length of service, as Berliner (1988, p.6) points out: “the duration of time spent in a stage can be expected to vary widely”. He found that expert teachers differed from novice teachers in the following ways: (1) they were more confident, effortless, and fluent and gave more detailed and descriptive comments when they interpreted what was happening in the classroom; (2) they could discern important aspects of classroom activities; and (3) they were able to predict students’ cognitive levels, how students would respond, and what types of errors students might make.

Expert teachers generally have extensive knowledge of, for instance, classroom talk, questioning strategies and how to adapt teaching to students’ needs (Brown and McIntyre, 1993). According to Brown and McIntyre (1993), expert teachers have clear goals when they arrive at the class, and they can make rapid decisions about the factors influencing their teaching based on their knowledge and the actual classroom situation. This agrees with Tytler and Aranda’s (2015) findings, which show that expert teachers’ discursive moves were not limited to IRF and went towards clarifying and extending student ideas when lessons proceeded.

Regarding teacher questioning, Roth (1996) finds that an expert teacher with experience of designing an engineering curriculum, observing construction sites, and talking with engineers asked questions covering different knowledge domains (e.g., materials, design, and performance of final products), rather than focusing only on factual knowledge. He also demonstrates that beginner teachers could gain access to the knowledge of expert teachers and improve their own questioning skills by observing expert teachers' high-quality and complex questioning practices.

3.6.3 Polished lessons

Polished lessons, a term with Chinese characteristics, have a significant impact on teachers' classroom practices. I searched related literature in the China National Knowledge Infrastructure (CNKI), using search titles in Mandarin (磨课 or 课例研究), and then focused on widely cited literature in high-quality journals. I also reviewed the policy documents on polished lessons on the MOE website. Purposes of this review are to provide an historical background, understand policy contexts and make a comparison between Chinese polished lessons and international lesson study.

The term *磨课* (polished lessons) is also translated into *lesson study*, *burnishing courses* (Lang, 2012) or *grinding courses* (Cheng, 2019). However, as described in section 1.3, I used the term *polished lessons* because it is derived from teachers' language and its meaning shows teachers spend much time and effort improving a lesson. It originated from teaching research activities in which teachers have a long tradition of collective discussions on how to improve a lesson. Unfortunately, *polished lessons* remains a poorly defined term. Liu (1999) states that polished lessons involve all the colleagues in the same grade discussing the key teaching points and difficult teaching points in the textbook and taking advantage of the collaborative effort in thematic seminars, to have a breakthrough in a certain target and obtain top-quality lessons. Pang and Jiang (2020) review many definitions and argue that polished lessons optimize classroom teaching and learning through collective and cooperative activities that include multiple rounds of classroom observations, discussions, and reflections. They also point out the purposes of polished lessons include to improve the quality of classroom teaching, to enhance teachers' teaching and research capabilities, and, consequently, to promote teachers' professional development (Pang and Jiang, 2020). Although differences of opinion still exist, in my view, a common ground among the definitions of polished lessons is that they help to develop and refine teaching and learning based on colleagues' suggestions after their live observation of the lesson. In addition, the focus of research has shifted recently from refining lessons through discussion and cooperation between teachers to supporting professional development.

This terminology was first used in the official document Sending Teaching to the Countryside Training Guide released by the General Office of the Ministry of Education [MOE] in January 2016. Polishing lessons is one of the main activities of sending teachers to the countryside, which means urban teachers go to rural schools to help rural teachers improve teaching by, for example, demonstrating high-quality lessons and observing rural teachers' classroom teaching. According to this policy document, polished lessons is an effective way of providing practical solutions for teaching problems and lessons are continuously improved by refining learning objectives, teaching content, teaching methods and assessment methods (MOE, 2016). In recent years, there has been an increase in the amount of policy support for polished lessons. For example, the local government in my study has launched the *excellent teachers+* project to promote educational equality and the balanced development of urban and rural education. Many research groups have been set up to mingle expert teachers (e.g., provincial expert teachers) and other teachers who teach the same subject. It was required for each research group to carry out at least one *sending teaching to the countryside* activity every year. Every group is expected to polish at least ten top-quality lessons every year and share them on the high-quality education resource online platform.

The organizers of polished lessons could be a teaching research group of a subject in a school, a school, a government education research institute, or a national training project (Pang and Jiang, 2020). Three essential features of polished lessons are identified in my study: (1) the teacher who teaches the lesson does a great deal of planning, preparation, and refinement; (2) teachers collaboratively discuss how the lesson can be improved after the live classroom observation; and (3) the discussion revolves around specific details of teacher teaching, including teacher language, transition, blackboard writing and teacher questions. Wang (2017) gives an example of polishing a lesson. A teacher initially asked during the lesson: "When the final product (glutamate) is too much, it will inhibit the activity of glutamate dehydrogenase. Which type of regulation is it?" One student answered: "Feedback regulation." The teacher did not give feedback and waited until the third student said the correct answer: "The regulation of enzyme activity." After polishing, the teacher asked a different question to develop student thinking: "OK, now we have three answers, feedback regulation, negative feedback regulation and enzyme activity regulation. Which answer or answers do you agree with? What is the relationship between them? Please tell me your reason, think about the reasons why you don't agree with a certain answer, and then discuss it with your classmates who are near you and disagree with you."

Yang (2019) argues that polished lessons are a kind of Chinese lesson study, one of three lesson study models – the other two being Japanese lesson study, and the learning study structured by variation theory in Hong Kong and Europe. However, in my view, polished lessons are slightly different. Firstly, the teacher sometimes studies curriculum standards alone and writes lesson plans alone before inviting colleagues to observe the lesson. Secondly, classroom observation and subsequent discussion focus more on teacher teaching, rather than student learning and engagement. Japanese teachers, however, do not sit at the back of the classroom; they approach students, listen to students' views, watch how students work in small groups and observe when and where students are stuck (Chen, 2011). Their discussion focus is therefore almost entirely on students' learning content, methods, and effects (Chen, 2011). Thirdly, polished lessons are supported by the Chinese teaching research systems (Yang, 2019), which exist in provinces, cities, and counties. The school-level teaching research group is composed of teachers who teach the same subject in the school, while the teachers who teach the same subject and the same grade constitute a smaller lesson preparation group. If there is a need for a demonstration of a top-quality lesson, the school's teaching research group will carry out polished lessons, and every teacher, as a member of the teaching research group in the school, will be involved in the process.

3.6.4 Teacher tension

Teachers may have competing thoughts or beliefs when they prepare lessons or take actions in the classroom. The term teacher tension describes when teachers are being pulled in different directions by multiple factors affecting teacher practices and they have to negotiate these forces, which can give teachers creative and positive energy or make them feel tense and stressful. For example, a teacher strikes a balance between a group work activity in which each group heats a leaf in a test tube of boiling ethanol in a beaker of hot water and thinks about why the green colouring of the leaf disappears, and a form of demonstration which ensures the health and safety of students. There might be a tension between the teacher's personal willingness to give students opportunities to do science and school policies that consider student safety in the lab to be a priority. Focusing on tensions is a valuable step towards understanding teachers' difficulties when implementing scientific practices, exploring multiple reasons or contradictions behind their classroom practices, and gaining a deeper understanding of the relationship between teachers' beliefs and practices (Wallace and Kang, 2004).

Kim et al. (2013) conducted questionnaire surveys, reflective writing, and group discussions with pre-service and in-service teachers, identifying three types of tensions in inquiry-based teaching in Singapore. Firstly, teachers were in favour of inquiry developing students' interest and curiosity, but highlighted the importance of student academic performance due to the pen-and-paper test assessment and accountability. Secondly, they considered whether to give priority to inquiry skills (e.g., analysing and interpreting data) or canonical science knowledge. Similar tensions are reported in other studies. For example, Ryder and Banner (2013) discuss a tension existing between the teaching of social-scientific issues and the teaching of traditional subject knowledge. According to several teachers, the goal of scientific literacy conflicted with their desire to teach science knowledge. Thirdly, teachers on the one hand stated students should have the freedom to do what they were interested in within an ideal inquiry lesson, while on the other hand emphasizing the importance of teachers' intervention and guidance. Kock et al. (2013) conducted a case study about a series of open-ended inquiry lessons on simple electric circuits, describing some confusion about how much guidance or freedom should be given to students. They found that students in a very open inquiry environment could not set up the correct structure of the circuits and get expected results without sufficient teacher support. However, there is a strong possibility that teachers cannot carry out open inquiry due to these tensions. For example, Biggers (2018) claims that investigation questions were overwhelmingly provided by teachers, materials or other sources and that students were not given opportunities to ask their own inquiry questions, because teachers were pressed for time and by teaching requirements.

Wallace and Kang (2004) investigate the tensions six secondary science teachers faced when they implemented inquiry and find two major competing belief strands (see Figure 3.3): (1) teachers' personal interests – for example, fostering independent thinking, promoting problem solving, and stimulating creativity by inquiry, rather than only transmitting science knowledge; and (2) cultural constraints, involving students' ability, exam assessment, and teaching efficiency. They illustrate how teachers reconciled these tensions by their creativity, intelligence, and effort. For example, teachers conducted cookbook labs most of the time to teach canonical science knowledge, which was the culturally based goal, and carried out a few open inquiry activities to achieve their personal goals of developing scientific thinking. In another example, a teacher asked thought-provoking questions to satisfy her personal desire to encourage students to figure things out while she was doing demonstrations, using them as a type of inquiry to reach her culturally based goal of covering what students needed to learn in a short time.

Figure 3.3 Teacher tensions from two competing belief sets about inquiry

These studies tend to focus on teacher tensions in the context of scientific practices. Nevertheless, few studies have explored teacher tensions within the context of teacher questioning in much more detail. As described in the section on typologies of teacher questions, Van Booven (2015) focuses on the tension in teacher questioning in inquiry-based classrooms between the authoritative and dialogic. He suggests finding a middle ground that was neither too authoritative nor too dialogic in order to meet the teachers' diverse learning objectives and students' needs. However, further studies relating to tensions between open and closed questions and teacher tensions within a different cultural context are needed.

3.7 How do students respond to different modes of interactions in the classroom?

Students are the recipients of school education, their voices are valuable and therefore they need to be heard by teachers, researchers, and policy makers. To some extent, the importance of students' views is similar to that of patients' opinions about a new medicine. Without the data on patients' perceptions and experiences after taking the medicine, it is hard to know patients' expectations, emotional reactions, and side effects, to assess whether the medicine meets patients' needs, and to identify areas that need to be improved. During the last three decades, there has been growing interest in examining students' views about good teachers, the role of the science curriculum, open inquiry, the nature of science, and attitudes towards learning science, and the use of questionnaires is prevalent (Bakx et al., 2015; Osborne and Collins, 2001; Wall et al., 2005). The following studies have adopted a qualitative method in an attempt to explore students' in-depth perceptions.

Osborne and Collins (2001) conducted 20 focus group interviews with 16-year-old students from three cities in England, finding that students expressed a great interest in practical work because: (1) they were able to select appropriate equipment and had a sense of autonomy when planning and carrying out investigations; (2) dissection (e.g., a pig's heart and kidney) was fun; and (3) scientific concepts were easier to understand and remember. These are consistent with Abrahams' (2009) findings that group reasons why students liked practical work into three categories: reasons related to affective responses; reasons related to doing science; and reasons related to learning things. Osborne and Collins (2001) also find that, regarding the science curriculum, students expressed a desire for challenge, fun teachers and teaching, and a humorous, happy, and relaxed learning environment. In terms of the more boring aspects of science, students stated that the transmissive mode of teaching, where the teacher spoke and they wrote down what they remembered, was uninteresting because they were not given time to absorb and discuss what they had just learnt.

Previous studies have shown students like open inquiry. For example, Roychoudhury and Roth (1996, p.439) show that most students demonstrated positive views about group work in open inquiry physics activities: "three people can extract much more information from a set of results than one person can". Hume and Coll's (2008) research supports this finding; students valued the opportunities to work with group members because they easily shared knowledge and expertise to solve a problem and felt safe to clarify misconceptions in a small group. Rivera Maulucci et al. (2014) explore six urban middle school students' reflections on authentic science inquiry and find that participating in the authentic science inquiry programmes can transform students' interest in science and develop a sense of agency. One student commented that learning how to set up a controlled science experiment to observe the effects of different chemicals on algae made the discovery cool and enjoyable.

However, I was not able to find any studies that specifically focus on students' views about teacher questions. A possible reason is it is difficult to get students' detailed descriptions of their perceptions about a particular question or a sequence of questions. Much of the qualitative research on teacher questioning has been reliant on teacher perceptions and classroom observations. Soysal (2022) examines 22 science teachers' lessons and develops eight types of challenging questions used to persuade students to abandon naïve views (e.g., the earth is flat and stationary) and talk about science phenomena in scientific ways. For example, one interesting type of challenging questions involves playing the role of devil's advocate and asking students to play the role of a designer of the periodic table, a small particle, etc. One limitation of this research is that students' perceptions of these types of questions – for example, their experiences, needs, what they value and what aspects they find interesting – are unknown. Van Zee at al.'s (2001) study is one that presents students' comments on their teacher's questioning approach, in which the teacher adopted a questioning strategy. After one student raised a question, the teacher asked the whole class, "What do you guys think?" in order to discuss this student's question and elicit many possibilities, rather than providing a correct answer. On the one hand, a student commented that the teacher made them figure out what they were asking, but on the other hand the student who asked the question stated the responses were irritating and ambiguous. Such comments are important because they not only reveal what students perceive as teacher questioning and why, but also prompt deeper reflections for teachers. However, such an example is rare in the literature. The research into students' views on teacher questioning to be reported in my thesis was undertaken in a way similar to that expressed in the example.

3.8 Summary

The chapter identifies research trends in literature concerning teacher questions and illustrates how this research relates to other studies on factors that influence teacher practices, particularly in the context of curriculum reform and students' voice on various classroom interaction modes. It aims to identify gaps in existing research and lay the foundation for subsequent data collection methods, data analysis, research findings, and discussions. It was pointed out that much of this research has depended on classroom observations to access and interpret the purposes behind teacher questions instead of in-depth interviews. This suggests a need to incorporate lesson data and teachers' reflections to represent the complex and multifaceted purposes of questions. This chapter has shown that research on factors influencing teacher questions tends to focus on only one area (e.g., teacher knowledge), with less attention given to holistically examine how questions are influenced by institutional and external contexts. A broad focus is therefore distinctive not only to understand how teachers use their questions within a social and cultural context but also to offer insights for teacher education, encouraging teacher trainers to understand the tensions teachers face from different areas when using questions. The literature review also reveals that students' views about teacher questioning are rarely reported. However, gathering these insights is beneficial not only for offering suggestions for teaching and teacher education but also for enhancing student motivation to learn and fostering their sense of community engagement. This leads to further exploration of students' voice on teacher questioning.

Chapter 4 Methodology

In this chapter, I first describe the research aims and RQs, then present the research philosophy, an overview of the research design, pilot study, sampling strategy, formal data collection, data analysis, and ethical considerations, and discuss my reflexivity and researcher positionality. Moreover, as the pilot study and formal data collection were carried out during the global spread of the novel coronavirus disease 2019 (COVID-19), the impact of COVID-19 is discussed in the final section.

4.1 Aims and RQs

This study has two principal aims. The first aim is to explore teacher and student reflections on teacher questions in an attempt to potentially address the research gap. The second involves exploring and exemplifying how teachers use questions to engage students in scientific practices in secondary biology classrooms to inform the design of teacher professional development and policy. As mentioned in section 1.1, I do not use empirical data concerning the impact of teacher questions on student outcomes. Focusing on teaching, even without considering student learning outcomes, remains a powerful approach. Such a focus provides valuable insights for teachers, teacher trainers, and policymakers. The aims for the study can be shaped by my RQs. In framing these RQs, I distinguished between the terms *teacher questions* and *teacher questioning* to clarify the primary focus of each RQ. For some RQs, I used the term *teacher questions*. However, in others, I emphasized *questioning* referring to strategies that encompass not only teacher questions but also consider their context and progression over time.

RQ 1 *What types of questions do teachers ask during teaching that encourages students' engagement in scientific practices?*

This question quantitatively describes the extent to which participant teachers posed different types of questions and the differences and similarities in how they used the questions. This question is related to the other RQs. RQ 2 shows the purposes of certain types of teacher questions; RQ 3 involves exploring the reasons behind questioning practices; and RQ 4 reveals student views about a certain type of teacher questions.

RQ 2 *What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?*

Here I am using the term *teacher questions*. However, this RQ starts to shift its focus towards questioning strategies and the context of teacher questions. This is because the purposes of teacher questions often emerge from their setting and from the surrounding classroom discourse. This question involves exploring the teachers' purposes behind their questioning, especially purposes related to scientific practices, and significant differences and similarities between participant teachers' purposes are discussed. As described in the literature review, existing studies tend to rely on classroom observations to interpret the purposes of teacher questions. I used two strands of data to gain a deeper insight into those purposes: lesson data, and interview data.

RQ 3 *What are teachers' reflections on factors influencing teacher questioning strategies?*

As described in the literature review, previous studies have tended to consider factors influencing teacher questions from only one area (e.g., Carlsen, 1987; da Silva and dos

Santos, 2021). The literature overall has paid less attention to how questions were influenced by many different factors within a broader picture: for instance, teacher's personal views about open and closed questions, students, school policies, and national college entrance exams. They therefore missed some important issues for teachers. RQ 3 takes a holistic approach throughout and explores the factors influencing teacher questioning on personal, internal, and external levels. The external level describes how the national college entrance examination, the high school entrance exam, and policies on teacher development influence teachers' use of questions. The internal level includes the impact of the institutional policies, students, and teacher working practices. The personal level involves teachers' personal motivations, views, and pedagogical knowledge. This RQ also explores the alignment or tension between different levels of factors; for example, some factors pushed teachers in opposite directions and teachers experienced tensions.

RQ 4 *How do students perceive their teachers' questioning in class?*

As was mentioned in the previous chapter, students are the target audience of school education, and their voices are important. Studying their views can not only provide insights into how they perceive teacher questioning and how their learning, motivation, and engagement are affected by teacher questioning, but also inform teacher professional development programmes; for example, teacher training can use this information to help teachers reflect on teacher authority in teacher questioning. However, few studies treat students' views about teacher questioning in much detail, as stated in the literature review. A possible explanation may be the difficulty in stimulating students to focus on teacher questions and articulate their feelings. It was therefore necessary for this RQ to explore students' perceptions of teacher questions. It involves students' views about open and closed questions, the sort of teacher questioning they like, or do not like, and their feelings about the role of teacher questions. This RQ connects student views with teacher views on teacher questioning.

4.2 Research philosophy

According to interpretive approaches, “the social world can only be understood from the standpoint of the individuals who are part of the ongoing action being investigated and that their model of a person is an autonomous one, not the version favoured by positivist researchers” (Cohen et al., 2018, p.17). Research is socially constructed, rather than a case of learning and exploring the world through objective scientific methods (Willis et al., 2007). Its purpose is to understand a particular context or a group of people, rather than generating a universal pattern. To understand an individual’s perspectives, it is therefore necessary to “get inside the person” in order to understand their attitudes and behaviours, as well as having detailed knowledge of the social, historical, and cultural context (Cohen et al., 2018, p.19): for instance, of a specific organization, or a participant’s background and beliefs, and political policies (Creswell and Creswell, 2018). Furthermore, this paradigm places more emphasis on the dominant role of the researchers, who therefore need to acknowledge that their research questions, methodologies, interpretations, and conclusions are affected and shaped by their experiences and perspectives.

Throughout this thesis, I also take a holistic stance that means “the whole is understood as a complex system that is greater than the sum of its parts” and “a description and understanding of a person’s social environment or an organization’s political context is essential for overall understanding of what is observed” (Patton, 1990, p.49). This perspective has three implications for my research: (1) teacher questions, teaching and learning are integral to a teacher’s role, and it would be inappropriate to neglect teaching and learning and simply collect data on isolated dimensions (e.g., teacher questions); (2) portraying a comprehensive picture of the whole would be impossible if only describing teacher questioning at one time and in one place, without exploring how teacher questions and teachers' perceptions of teacher questions change over time; and (3) I cannot understand teachers' and students' reflections on teacher questions without understanding the larger social and cultural context in which participants are situated. "Taking context seriously is an important element of holistic inquiry" (Patton, 1990, p.52).

In this study, although RQ 1 provides a quantitative overview of how teachers used different types of questions, I mainly adopted qualitative approaches, rather than questionnaires or surveys, to investigate the ways in which secondary biology teachers in mainland China used teacher questions to engage students in scientific practices. The reason was that qualitative methods considered individuals' lived experiences and natural settings and allowed me to develop a rich and holistic view of a process. I also selected qualitative methods to address RQs 2, 3 and 4 because I aimed to provide detailed examples and illustrations of insights that were gained from lesson data and interview data, and produce new and compelling evidence to inform teachers, policy makers and teacher training in order to improve classroom practices.

4.3 Overview of design

The first RQ uses lesson data to find out how teachers quantitatively use different types of questions. The second RQ explores the purposes of those teacher questions. This involves teacher questions used in the classroom and how teachers talk about their questions and purposes; therefore, it requires data from both classroom and interviews. The data obtained with different methods were like pieces of a jigsaw puzzle and would help me to gain a richer understanding of the purposes of teacher questions (Erzberger and Kelle, 2003). RQ 3 asks for teachers' reflections on factors influencing their questioning. It was impossible to gain such insights using lesson data alone and therefore I conducted interviews with teachers. The final RQ about students' perceptions of teacher questions is addressed through interviews with students. In all, I mainly used two types of data: lesson data and interview data.

4.4 Pilot study

Piloting is of crucial importance because it is done to test out the research design and improve research methods (Thomas, 2013). For example, piloting the interview schedules helped me refine the questions that the interviewee did not know how to answer (e.g., How do you design questions?) (Cohen et al., 2018). I carried out the pilot study in the secondary school I worked at because I knew my colleagues there well and I could gain invaluable feedback on one or more aspects of my project: for instance, interview schedules and the data analysis approach. The pilot study started in September 2020 and ended in January 2021. It was conducted online due to Chinese international flight restrictions during the pandemic as described in section 4.11 on COVID impact.

I first describe my piloting with a teacher and what I leaned from the pilot, then go on to present the piloting with students and my reflections.

4.4.1 Piloting with a teacher

As stated earlier, I needed to gather information regarding classroom questioning practices and to understand the questioning context by using lesson data, which is essential to a holistic approach (Patton, 1990). I could not obtain everything I needed by using lesson data alone and therefore needed to conduct interviews to find out those things that could not be directly observed: for instance, teachers' reflections on their questioning practices (Patton, 1990). I did three online interviews and collected three audio-recorded lessons with one biology teacher, Joan, who taught Grade 10. (Note that I used pseudonyms for all the teachers and students in my study to protect their identities.) Joan had many years of experience in teaching secondary biology and had been awarded the honorary title of provincial expert teacher. The rationale for selecting a teacher with extensive classroom experience and a stellar reputation for teaching excellence is detailed in section 4.5.2. Each interview took about one hour, and each lesson was about 45 minutes. The sequence of data collection was interview 1, the first and second lesson, interview 2, the third lesson, and interview 3.

The piloting was not only to test out the data collection and data analysis but also to develop and refine them. In terms of data collection methods, I found that three interviews per teacher were appropriate because the longer I engaged in a dialogue with the teacher, the more I learnt. These interviews helped me gather a lot of sophisticated and thoughtful insights from the teacher. For example, she was trying to promote problem-solving skills, develop critical thinking, and draw upon ideas of social responsibility and scientific practices, which affected her teaching and questioning. Moreover, I gradually developed an idea for the sampling criteria. I needed teachers who used questions in very sophisticated ways in Chinese classrooms, which is discussed in more detail in the section on sampling strategy.

Prior to the first interview, Joan requested that I send her the interview questions. I considered the advantages and disadvantages of sending teachers the interview guides in advance. Knowing interview questions in advance could help teachers prepare for the interviews but it might lead them to say what I wanted to hear. Therefore, I finally decided not to tell them the interview questions in advance.

Interviewing requires practice and skills – for example, asking the right questions to overcome shyness at the beginning – and I learnt several interview techniques from the pilot study. First, I learnt how to ask follow-up questions to elicit more ideas and increase the richness of data: for example, asking the teacher to give examples of what she said. Second, I initially focused mainly on teacher questions, but I later realised that I should give the teacher more opportunities to talk about the school context in which she was working, such as the school leadership, projects, and resources, as this was a part of the local school structure within which she was employing questions. I needed to ask open questions to understand the teacher from a broad perspective: for example, "What is good teaching?", "What do you mean by scientific inquiry?", and "Why are you interested in the history of science?" Third, I asked directly what Joan thought of the purposes of her questions were. This was quite difficult for her to answer. I was able to provide her with an episode from the lesson, and then asked her to talk about the teaching. The episode was a teaching extract around three minutes in length from the lesson transcription. I asked her to talk through what was going on in her mind, rather than asking what the purposes of questions were, which was more accessible for the teacher. The idea behind this approach was that the purposes of the questions were linked to longer sequences of teaching, and it is not helpful to try to disentangle a teacher question from a teaching approach or a general sequence of teaching.

In terms of data analysis, I learnt three things. First, I needed to write up the process of data analysis and how I generated the categories and themes, rather than only presenting a final analysis product. Second, I needed to use examples of interviews to show the meaning of codes. I should use more quotes, which allow the readers to hear what Joan said in her own words and get a better understanding of the claims, rather than making unsubstantiated claims. Third, sometimes it was not clear what was my interpretation or speculation and what was based on what Joan said. I should draw a clear distinction between writing about the data and putting things in my own voice.

4.4.2 Piloting with students

The focus group methodology is a highly effective method of data collection that could be used to explore students' understanding of teacher questioning, because not only was I able to collect data from different individuals within a limited time frame, but I also encouraged discussion and benefited from the added value of participants responding to each other (Patton, 1990). Following the observations of three of Joan's lessons, an online group interview was arranged with a selection of students. As suggested by Morgan (1998, cited in Gill et al., 2008, p.293), a focus group would not generate the best quality of discussion, "if participants are uneasy with each other" or "if the topic of interest to the researcher is not a topic the participants can or wish to discuss". Therefore, I asked Joan to select two male and two female students who normally worked together and who were happy to talk to me about teacher questioning. These students, aged 15 to 16, were interviewed together in front of a laptop at school in January 2021. I tried to be affable during the focus group interview and maintained a neutral attitude towards their comments in an effort to reduce any form of implicit bias. A focus group interview schedule was used, and students were asked to draw a picture about their understanding of Joan's teacher questions at the end of the interview (see Appendix 2). The interview lasted about one hour and was audio recorded and transcribed for analysis.

This pilot interview identified several areas for improvement: (1) it was inconvenient to conduct online interviews with three or four students due to the difficulty in finding a suitable time when multiple students were available; (2) due to the lack of anonymity, students was reluctant to discuss sensitive topics in public (Qu and Dumay, 2011), such as any disadvantages of teacher questioning; and (3) the number of interview questions was limited, because the response time to any given question was much longer than that in individual interviews (Patton, 1990). Thus, a private one-to-one interview might be more useful to elicit a student's personal views about teaching and teacher questioning.

I also reflected on how to improve the interview questions and how to use the student drawings. First, I needed to use episodes and to talk with the students participating in the lesson that was recorded, because I could relate how the teacher and the student talked about a specific part of the lesson and help the student to be clearer and more specific. In this pilot interview, I did not use episodes and most of student answers were about lessons I had not listened to. However, if I asked students to talk about lessons I had listened to, the data set would be more about the teacher and the collected lessons. Second, I asked students to draw their understanding of Joan's questions and their images (see Appendix 3) were limited to teacher questions, and Joan did not appear in the drawings. Thus, I could instead ask students to draw a diagram that represented how this teacher worked with them when they were learning about science, because that would put the emphasis on the teacher and how the teacher worked with students. Another problem was I only asked students to draw and write down their explanations, but I did not give them opportunities to talk about their drawings. This approach could be improved by inviting students to share their views.

4.5 Sampling strategy in the formal data collection

Having discussed the pilot study, I now turn to the sampling strategy. Before talking about how I approached and recruited participant teachers and students, it is necessary to introduce the population that I sampled from.

4.5.1 Population

This study initially selected secondary biology teachers in Shaanxi Province. I considered recruiting participants from Xi'an City, the capital city of Shaanxi Province, or from the rest of Shaanxi Province. I worked in Xi'an City as a secondary biology teacher for eight years, which ensured the familiarity of subject matter and convenient access to schools. However, in the event I decided to include teachers outside this city for two reasons. First, different locations and local authorities might affect teachers' enactment of scientific practices. I would perhaps find out how teachers implement scientific practices in different conditions and with varying resources. Second, when I contacted senior secondary biology teachers in Xi'an City, I encountered some difficulties. Because of the stresses and strains of the job, which required successful academic achievement, some senior secondary biology teachers in Xi'an City did not want to spend much time engaging students in scientific practices and declined. For example, one teacher asked me why, because the school term was very short, he should spend twenty minutes enacting inquiry if he could spend ten minutes teaching the knowledge. In response to this, I felt that senior secondary biology teachers outside the city were not so stressful and had more time to conduct scientific practices.

There are different types of secondary schools in this province: public schools, private schools, and university-affiliated schools. Public schools are funded by the government, and private schools are mainly funded by student tuition fees and owned and managed by an individual or a company. University-affiliated schools are run by universities, and they recruit many students whose parents work at related universities or whose grandparents had retired from them.

As described in section 1.3 and section 2.3, teachers were encouraged to take part in different levels of teaching competition and apply for different levels of honorary titles. These affected teachers' salaries, promotions, and reputations, and I provide more details about them here, as they were related to the sampling strategy. First, the national competitions are very competitive. If teachers want to succeed, they are required to have a deeper understanding of curriculum standards, put their understanding into classroom practice, and dedicate themselves to enhancing the quality of their lessons. For example, in the 8th National Primary and Secondary School Experimental Teaching Activity organized by the Ministry of Education of the People's Republic of China in 2020, 6692 teachers from across the country submitted their slides and 15-minute experimental teaching videos to an online platform. After being reviewed by the expert committee and approved by the Ministry of Education, only 158 teachers from different disciplines (e.g., physics, chemistry, biology, and geography) proceeded to the final round. In addition, many topics centred around scientific practices: for example, investigating the factors affecting floating and sinking by employing 3D printing technologies, and the effect of light on photosynthesis.

In terms of the city-level or provincial expert teachers, the honour might be received only if teachers demonstrate a wealth of teaching skills (e.g., making clear what students are expected to do). Take the provincial expert teacher as an example. When secondary biology teachers participate in the competition organized by the city-level and provincial education authorities and the Department of Human Resources and Social Security, they are not allowed to bring any personal teaching materials or electronic devices. The typical process is that the teacher completes a lesson plan within a limited time after drawing a lesson on-site, talks about the lesson plan to a panel of judges in 10 minutes and teaches a 15-minute lesson in a classroom where the teacher does not know the students. This indicates that every teacher must be familiar with the curriculum standards and textbooks and be proficient at teaching (e.g., teachers can engage students actively in the learning process) to succeed. Furthermore, the appraisal criteria in the competition put the emphasis on the implementation of curriculum innovation: for instance, the development of students' core literacies (Tong and Luo, 2018). The biology core literacies consist of four dimensions: big ideas of biology, scientific thinking, scientific inquiry, and social responsibility (MOE, 2017b). Scientific inquiry is an important aspect of the biology core literacies. In summary, I assumed that those teachers who succeeded in this competition would have a better understanding of the biology curriculum standards, support scientific inquiry, and possess a broad repertoire of teaching strategies.

4.5.2 Selection of teachers

Purposive sampling was undertaken to gain access to teachers who might have rich and diversified purposes for their teacher questions and use a relatively larger number of dialogic and interactive questioning sequences (Mortimer and Scott, 2003) in their classrooms. This is based on both the RQs and research aims. For example, the second RQ explores the purposes behind teacher questions developed for scientific practices. One of the research aims is to provide question examples and illustrations of insights to help teachers improve their questioning practices and engage students in scientific practices. Therefore, the sampling strategy was to identify teachers who used different question types, including those that might be rarely used across the overall teacher population. Using this sampling strategy enabled me to conduct an exploration of possible, rather than typical, questioning strategies, and to draw out the significant implications for classroom questioning practices and teacher professional development. The sampling strategy was not to try to get close to a large number and wide range of teachers across a variety of types of schools because I could only sensibly address my

RQs by interviewing a manageable number of teachers who had a deeper understanding of scientific practices and used questions in best-case scenarios.

The selection criteria for this study are listed as follows:

(1) Many years (e.g., at least five years) of classroom experience in secondary biology teaching. Berliner (2004) argues that it might take a teacher five to seven years to gain expertise in teaching. Those experienced teachers' hundreds, or even thousands, of hours of classroom experience and extensive communication with students can help them to develop their questioning practices. For example, Joan, who had taught secondary biology for nine years, stated that when she was a novice teacher, many of the questions she posed were too closed; that is, students' answers were what were on her mind. However, she then asked more open questions – for example, finding out what features these amino acids had in common – and her students' responses surprised her. Therefore, teachers may change the ways they use questions over time. I did not look for novice teachers because they might not be able to use open questions more flexibly to engage students in scientific practices.

(2) A good reputation of excellence in teaching. As described in the literature review, previous studies used different selection criteria to define expert teachers. I decided to select the teacher who won a prize in the national teaching competition or was awarded the honorary title of city-level or provincial expert teacher by the Department of Human Resources and Social Security. Some details on the expert teachers' background information were provided in the section on population. Here, I focus on the expert teachers because, as described in the literature review: (1) they could give a detailed account of what was happening in the classroom (Berliner, 1988); (2) their classroom discourses might not be limited to IRF (Tytler and Aranda, 2015); and (3) they were able to engage students in scientific practices (e.g., interpreting and analysing data) rather than just transmitting knowledge without devised questioning.

Although teacher questions can represent indices of quality teaching (Carlsen, 1993; Roth, 1996), I was not suggesting, of course, that expert teachers who had been given recognition for their work would certainly use lots of dialogic and interactive question sequences in their lessons. However, during the pilot study, when I interviewed Joan, who had received the provincial expert teacher honour in 2020, I found the purposes of her questions became more and more diversified as time went by. For example, when she was preparing for this competition, she started to get interested in the history of science and tried asking open questions after telling a brief story on the history of science. She stated that this was not only to interest and motivate students, but also to develop students' abilities and competencies (e.g., extracting valuable information from text). Thus, I speculated that expert teachers might diversify the purposes of their questions within the context of scientific practices and offer deeper insights into teacher questioning.

(3) Strong willingness to collaborate in this study. This ensured that the teacher was enthusiastic about this project and happy to talk to me. All participant teachers were required to be interviewed three times, audio record three lessons and take photos of their lesson plans and students' work, which, no doubt, increased their workload. Normally, teachers are quite busy; therefore, their willingness to get involved was crucial.

However, the sampling strategy has its limitations. It does not include the teachers who use diverse questioning strategies but have not been recognized with any awards. Additionally, I focused on expert teachers and the exemplary cases of questioning in order to inform some developmental work that might be done for other teachers. It is not representative and consequently the findings cannot be generalized across all the Chinese secondary biology teachers. In terms of the size of the sample, given the limited time and effort available, it was considered feasible to have six to eight teachers for formal data collection. This number would still provide rich and contextualized insights to address my research questions.

I selected no more than two teachers in one school for the sake of convenience, but on the other hand I expected more participant schools to identify important common patterns across different schools. The schools were determined by teachers. The decision to contact teachers first, rather than initially identifying specific schools and then contacting headteachers, was because headteachers were so busy that they might not have time to reply to my email or give me an opportunity to talk about my project. I would be unable to approach any teachers if headteachers refused permission. Nevertheless, if I contacted the potential participants and teachers agreed in principle to participate, they could talk about this project with their headteachers to ask for permission for the research.

In terms of how I contacted teachers, I firstly made the effort to approach teachers recommended by my colleagues and specialists in curriculum and pedagogy. I contacted teachers via phone calls, Tencent QQ, and WeChat. QQ and WeChat are widely used Chinese apps that can provide text messaging, voice chat and file transfer capabilities. The digital teachers' information sheets and consent forms were sent to teachers by QQ or WeChat, then, after teachers were made aware of the research information and agreed to participate, I sent them a digital letter for the headteacher containing my research purposes and potential benefits and requested teachers to contact their headteachers. Because I did not need to get access to the schools, as all lessons were audio recorded by teachers and all interviews were conducted online, it was easy to get headteachers' permission during the global COVID-19 pandemic. The ways through which I approached teachers, how I told them about my study, and how I invited them to take part in the project are related to ethical issues explored later in more detail.

I tried to select teachers who not only met my predetermined criteria, but also displayed a variety of teaching experience levels, grade levels and school types. Eight teachers participated in the project initially, including six from Xi'an City and two from outside it. However, the two teachers from outside the city withdrew from the study because they did not respond to attempts to contact them. I summarize the characteristics of the final six teachers, all of whom worked in Xi'an City, in Table 4.1.

Teacher	Gender	Teaching experience	Grade	Description of the teacher
Ziv	M	21	7 (junior secondary)	National award winner, private school A
Sue	F	10	7 (junior secondary)	Provincial expert teacher, private school A
Zachary	M	26	7 (junior secondary)	Provincial expert teacher, university-affiliated school B
Wynne	F	10	7,8 (junior secondary)	National award winner, university-affiliated school B
Simon	M	23	10 (senior secondary)	City-level expert teacher, university-affiliated school C
Helen	F	12	10 (senior secondary)	Provincial expert teacher, public school D

Table 4. 1 Details of the six biology teachers involved in the study

4.5.3 Selection of students

I recruited participant students by requesting the six teachers to ask their students if anyone in the classes that were going to be audio recorded would like to be interviewed. Student information sheets about my project were distributed to students. To encourage volunteers, I also made a video in which I clarified the anonymity and confidentiality of the study and talked about why I was doing the study and how much I would appreciate their involvement. Students could see me and my workplace in this video. I finally recruited two students, 15 to 16 years old, from Helen's class (S1_Helen and S2_Helen), three students, 15 to 16 years old, from Simon's (S1_Simon, S2_Simon and S3_Simon), and three students, 12 to 13 years old, from Ziv's (S1_Ziv, S2_Ziv and S3_Ziv). Sue said that her school leader was still a bit worried that students would tell me about some bad things that happened at the school and asked me not to recruit any students. Furthermore, no student volunteered from Wynne's and Zachary's classes. These eight students were very interested in my research and happy to talk to me. Digital student consent forms and parent consent forms were obtained before the student interviews took place.

There are several limitations on student sampling. As described in the literature review, little is known about students' views about teacher questions, which meant the study could be a significant research contribution. However, I did not have student data for three teachers and the number of participant students was much lower than expected. A possible explanation for this might be that I was unable to observe the lessons and meet the students face-to-face due to the impact of COVID-19, as described in section 4.11, and it was difficult to establish trust and rapport as a result. The small sample size meant I was unable to select students who liked biology and students who disliked the subject. The students' academic performance in biology might have been above average and they probably talked about their enthusiasm for biology in the interviews. They might be familiar with the biology teachers and highlight the advantages of teacher questioning in the interviews. I tried to minimize these issues. For example, at the beginning of student interviews, I verbally clarified the ethical issues again: for example, that students were free to talk about anything, I reminded them that I would keep data confidential, students were able to withdraw anytime without any reasons before

September 2022, and the data were anonymized in the transcription and would be destroyed after the completion of the project.

4.6 Formal data collection

Formal data collection lasted nine months, beginning at the start of the school term in March 2021, continuing through the summer holiday and ending in November 2021. In this section, I first present an overview of the data and then illustrate some of the details of the two main data collection methods: lesson data and interviews.

4.6.1 Summary of modes of data collection

The connections between RQs and the data and data sources is summarized in Table 4.2. Yin (2016) asserts that, prior to classroom teaching and interviews, the researcher may have to review many documents and know their contents in order to gain an overview of contextual information. Biology textbooks, slides, the videos teachers used in the classroom, photographs of lesson plans, physical models, lesson handouts and students' work were valued and collected, because they could provide important information about the context surrounding the questioning and teaching, teachers' planned questions and the purposes of teacher questions. These documents are associated with each lesson. As shown in the table, lesson data and interviews were the main data collection methods and are discussed next.

Research Question	**Method**	**Data Source**	**Total Amount of Data**
1. What types of questions do teachers ask in a setting that encourages students' engagement in scientific practices?	Lesson data	Audio recordings of lessons taken by the teacher	18 audio recordings of lessons (three lessons per teacher) 20 one-to-one teacher interviews (three or four interviews per teacher) 8 one-to-one student interviews and eight student diagrams (one interview per student) Documents: slides, photographs of lesson plans, physical models, lesson handouts and students' work
2. What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?	Lesson data Interviews	Audio recordings of lessons Interviews with six teachers	
3. What are teachers' reflections on factors influencing teacher questioning strategies?	Interviews	Interviews with six teachers	
4. How do students perceive their teachers' questioning in class?	Interviews	Interviews with eight students	

Table 4. 2 Summary of the modes of data collection

4.6.2 Lesson data

I did not visit schools because of travel restrictions during the global pandemic. Instead, I collected three lesson recordings per teacher, thereby collecting a total of 18 lesson recordings. The lessons covered a range of topics included in the national biology curriculum standards. To address the issue of minimizing disruptions to the teacher and students, video-recording techniques were not used. Lessons were audio recorded by teachers using recording pens or smart phones. More details regarding the selection of lessons are discussed below.

After identifying secondary biology teachers, negotiations to decide the selection of three lessons were carried out with each teacher. Two requirements were emphasized during this process. First, the lessons should highlight students' participation in scientific practices, such as developing and using models, planning and carrying out investigations and engaging in argument from evidence, as scientific practices are the focus of my thesis. Second, among these lessons, polished lessons were given priority. (The nature of polished lessons was discussed in section 3.6.3 in the literature review.) Lessons could have been polished during the latest school term or several years ago. They were honed and modified based on collective lesson observation and lesson discussion. Teachers probably thought carefully about teaching details and refined their teacher questions on several occasions. Thus, polished lessons were more likely to demonstrate sophisticated questioning strategies related to scientific practices. The context of polished lessons is related to two research aims. It allows me not only to explore how teachers use their questions and how questions are changed and devised in this context but also to use the findings to inform teacher development and policy. Which lessons were recorded was finally determined by the teacher, as I enabled teachers to have some control over how they were involved in the study. So, they showed initiative, expressed positivity, and were willing to share their views on the lessons they selected during the interviews.

4.6.3 Interviews

I first discuss the use of teaching episodes and their value for the dataset, and then describe online interviews with teachers and students separately.

4.6.3.1 Selection of teaching episodes for interview discussion

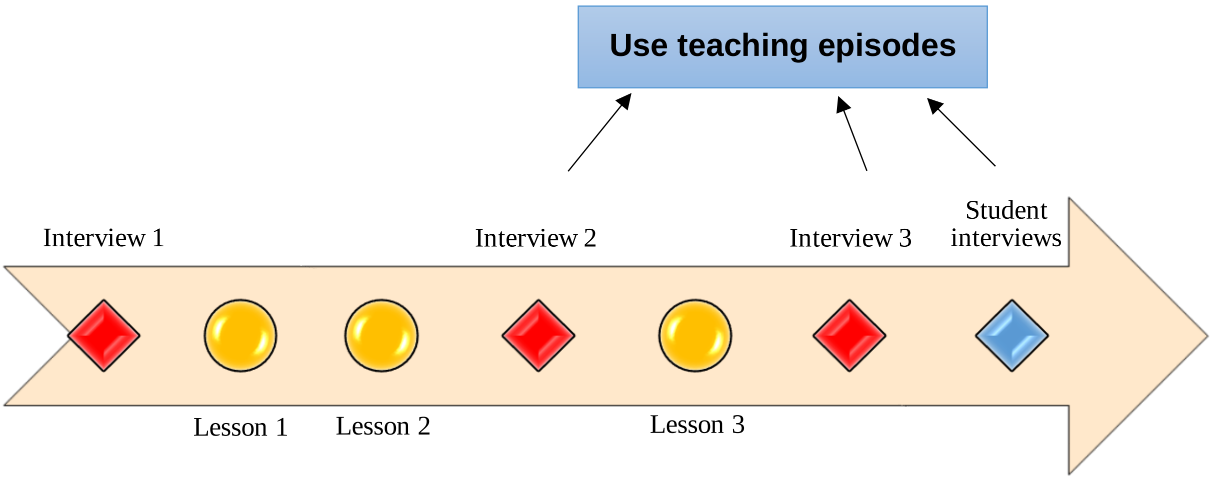


Figure 4.1 A data collection sequence for each teacher

As shown in Figure 4.1, I used teaching episodes as a tool with which to interview teachers and students. A teaching episode here refers to a classroom teaching and learning sequence that mainly represents language exchanges between the teacher and students. The average length of an episode is about five minutes. About two days before the second teacher interview, I selected three or four episodes from two collected lessons and sent them to the teacher. It could be one, two or three episodes selected from one lesson, depending on the classroom teaching. For example, when the teacher spent less time engaging with scientific practices in a lesson, I might select only one episode. Similarly, two days before the third interview, I selected about three episodes from the third lesson and sent them to the teacher. These episodes are detailed in the chapter on the findings of RQ 2. The reasons for selecting these episodes were to use them as a stimulation that helped the teacher reflect on the lessons and elicit more ideas on scientific practices and teacher questions. In this way, I could develop a range of sophisticated questioning strategies related to scientific practices based on data.

As mentioned earlier, I used episodes during the interviews with students. I sent about three or four episodes to the student about two days before the interview, which has been selected from those I sent to their teachers. During interviews, I talked about these episodes: for example, “Now we turn to episode one, what do you think about this episode?” and “What do you think about the teacher question in this episode?” There are several reasons for doing this. First, this enabled students to talk about the lessons I was familiar with. Second, I could compare how the teacher talked about a particular episode with how students perceived it. Third, this approach helped students to be clearer and more specific. In the pilot study, I did not use episodes and I asked students what they thought of your teacher’s questions. Students did not know how to answer because my question was general, and students had to recall teacher questions and then make judgements. When I was using an episode, I asked what they thought about how the questions their teacher used in this episode, which not only presented students with teacher questions but also put teacher questions in the context of teaching.

4.6.3.2 Interviews with teachers

Seidman's (2006) method is an excellent guide to phenomenological interviewing which essentially focuses on understanding experience from the perspective of the interviewees. To obtain rich data and interpret the interviewee's experience through being unbiased, he suggests three interviews per person. The first interview involves a biography that focuses on background information, followed by an interview to provide details of the person's present experience, and finally an interview related to future expectation. Although it is time-consuming, this approach may have been particularly helpful for me because I needed more time to establish rapport with teachers and learn the craft of qualitative research interviewing. I therefore conducted three semi-structured interviews with each teacher, with each interview designed to be about one hour in length.

The first interview was before the first lesson, the second after the second lesson, and the last interview after the third (see Figure 4.1). The interview guide can be seen in Appendix 4. In the first interview, the teacher was asked to tell as much as possible about their work background, the context of the school, and their experiences of polishing lessons and implementing scientific practices.

During the second interview, I used teaching episodes that showed engagement with scientific practices (e.g., students drew conclusions based on evidence) and the word document was sent to the teacher about two days before this interview. Moreover, before the interviews, I told teachers that one interview question was a chance to describe what they thought went well in these lessons, with the aim of giving them an opportunity to talk about what they valued most in their teaching. I also wanted to listen to what they thought went well in teaching, as it might be different from my view.

In interview three, about three episodes were selected from the third lesson, and the teacher was asked to make comments on the teaching and teacher questions based on the episodes I selected. In addition, interview questions took on a future orientation: for example, "Could you please talk about how the purposes of your teacher questioning will be different by 2030?"

At the end of the data collection, I planned to use teacher questionnaires to give teachers enough time to think and collect their views in the form of writing. I tried this with Helen and Simon. However, both preferred to talk again rather than write. Therefore, I interviewed them for about half an hour, and questions involved something from the last three interviews that needed further clarification or explanation. I did not do it for the other four teachers. There were 20 interviews in total, all of which were audio recorded and transcribed for analysis. After each interview, I completed a post interview review (see Appendix 5) that helped me think about the main issues or themes that struck me during the interview, how to use the data to address my RQs, and what in the interview I needed to improve.

4.6.3.3 Interviews with students

I interviewed eight students: S1_Helen, S2_Helen, S1_Simon, S2_Simon, S3_Simon, S1_Ziv, S2_Ziv and S3_Ziv. Each interview lasted for about 40 minutes, and they were all conducted online, one-to-one and after the third lesson. The student interviews were very different from interviews with expert teachers because some students provided less extended responses than others, and they were not good at using examples. For example, when I encouraged a student to give me an example of how Joan used questions to help him to argue, he could not think of an example and had nothing to say in the pilot study. To draw out students' experiences about their teachers' teaching and questioning, I did two things in data collection.

The first thing was using episodes when interviewing students as detailed in section 4.6.3.1. The second thing was changing how I used student drawings. During the interviews, students were asked to draw a diagram that represented how this teacher worked with them when they were learning science knowledge. Initially, the first two students (S1_Helen and S2_Helen) I interviewed were asked to draw diagrams and describe their drawings in a few written sentences at the end of their interviews. After they completed their drawings, they spent a few minutes talking about them. Later, students were asked to draw before the interviews, and they did not need to write down their explanations. Instead, they talked about their drawings at the beginning of the interviews. This change produced two advantages. First, students' drawings were used as a tool to start the interviews, elicit students' perspectives, and create a relaxed environment in which students felt free to talk about their own pictures. As a result, the drawings helped students to take the initiative to share and talk at the beginning of the interview. Second, before I used drawings, I asked questions to begin the interview: for example, "What do you get from biology lessons with this teacher?" and "What do you think are the strong points of her teaching?" These interview questions were only within the context of verbal communication. However, visual drawings provided a different way to hear students' thoughts. They gave students a quiet space to collect their thoughts and to capture features of their biology teachers without any disturbance from me, before the interview.

Interview questions were not limited to episodes and teacher questions. As shown in the full interview schedule in Appendix 6, I firstly talked about teaching in a lesson, then focused on teacher questions in an episode, before finally going beyond the lesson I listened to. For example:

- I started my questions specifically about the lesson: “What do you think of the lesson I listened to? What do you think the highlights of this lesson are?”
- I shifted to one or two episodes: “What do you think about what your teacher said? What do you think about the questions your teacher asked in this episode? Which question do you like best in this episode?”
- Finally, I broadened the focus on the lesson: “What do you think about how this teacher works for you overall? What are the good points of your teacher’s questioning? What do you think about your teacher’s use of questions in other lessons?”

4.7 Data analysis

According to Yin (2016), the first step of qualitative data analysis is compiling the data. In this study, this involved creating (1) visual data files (e.g., student diagrams and photographs of lesson plans); (2) audio files (e.g., audio recordings of lessons and interviews); (3) word text files of transcripts; and (4) hard copies. All audio data were transcribed, and all the transcriptions and visual data files were printed for analysis. When using transcriptions, I ensured a pseudonym was used for each participant. The transcription of lesson recordings captured only the teacher talk and student talk. Some conventions were used: for example, ‘Ss’ means several students talked at once; ‘seventeen/eighteen’ means there was overlapping or simultaneous utterances by several students; ‘…’ means people did not finish the sentence they were speaking; ‘[]’ means an insertion I added to clarify meaning; and ‘(…)’ refers to the deletion of a brief segment of text from the transcript.

Yin (2016) suggests that qualitative data analysis includes five phases: compiling, disassembling, reassembling, interpreting, and concluding. The first phase, compiling, involves transcribing data and putting that data into a consistent format. The second phase, disassembling, is “breaking down the compiled data into smaller fragments or pieces” (Yin, 2016, p.186): for example, manually coding data or using Computer Assisted Qualitative Data Analysis (CAQDAS) techniques (e.g., NVivo), if necessary. The third phase, reassembling, calls for reorganizing these fragments or pieces to construct the categories for analysis. The two further steps, interpretation and concluding, mean helping readers to understand the findings and the significance of the entire study. Furthermore, Braun and Clarke (2006) provide a six-phase model of thematic analysis: familiarizing yourself with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. Cohen et al. (2018) list multiple texts on the steps for qualitative analysis. These approaches emphasize researchers must (1) immerse themselves in the data, read repeatedly and reflect on all transcripts; and (2) be transparent, systematic and show the validity of the process from data to category generation (Cohen et al., 2018). Therefore, I read and re-read the text in order to obtain a thorough understanding of the meanings and key issues and made notes in the margins. In the following sections I will elaborate on how I used all the relevant data to answer my RQs.

4.7.1 Data analysis in relation to RQ 1

To answer the first RQ, “What types of questions do teachers ask during teaching that encourages students’ engagement in scientific practices?”, I used a question classification framework to analyse the lesson transcriptions, as described below.

4.7.1.1 A question classification framework

As described in the literature review, Blosser’s (1975) QCSS categorizes teacher questions into four main types: closed, open, rhetorical, and managerial questions. In his framework, the closed and open questions can be further subdivided into four types: closed cognitive memory, closed convergent thinking, open divergent thinking, and open evaluative thinking. In the literature review, I compared several research papers concerning the typologies of teacher questions. There are three reasons why I drew on a framework adapted from Blosser (1975) (see Table 4.3). First, it classifies teacher questions according to the question function – e.g., whether questions can open up student thinking and discussion – which is an important part of science teaching and learning. Second, I can make a comparison of teachers' different use of different types of questions, offering glimpses of their classroom questioning practices. Similarly, Eliasson et al. (2017) have adopted Blosser's four types of open and closed questions to explore the extent to which male and female science teachers posed different types of questions, and their approach produced convincing results which might help teachers pay attention to, for example, the effect of different types of teacher questions on students' opportunities to talk about science. It was worth trying out this approach for my data. Third, given that there are many factors behind the use of open and closed questions, addressing how teachers use these questions differently helps to lay the foundations for RQ 3, which focuses on factors influencing teacher questions.

I have made several modifications to Blosser's QCSS (see Table 4.3). First, I used the label *closed other* rather than *closed convergent* to make the meaning more transparent. Blosser (1975) does not fully explain the meaning of convergent, making it difficult for readers to apply the concept consistently. I assume that it means student answers are expected to be similar or fixed, rather than divergent. *Closed other* is clearer because if a closed question is not a closed memory question, it will be classified as closed other. Second, I added a new label, *open scenario-based* questions, that requires students to think from a different perspective. Students can pretend to be a person, plant, animal, or object and think about an imagined scenario. Simon used this kind of questions to encourage students to understand a living animal or a scientist: for example, "Imagine you are a mouse, what do you think?" and "Imagine you are a dung beetle, how do you feel?" The final modification was that I used the label *managing discussion questions* rather than *managerial questions*. Ordinary 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, I included managing discussion questions that were used to check consensus in the class or to encourage students to elaborate further on the topic: for example, "Does everyone agree with his idea?" and "Anything to add?" Teachers were asking other students if they agreed with a student's idea or had anything to add. Such questions might make a student defend his/her ideas. Therefore, using the label *managing discussion* could clearly indicate the function of these questions.

Note that open questions are very useful for eliciting student thinking from different angles. If different students use different words to answer a question but their underlying idea is the same, the question will be judged as a closed question. For example, in answer to the question "Why was an equal mass of steamed buns added to each test tube?", students may have different wording but the answer is that there is only one variable in a controlled experiment. Another example in this study, the question "How do you know it is starch?" is another closed question, in that the expected underlying idea is the same: that is, using iodine to test for the presence of starch.

Question type		Code	Description	Example
Closed questions	Closed memory	Cm	Closed, to recall knowledge	1. Does it have ribosomes? 2. How many pairs of chromosomes does a somatic cell have?
	Closed other	Co	Closed, to elicit higher cognitive thinking	1. How do you know it is starch? 2. Why was an equal mass of steamed buns added to each test tube?
Open questions	Open divergent	Od	Open, a wide range of possible answers	1. Which activities can destroy the balance of an ecosystem? 2. Why cannot frogs survive in water-scarce terrestrial environments?
	Open evaluative	Oe	Open, to encourage students to elaborate from their own perspectives	1. Why do you think its skin has this function? 2. Have you ever felt…when did you use simple reflexes?
	Open scenario-based	Os	Open, to think from another angle	1. Imagine you are the scientist Sutton or Morgan; what conclusions can you make from the data? 2. Imagine you are the spinal cord; what should you do if your finger is pricked, and neurons send this message to you?
Rhetorical questions		R	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		M	To check consensus, to probe	1. Anything to add? 2. Does everyone agree with his idea?

Table 4. 3 Analytical framework for the analysis of teacher question type, adapted from Blosser (1975) QCSS

During coding, I identified all the questions in the lesson and highlighted them in red for convenience during the later analysis. Here teacher questions refer to sentences that not only ask students to respond but also have the rising intonation and grammatical structure of questions (e.g., the question mark). I did not include sentences that were used to find out information but did not have the grammatical structure of questions (e.g., “Six essential nutrients, let’s say it together”). I also did not include those that were not related to the aims of the lesson (e.g., “Have you filled out this form?”) as I focused on the part where teachers were active in classroom teaching and learning and placed less emphasis on the sections of the transcripts addressing classroom management issues, quizzes, and the analysis of exercises. For example, at the beginning of one lesson, Sue spent at least five minutes dictating what students learnt in the previous lesson. She asked many fill-in-the-blank questions, and students wrote their answers down on paper. These questions were to assess students’ knowledge, and there was no direct connection between her questions and scientific practices. These questions were marked as ╳ during data analysis. All the questions coded ╳ were not included in the total number of teacher questions. The purpose of this counting was to explore RQ 1 within this thesis and quantitatively present how teachers utilized different types of teacher questions during teaching, emphasizing students’ engagement in scientific practices.

The remainder of the questions were coded according to the framework (see Table 4.3): for example, closed memory questions were coded Cm. I included questions that teachers asked but answered themselves. In Mandarin, such hypophora questions are called 设问 (shè wèn), which means a person asks a question and then immediately answers it. Nevertheless, there is a translation issue here. In English, hypophora is usually regarded as a type of rhetorical questions; however, they are not considered rhetorical questions in Mandarin. There are two clear distinctions between hypophora and a rhetorical question in Mandarin. First, hypophora requires the teacher to provide an answer but a rhetorical question does not: for example, “What determines the gender of fruit flies? It is determined by sex chromosomes.” Hypophora includes two parts: the teacher’s question, and the teacher’s answer. “Isn’t the gender of fruit flies determined by sex chromosomes?” is a rhetorical question. It is easy to find the answer in the rhetorical question: the gender of fruit flies is determined by sex chromosomes; therefore, students do not need to respond. Second, hypophora is mainly used to arouse students’ interest and make them think about the question, whereas the purpose of a rhetorical question is not to ask a question but to highlight or emphasize an idea. Therefore, these hypophora questions are not considered rhetorical questions in Mandarin and they are put in the group of closed or open questions in this study.

Teachers sometimes posed several questions sequentially before students answered their queries or repeated similar questions when only a few students responded. If there were only slight alterations in wording, these questions would be considered as one question. Nevertheless, if questions were different, they would be coded separately. When I was not sure which type a question was, I coded it as *uncertain* for the time being and wrote down the possible types in parentheses (e.g., uncertain (Cm, Co)). After the other questions in the lesson were coded, I looked back and identified the type again.

4.7.1.2 Double coding

Double coding means asking someone else to code some of my data to make sure my codes are valid and credible. After coding Ziv’s three lessons, I developed a two-page coding manual in Mandarin, including my definitions of codes and how to code. I printed both the coding manual and a transcription of Ziv’s lesson 1, and then provided a Chinese doctoral student studying at School of Education at the University of Leeds with training on how to use the manual. He coded lesson 1 alone, and afterwards we compared and discussed the results of our coding. This approach not only represented a good reliability check but also an opportunity to draw upon important emerging peer insights in order to obtain sharper definitions.

There was roughly 65 percent reliability using this formula:

$$reliability = \frac{number\ of\ agreements}{total\ number\ of\ agreements + disagreements} = \frac{28}{28+15}$$

To improve consistency in subsequent coding, some definitions needed to be narrowed, expanded, or amended in order to attain greater consistency. My colleague and I talked about the differences in our codings, and finally reached a consensus in the following aspects. First, we narrowed the definition of closed memory questions that referred to recalling knowledge. Therefore, if a closed question was not simply recalling knowledge and it involved referring, comparing or any other higher order thinking, it was a closed other question. Second, we redefined the meaning of open questions that had no fixed answers and required students to think and reply from multiple angles. Third, if a teacher asked several questions sequentially before inviting students to respond, we coded the last question because the last one was more likely to be what the teacher really wanted to ask. For example, Ziv asked in his first lesson, “Is it starch? How do you know it is starch?” and we coded the second question. However, I sometimes needed to consider students’ responses. Fourth, we paid attention to the context of a question before making a judgment, rather than only looking at the question itself. It was necessary to understand the meaning of the questions and the context of the questions as the actual situation was more complicated. For example, Sue asked, “How many sheep can my pasture support? Give me a description. You don’t necessarily tell me how many sheep I can raise. You say, what is your reasonable standard?” The student responded, “Moderate amount”. Although there were only two words in the response, the question was an open question because it required no specific answer. In another example, Sue asked, “There is a locust plague in the grasslands of Inner Mongolia now. It is spreading fast, and the number of locusts is particularly large. At this time, to destroy the locusts quickly, what measures should I take?” This question seemed an open question. However, Sue asked this question after students suggested some possible solutions to a locust plague. She was inviting students to recall them. Therefore, it was a closed question. Fifth, we listened to the recording and got the question intonation, if necessary, because it was sometimes difficult to judge whether it was a rhetorical question simply by looking at the transcript due to the complexity of Chinese grammar. More details are discussed below.

Rhetorical questions in this study included three question patterns: affirmative-negative questions, tag questions, and Chinese rhetorical questions. The structure of an affirmative-negative question is verb-not-verb: that is, a verb and its negative form (e.g., 是不是 (shì bu shì)) – for example, "加了碘液之后，淀粉是不是变蓝了?" If I translate it very literally, it will be "After adding iodine solution, does or does not starch turn blue?" It is a very common and natural way for teachers to ask questions in Mandarin. Students can answer with yes or um to affirm what was asked. They might not even reply.

The tag question places a phrase on the end of a sentence for emphasis: for example, "是吧?", "对吧?" and "对不对?" They can be translated into "right?", "OK?" or "isn't it?" – for example, "加了碘液之后，淀粉变蓝了，是吧?", which translated into English is "After adding iodine solution, starch turns blue, right?"

Chinese rhetorical questions have several structures. Their common feature is the teacher does not really expect an answer. The answer is so obvious that the teacher and students know the answer clearly, and the teacher wants students to share the same feelings or opinions: for example, "加了碘液之后，淀粉不是变蓝了吗?", which translated into English is "After adding iodine solution, doesn't starch turns blue?" It makes a positive statement that reminds students of a fact that starch turns blue after adding iodine solution.

Affirmative-negative questions and tag questions are sometimes used to check information. They provide students with both possible answers: either yes or no. However, in my view, they are mostly used to highlight teachers' opinions rather than ask students to choose between yes and no. If there was a difficulty in judging whether it was a rhetorical question, my solution was to go back to the audio recording, make sense of the context of the question, and finally make a judgement.

Because of the low consistency, I asked the doctoral student to code Ziv's lesson 2 later. We talked via WeChat as he had left Leeds at the time. I sent him both the revised coding manual and a transcription of lesson 2 of Ziv online. I talked about a few amendments based on our last discussion. He coded lesson 2 alone, and afterwards we compared and discussed the results of our coding. There was roughly 80 percent reliability:

$$reliability = \frac{number\ of\ agreements}{total\ number\ of\ agreements + disagreements} = \frac{53}{53+13}$$

We mainly disagreed in two aspects: (1) for some questions, I coded closed other, where he thought they were open; and (2) for some questions I coded closed other, where he coded closed memory.

4.7.2 Data analysis in relation to RQ 2

To address the second RQ, *What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?*, I used both lesson data and interview data to explore the purposes behind teacher questions. I also reflected on the differences between using lesson data and interviews to access teachers' question purposes.

4.7.2.1 Using two strands of data to explore the purposes of teacher questions

As described in the literature review, the existing typologies of teacher questions are from different perspectives: for instance, the purpose (Benedict-Chambers et al., 2017; Kawalkar and Vijapurkar, 2013), the cognitive level (Bloom, 1956), strategies to stimulate productive thinking (Chin, 2007), and teacher authority (Oliveira, 2010; Van Booven, 2015). My research explicitly focused on the purposes of teacher questions. The reason that this focus is a distinctive feature of the analytical approach in this thesis is to deploy two distinct forms of data to explore the purposes of teacher questions. As describe in the literature review, many researchers have tended to infer the purposes behind teacher questions through classroom observations without gaining access to the teachers' world by using interviews (e.g., Kawalkar and Vijapurkar, 2013).

Note that, in some cases, teachers might ask questions in the moment during lessons that they had not thought about, but they prepared thoughtful answers to explain during the interviews why they asked these questions. Their post hoc rationalizations did not necessarily reflect their thinking in the lessons. However, using two sources of data, I concentrated on both the level in which I described what teachers were doing and the level in which teachers interpreted what they were doing, and this helped me to get close to their motivation.

Regarding how to use two strands of data, I took three steps. Firstly, I coded each teacher question during the lesson in terms of its intended purpose from the perspective of the researcher. Secondly, I used the interview data to develop codes for the different purposes of teacher questions from the perspective of the teacher. Thirdly, I compared the two stands of coding and sorted them into more general categories. I analysed three lessons and three interviews of one teacher (Ziv) at the beginning so that I could refine the process and improve it after discussions with supervisors, and then I efficiently continued that process with the rest of teachers.

In the first step of coding, I coded a single teacher question or a sequence of teacher questions to work out its intended purpose after reading lesson transcriptions several times. At the same time, I looked at any related literature that could be applied to my data. For example, in the process of coding each teacher question, I adopted Chin's (2006) classification of the purposes of teacher questions described in the literature review, including eliciting, probing, extending, clarifying, prompting, challenging, and reinforcing. I also adopted the terms *opening up the problem* and *checking student understanding* developed by Mortimer and Scott (2003) when I coded each sequence of teacher questions.

The second step involved pairing lesson episodes with the stimulated-recall interviews. As described in section 4.6.3.1, I sent teachers episodes that showed engagement with scientific practices ahead of the second and third interviews. Therefore, teachers reflected on what was happening in selected episodes. However, teachers' answers were sometimes generic and not directed at specific teaching episodes: for example, "This lesson was mainly…Students [searching] for information in advance. I guided students to observe in the class" (Wynne). In summary, in terms of the interview data, there were some parts where teachers talked about the episodes I sent them, some parts where teachers drew upon other parts of the lessons, and some parts involving other lessons I did not listen to. For all the parts that were related to the recorded lessons and interpreted by teachers, I paired the interview data with the lesson episodes. The purpose was to familiarize myself with their teaching, understand teachers' interpretations and develop codes.

The interviews are key since they provide the teacher's voice regarding purposes. Initial codes for the purposes of teacher questions were derived from my pilot study: for instance, activating prior knowledge, challenging students, and implementing social responsibilities. However, as coding proceeded, codes could be split and merged as required to fit the interview data. In the end, I developed a coding manual with descriptions and examples.

Finally, I looked across the codes from two strands of data and identified the categories of purposes of teacher questions. After comparing two strands of coding, I removed very similar codes, searched for codes that could be merged into a single type, grouped them, and then created final categories and themes.

I used this final version of Ziv's question purposes to analyse those of the rest of the teachers. Similarly, I analysed each teacher's lessons and interviews. When I analysed the lessons, I coded the purposes of both a single question and a sequence of questions. When I analysed the interviews, I coded the teacher's question purposes. When new codes emerged, I added them to the list. If some codes in the list did not emerge in the data, I would delete them. By doing so, I generated a framework of question purposes for each teacher and explored the reasons behind these in RQ 3.

4.7.2.2 The distinction between exploring purposes with lesson data and with interviews

Coding lessons is a process whereby the teachers did not tell me their purposes, and I judged their question purposes (e.g., explaining and reinforcing) based on what they did in the classroom. Coding interviews is an inductive process of developing categories of purposes based on what teachers said. Teacher interviews provided the teachers with the opportunity to elaborate on contextual issues that were not evident to me: for instance, issues related to previous lessons, student behaviour, and external constraints on time. The teachers were more likely during interviews to speak expansively and describe what they did and their purposes.

4.7.3 Data analysis in relation to RQ 3

The RQ 3 is *What are teachers' reflections on factors influencing teacher questioning strategies?*. Teachers' teaching is not only influenced by their personal attributes but also structured by the context inside and outside school. As described in section 3.6.1 in the literature review, I reviewed two different frameworks on this, and I decided to use the framework offered by Ryder (2015). This framework categorized those factors into three levels – personal, internal, and external – and enabled me to (1) look at teacher questions more holistically, rather than disentangling teacher questions from their context; (2) sketch out complex reasons behind teachers' questioning practices from internal and external levels (e.g., the school and policy environment), rather than only considering factors from the personal perspective; and (3) explore how different levels of factors pushed the teacher into the same or opposite directions.

As described in the literature review, the personal level includes the teacher's subject knowledge, pedagogical skills, personal biography and beliefs. The internal level includes the impact of students' differing backgrounds and aspirations, textbooks, subject department working practices and school priorities. The external level describes how the national college entrance examination, national curriculum standards, time constraints, and Chinese traditional culture influence the way teachers use questions.

My coding was based on the analysis of six teachers and 20 interviews. The coding process was that I read through a printed interview transcription several times, read a unit of text related to RQ 3 repeatedly to familiarize myself with the data, and then asked myself which factor it was and which level it was: external, internal, or personal. Finally, I used NVivo 12 to code. Using this computer software, I selected the text content, and dragged and dropped it into a node performing a function of gathering materials with the same code into an envelope. All codes were data-driven; that is, they depended on what teachers said in interviews. However, some factors in my present study – for instance, school ethos and priorities, subject knowledge, and beliefs about how students learn – are similar to Ryder's (2015) findings; therefore, I have used a few codes in his study. Coding was not set in stone, and it continued to be developed and defined throughout the entire data analysis. For example, I initially categorized *learning objectives* provided for individual lessons as a personal factor, but later classified it as an internal factor. The reason was that, although learning objectives might come from teachers themselves, they might come directly from the Teachers' Guide and collective discussions with other teachers. Another example is *polished lessons*, which was a sub-code at a beginning but later stood out because it provided a distinctive contribution to the existing literature. Thus, *polished lessons* was broken down into three codes: *the role of polished lessons - external*; *the role of polished lessons - internal*; and *personal role in polished lessons*.

I used interviews to explore the factors influencing teacher questions. The conceptualization behind this decision was to discover the extent to which teachers could articulate what influenced them. What teachers did, what they knew, and what they articulated might be different things. Therefore, teacher reflection and its relation to teacher practices are discussed in the next paragraph.

As Korthagen and Lagerwerf (1996) point out, during teaching a teacher may have a perception or theory about a specific situation, then interpret the situation based on the theory and react on a conscious level. However, they also emphasize that teacher behaviour is not actually guided by logical and rational thinking in most situations. As in all professions, human beings' thinking, feelings, and acting are inseparable, and many actions are unconscious, spontaneous, automatic, and mechanical. A similar point may be highlighted with reference to Polanyi (1983), who focuses on the tacit knowledge of human beings, stating that "we can know more than we can tell" (Polanyi, 1983, p.4). In his view, people can do, but they cannot tell, even if they have acquired some knowledge. They may have a skill that combines some muscular actions that are not identifiable. For example, a person can ride a bicycle but cannot necessarily tell how they ride a bicycle (e.g., how they balance on a bicycle) (Wenger, 1998). These theoretical ideas are useful for developing the understanding of teachers' reflections on classroom teaching. Teachers could talk a lot about their teaching during interviews, but it did not represent everything they knew about teaching. I have tried to understand teachers' thinking or reflections by considering the limitations of my research. I asked teachers to talk about how they used teacher questions, but I did not assume everything they said represented everything they knew.

4.7.4 Data analysis in relation to RQ 4

The final RQ, *How do students perceive their teachers' questioning in class?*, was addressed by analysis of eight one-to-one student interviews and eight drawings. I firstly analysed the student interview data to develop themes and categories of students' views on teacher questions. I then analysed students' drawings, their written statements and transcriptions of the related interviews about their drawings.

Given that I did not find any previous studies focusing on students' perceptions of teacher questions in the context of scientific practices and there is no existing framework that can be used in my research, my data analysis was inductive. I employed six phases of thematic analysis to make the process as systemic and critical as possible: familiarizing myself with the printed interview transcriptions; generating initial codes; searching for themes; reviewing themes; defining and naming themes; and presenting the results (Braun and Clarke, 2006). In phase 1, I read the text many times and noticed students used a range of terms to describe their views about teacher questions: for instance, *challenging*, *interactive*, *developing thinking*, *paving the way for later learning*, *broadening knowledge*, *using the occasion to stop zoning out*, *focusing on easily confused knowledge* and *increasing difficulty gradually*. In phase 2, I wrote notes in the margin and then used NVivo 12 to collate extracts for each code. In phase 3, I drew mind maps in my notebook to group codes and discover themes. In phase 4, I selected codes; for example, although one student mentioned his view about spontaneous teacher questions, there were only a few words. This code was discarded because there was not enough data to support his claim. I merged similar codes; for example, I integrated *creating a relaxed and enjoyable atmosphere* into the code *increasing learning motivation*. Moreover, I re-examined all the printed transcriptions to check whether there was anything missing in my initial coding and whether there was anything that did not fit the codes or themes. In the final two stages, I identified my final themes, including students' views about different types of teacher questions and types of student attention to teacher questioning, and presented the analysis results.

I also made a comparison between what the students said and what their teachers said about particular episodes because I did stimulated-recall interviews and sent each student three or four episodes selected from those used to interview their teachers, as detailed in section 4.6.3.1. Both the teachers and students made comments on the same episodes or teacher questions.

Drawings have been used for many years in science education research to explore how students from kindergarten to college perceive scientists (e.g., Chambers, 1983; Losh et al., 2008; Steinke et al., 2007). These studies used the Draw-a-Scientist Test as a tool to focus on students' stereotypes of scientists, the primary source of information for students' perceptions of scientists, and interventions or factors (e.g., socioeconomic status and gender) influencing students' images of scientists. The Draw-a-Scientist Test Checklist was developed later by Finson et al. (1995) for use when marking students' drawings.

Based on previous studies, Thomas et al. (2001) created a Draw-A-Science-Teacher-Test Checklist (DASTT-C), including an instrument, a score sheet and a teaching style continuum. In their study, the preservice teacher was asked to draw a picture in which he/she works as a science teacher. A score sheet (see Table 4.4) was then used to judge whether the teaching in the picture was teacher-centred or student-centred. Teacher-centred means that a teacher treats learning subject matter knowledge as important and ignores the development of students' competencies (e.g., student-student cooperation and the ability to ask questions). Student-centred means that a teacher listens to students' ideas, encourages students to argue, work collaboratively and do what they are interested in, and the aim of science teaching is to learn subject matter knowledge and develop students' competencies. Each element in this score sheet is teacher-centred – for instance, lecturing/giving directions (teacher talking). If a drawing gets a higher score, it means the teaching is more teacher-centred (Thomas et al., 2001). DASTT-C has been used to explore science teachers' changes in their beliefs about science teaching after training courses (e.g., Ambusaidi and Al-Balushi, 2012; Minogue, 2010). Similar instruments were created and validated in, for instance, mathematics and engineering (e.g., Utley et al., 2020; Vo and Hammack, 2022). However, it has not been used to assess students' drawings of their science teachers.

Section	Sub-section	Statements	S2_Helen
Teacher	Activity	1 Demonstrating experiment/activity	0
		2 Lecturing/giving directions (teacher talking)	1
		3 Using visual aids (chalkboard, overhead, and charts)	1
	Position	4 Centrally located (head of class)	1
		5 Erect postures (not sitting or bending down)	1
Students	Activity	6 Watching and listening (or so suggested by teacher behaviour)	1
		7 Responding to teacher/text questions	0
	Position	8 Seated (or so suggested by classroom furniture)	1
Environment		9 Desks are arranged in rows (more than one row)	1
		10 Teacher desk/table is located at the front of the room	1
		11 Laboratory organization (equipment on teacher desk or table)	0
		12 Symbols of teaching (ABC's, chalkboard, bulletin boards, etc.)	1
		13 Symbols of science knowledge (science equipment, lab instruments, wall charts, etc.)	0
Total Score			9

Table 4. 4 Draw-A-Science-Teacher-Test Checklist (DASTT-C) score sheet and S2_Helen's scores

In analysing students' drawings, I first read students' drawings, their written statements and how they talked about their drawings in interviews: for example, what was in the teacher's hand and what students were doing in the image. I then separately marked the 13 elements in the score sheet. If an element appeared in the drawing, I marked it as a '1'. If it was missing, I gave a '0'. The total score range was from 0 to 13. Table 4.4 shows an example of the score of S2_Helen (see Figure 4.2).

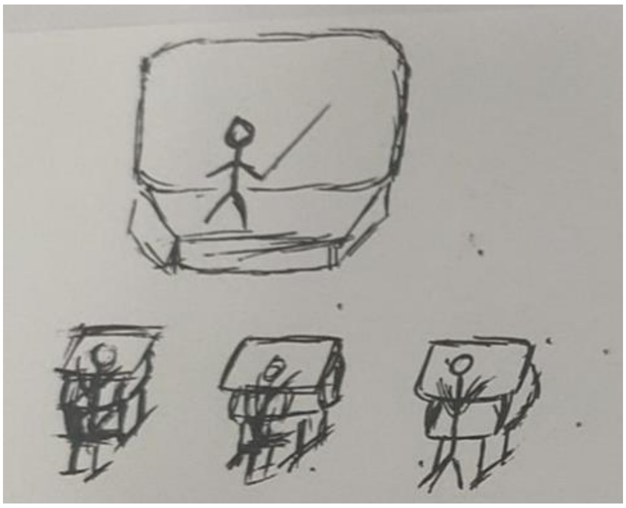


Figure 4.2 How Helen works with students when they are learning science knowledge (a drawing of S2_Helen)

The score sheet does not include the interactions between teachers and students, teachers and materials and students and materials, or the size of the teacher compared to students. Going beyond the characteristics present in the score sheet, I analysed not only the role of the teachers, the role of the students, and the environment but also the relationship between the teacher and students and interactions between the teacher/students and materials. Similarities and differences in the drawings were also discussed. These drawings provide information on how their teachers usually perform in the science classroom and complement the data on how teachers talked about their teaching.

4.8 Trustworthiness

Having presenting data analysis in relation to each RQ, I now discuss trustworthiness. From my perspective, trustworthiness means exploring approaches to ensure the validity of the analysis. I adopted several strategies to enhance the quality and credibility of my research (Patton, 1990; Shenton, 2004).

Regular debriefing sessions between my supervisors and myself. Discussions with supervisors helped me realize the importance of the justification for my actions and selections (e.g., justifying using the label *closed other*, rather than *closed convergent*) and the flaws in my reasoning. They also helped me recognize the huge culture differences that I should give a detailed account of in order to enhance trustworthiness.

Double coding. In terms of RQ 1, I asked a doctoral student to use a question classification framework to code some of my lesson data to make sure my coding was valid and credible.

Peer scrutiny of the research project. I had the opportunity to participate in the European Science Education Research Association summer school in 2021. During the event, I received valuable comments and feedback from tutors and peers regarding my small group and poster presentations. For example, they suggested defining expert teachers and utilizing a framework discussed in the paper titled *Validating the Draw-A-Science-Teacher-Test Checklist (DASTT-C): Exploring mental models and teacher beliefs* by Tomas et al. (2001). This framework was used to analyse student drawings.

Thick description. This involves making explicit the situations in which lessons happened (e.g., the number of teachers who observed the polished lesson) and the context in which the teachers worked (e.g., the characteristics of the school). It is valuable because I was not able to conduct the lesson observations or school visits that would have provided useful local context insights. The broader context and more detailed research information (e.g., the number and length of the episodes) can help readers feel that the data collection and analysis were properly devised, and they are able to scrutinize the research. Moreover, I can use tables or figures to demonstrate an "audit trail" (Shenton, 2004, p.72); for example, readers can trace my thinking about how I developed the purposes of teacher questions based on lesson data and interviews step by step by reading the tables and procedures.

Member checks. Simon is the only teacher who checked the accuracy of the transcriptions of his lessons and interviews on his own initiative. I did not ask the other teachers because they lacked time. Immediately after finishing Simon's transcription, I sent Simon each transcription immediately after finishing it, which he then read and checked. For example, he told me that $P^{31}$was wrong and the correct spelling was ^{31}P. He also told me that he was happy when he saw I had typed a rare and difficult word (攮 nǎng) correctly. Several different Chinese characters are pronounced the same way, but this character matched exactly what he said in his lesson.

4.9 Ethical considerations

Several important ethical issues were considered during the design and conduct of the study, including informed consent, rapport, data management and confidentiality (Cohen et al., 2018). Ethical approval was obtained before data collection. I used a letter to the headteacher (see Appendix 7), teacher information sheet (see Appendix 8), student information sheet (see Appendix 9), and teacher, student, and parent consent forms (see Appendices 10, 11, 12 and 13) to make explicit how the data would be collected, stored, and used; how and when the data would be destroyed; and that consent could be withdrawn at any time before September 2022. Signed teacher, student, and parent consent forms were also collected.

Considering that a headteacher might use their authority to encourage or even require a teacher to get involved against his/her will, I decided to contact the teacher first, and then requested the teacher to contact the headteacher to ask for permission. Furthermore, teachers and I have asymmetric positions of power (Cohen et al., 2018); for example, I determined the data collection sequence and stated the two requirements for lesson selection: teachers should highlight students' participation in scientific practices, and give priority to polished lessons. To mitigate this issue and encourage teachers to take the initiative, they had some power over decision-making; for example, they decided which three lessons were recorded. As mentioned in section 4.5.3, I asked teachers to help me recruit participant students in the classes where lessons had been audio recorded, which might have caused teachers to pressurise students to engage in the study, either knowingly or unwittingly. To gain informed consent and respect autonomy, ahead of arranging the interview, I asked the student whether or not they wished to be involved. At the beginning of each student interview, I also emphasized that everyone had a right not to take part and the student was free to decline any interview questions and free to withdraw consent without any negative consequences before I wrote up my thesis.

It was difficult to build trust and rapport online. I adopted several strategies to deal with this challenging problem. For example, I talked about my eight years of teaching experience to ensure teachers could relate and explained why I studied a PhD in the UK, describing the possible benefits and the impact of the research to make teachers feel they were doing a meaningful thing that could improve classroom practices and positively impact teacher professional development programmes in China. During the interviews, I sincerely praised these expert teachers for their teaching excellence and created a friendly and enjoyable interview atmosphere. They felt positive about the interviews as detailed in section 7.2.3 in the chapter on the research findings of RQ 3. I appreciated all the participant teachers' time and effort during the research and sent thank you messages to them after each interview.

In terms of confidentiality, interviews and lesson data mainly involved teachers' and students' views about teacher questioning and did not require the collection of sensitive data (e.g., religious beliefs, political opinions, health, and sexual orientation). How I processed and stored data was stated clearly in the data management plan submitted to the ethical review committee. Specifically, the participant schools, teachers, and students were presented using pseudonyms to ensure that a teacher from my area reading the thesis could not identify the school, teacher or student based on the characteristics provided in this thesis. In addition, the research data were collected and stored securely in accordance with the University of Leeds Data Protection Policy. All hard copy documents – for instance, printed lesson plans and transcriptions – were kept in a locked filing cabinet in my office at the School of Education at the University of Leeds. All digital data (e.g., photographs of students' drawings, audio recordings and digital transcripts) were saved in a secure cloud storage (the University of Leeds M: drive), and data were only accessible to me during the four-year research project. As peer-coding of data was needed (Patton, 1990) to address RQ 1, I asked the other coder to verbally agree not to disclose any research information to anyone.

4.10 Reflexivity and researcher positionality

In qualitative research, the researcher is a key research instrument and plays a crucial role in knowledge production (Cohen et al., 2018). The way of looking at and interpreting the research was affected by my nationality, background, experience, knowledge, beliefs, interest, gender, age, etc. I therefore needed to reflect on who I am and consider how my lenses might influence the research.

As detailed in the introduction chapter, I conducted research into scientific inquiry when I studied for a three-year Master's degree. I then taught secondary biology in Xi'an City. I was interested in teacher questions and scientific practices. Therefore, I selected those RQs and conducted the pilot study in my own workplace. I worked in the school for eight years, and it was easy to gain permission from the school leader and convenient to collect data there. I knew the history of the school, its policies, how teachers worked together, and the students' backgrounds. I observed Joan's lessons dozens of times. When Joan talked to me during the interviews, I was treated as an insider; for example, she said, "Do you remember the school-based curriculum we developed and taught together?"

I interviewed six expert teachers. They had different attitudes towards me, which was reflected in the ways they addressed me. Some teachers showed great respect to my research and expected that I would be a promising scholar in China, and as a result they called me *Teacher Zhang*. Some enjoyed high status at their schools and were prestige teachers senior to me, and they called me *Zhongyan* or *Little Zhang*. In response to this, I showed modesty to all the participant teachers and politely listened to what they had to say.

Four teachers in the formal data collection taught junior secondary biology, and each teacher selected three lessons. I myself taught these lessons several times when I was a teacher. Sometimes I unconsciously and spontaneously compared their teaching with mine. I was happy when I noticed something different from my teaching, especially some novel and insightful ideas about teaching and questioning (e.g., scenario-based questions). In another example, I used slides for every lesson, while Sue did not like using slides because it limited the students in their imagination and thinking to some extent. I respected the participants and I did not judge them or their work.

4.11 The impact of COVID-19

The pandemic had a significant impact on my pilot study and formal data collection. My pilot study ran from September 2020 to January 2021, and the formal data collection from March 2021 to November 2021. However, in March 2020, Chinese airlines launched a Five One policy to curb the COVID-19 crisis, allowing one airline to serve one country, from one Chinese city to one foreign city, with no more than one flight a week. From December 2020 to August 2022, there was no direct flights between the UK and mainland China. Tickets were very expensive, and people had to self-isolate in hotels for at least two weeks after arriving in China. It became extremely difficult for me to fly to China to collect data. I was therefore not in China for any the data collection.

In my transfer document, I planned to carry out three face-to-face interviews per teacher, observe three secondary biology lessons in person for each teacher, and conduct six focus group interviews with students. However, these plans have been disrupted by COVID-19. I had to change my data collection methods so that they were non-contact: for example, moving from face-to-face teacher interviews to online interviews and moving from four-student focus groups to one-to-one online interviews. I also requested each teacher to audio record three lessons. Although online interviews are convenient, acceptable, and productive, I am an interviewer who prefers to observe people’s responses, facial expressions, and emotions. If I had sat and talked with participants face-to-face and used visual cues, I would have asked different follow-up questions.

It was also more difficult to establish rapport and build trust with teachers online. Teachers sometimes scheduled interview meetings with me after I contacted them two or three times. However, I tried my best to adapt to these challenges; for example, I shared my work experience with teachers as described in section 4.9.

During the pandemic, it was difficult to observe student responses in the classroom and meet them face-to-face, which caused difficulties in building trust between the students and myself. It was therefore not easy to recruit student volunteers as I could not observe their lessons and stand in front of the classroom to advertise my project. I developed the idea of using a video to address this. However, if I was in the classroom, I might have found opportunities to interview more students and different ways of interviewing students to make my data richer and more diversified. For example, I might spend a few minutes asking students a series of questions about their feelings and responses to teacher questions immediately after a lesson. Questions could include what the students' feelings were when they replied to a question, what they liked and did not like in terms of teacher questioning in this lesson, and why they responded to this teacher question in the way they did.

Furthermore, I was stressed and worried because the schools were likely to be closed if there were a few COVID-19 cases in Xi'an city. In some cities, schools were closed after Covid infections increased, and teachers delivered online lessons to students who stayed at home at the time when I collected my data. There was major uncertainty around how things would develop. I faced a massive challenge and made three contingency plans in case of school closures in Xi'an City.

Plan A was to contact the alumni of my university to request them to recommend expert teachers who received honours for teaching excellence in their schools. As most of my classmates were teachers and they worked in different cities, the six participant biology teachers could come from different provinces and different cities in mainland China.

Plan B was to recruit expert teachers in one developed city (e.g., Shanghai) where schools were open. It was difficult to get in touch with them, as their contact details were not available. Therefore, I planned to identify several schools, and then send headteachers emails to get access to expert biology teachers. The disadvantage of this sampling method was that I might not be able to approach the teacher if the principal refused permission. Moreover, it was not easy to build trust with a teacher and obtain consent as we were from different cities. However, this plan might have enabled the opportunity for me to get access to higher levels of scientific practices, in that the bigger cities are much more developed than Xi'an City. For example, Shanghai has long been regarded as the site of successful reform in education in mainland China.

Plan C was to be adopted if the above plans did not work. I could collect lesson recordings that had been recorded over the last two years. However, in that case the interviews would be less productive, as the teacher might have forgotten many of the details. I only considered this plan when there was no better way of collecting data.

I did not implement these contingency plans as the schools where the participant teachers worked were open during my data collection in Xi'an City. Nonetheless, these backup plans were necessary at the time in case data collection was interrupted due to school closures, preventing teachers from conducting face-to-face teaching.

Chapter 5 Research Findings of RQ 1

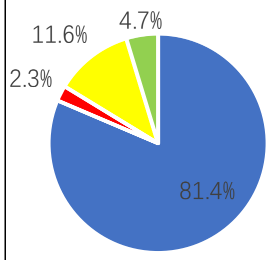
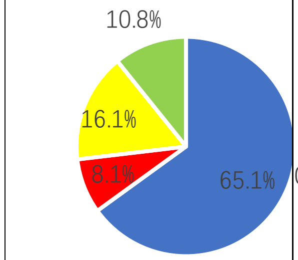
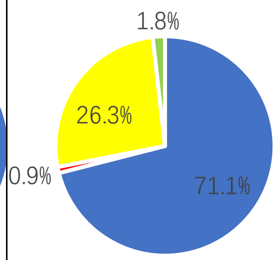
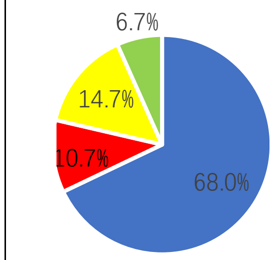
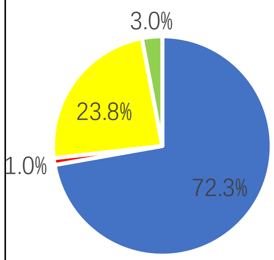
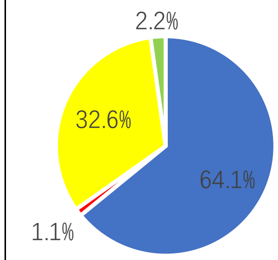
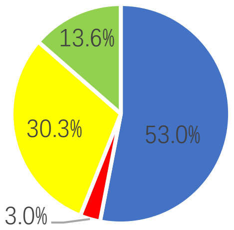
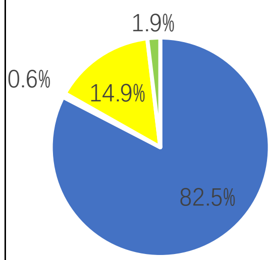
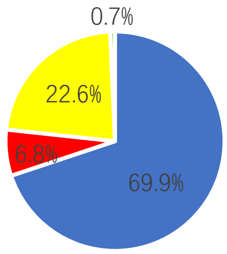
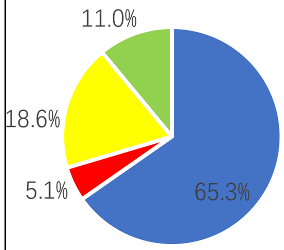
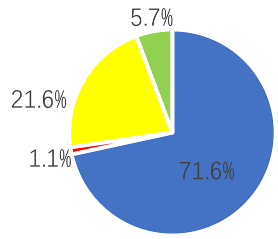
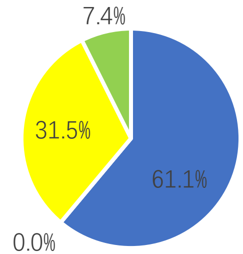
In this chapter I use numbers, tables, and figures to present an overview of how teachers use different types of teacher questions. This analysis addresses RQ 1: What types of questions do teachers ask during teaching that encourage students' engagement in scientific practices? The findings show the extent to which each of the six teachers posed different types of questions and the differences and similarities in their use of questions. They lay the basis for later analysis and discussion: for instance, the purposes of scenario-based questions and reasons for a higher proportion of open questions in polished lessons.

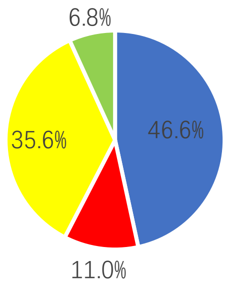
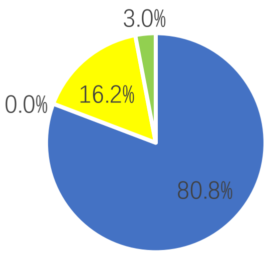
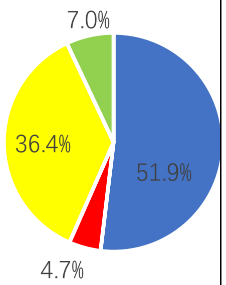
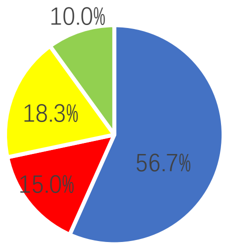
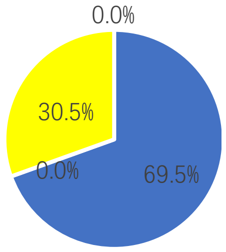
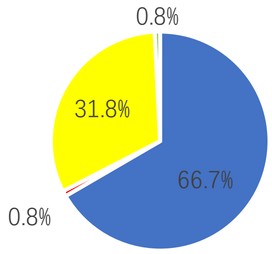
This chapter begins by presenting how each of the six teachers used different types of questions in three lessons, then describes the main findings, and finally summarizes the findings that will be used to inform the deeper contextualized analysis.

5.1 How did each teacher use different types of questions in three lessons?

As described in section 4.7.1.1 in the methodology chapter, I used an analytical framework adopted from Blosser's (1975) QCSS for the analysis of teacher question type. I asked a researcher to code some data to increase the data's validity and credibility, and the analysis results are shown in Appendix 14. The length of the recording, number of different types of teacher questions, and the total number of teacher questions can be seen in these detailed tables. I converted the data in the tables into pie charts (see Table 5.1) as a visual aid to show the percentages of different types of questions for each lesson and thereby to illustrate the overall quantitative similarities and differences across the six teachers.

The data serves as the foundation for teachers' reflections on these types of questions, for instance, the openness of teacher questions and scenario-based questions. I am not suggesting that the proportion of different types of questions is directly correlated with the efficacy of student learning outcomes. I acknowledge that students can achieve high test scores via closed questions and it is plausible for a teacher to use lots of open questions but the students' learning outcome is weak.

	Ziv	**Sue**	**Zachary**	**Wynne**	**Helen**	**Simon**
Lesson 1						
	Investigate the role of saliva, teeth, and tongue in digesting starch in the lab.	☀Explore the roles of animals in the biosphere.	Blood transfusion and blood types	☀Characteristics of reptiles	☀Explore what happens to homologous chromosomes during meiosis.	Genes are located on chromosomes: Sutton's theory and Morgan's experiment.
Lesson 2						

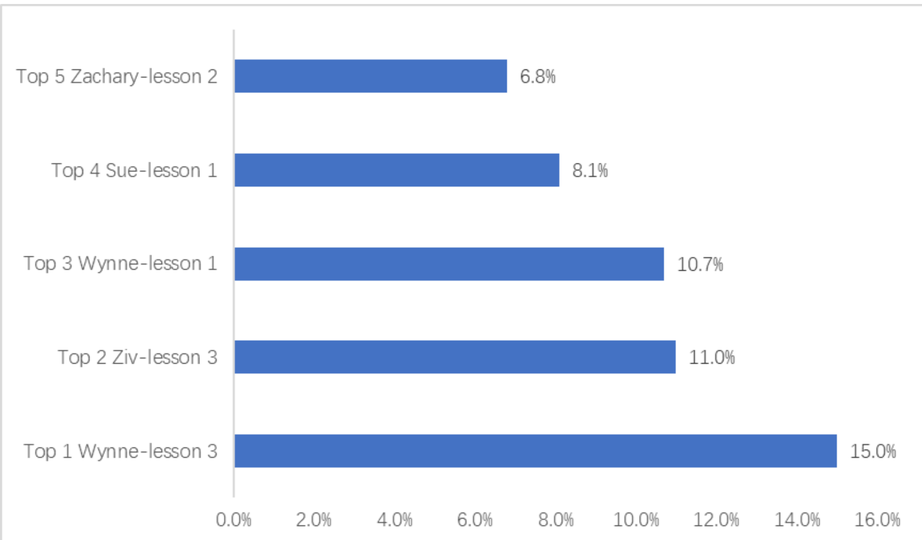
	Analyse experimental results in the classroom. Draw a conclusion that saliva, teeth, and tongue affect starch digestion.	Describe the structure of the respiratory system and mainly focus on the functions of the respiratory tract.	Amphibians and reptiles	☀The bones, joints, and muscles, and how they fulfil their function in the movement of animals	Genes are located on chromosomes.	Genes are located on chromosomes: infer the location of the eye colour gene in *Drosophila* based on Morgan's experiment.
Lesson 3						
	☀Healthy diet and food safety	Components of the nerve system and the structure and function of a nerve cell	Characteristics of mammals	☀The four main components of an ecosystem	DNA is the main genetic material: experiments by Griffith, Avery, Hershey, and Chase	DNA is the main genetic material: Griffith's and Avery's experiments.

Note: (1) Percentage=number of a type of questions in one lesson/total number of four types of questions in this lesson. (2) ■ represents closed questions, ■ represents open questions, ■ represents rhetorical questions, and ■ represents managing discussion questions. (3) Polished lessons are marked by ☀ and highlighted in colour.

Table 5. 1 An overview of different types of questions across 18 lessons

5.2 Main findings

As shown in Table 5.1, closed questions were used significantly more often than the other three types, and open and managing discussion questions were used less frequently. Wynne used a higher proportion of both open and managing discussion questions compared with the other teachers. Conversely, two senior secondary school teachers – Simon and Helen – used a very low proportion of these two types of questions. For example, in Simon's lesson 3, only 0.8 percent of his questions were open and only 0.8 percent managing discussion questions. There were no open questions or managing discussion questions used in Helen's third lesson. This lack of open questions and those that invite other students to engage in classroom discussion might result in too much teacher control, which in turn limits students' participation in knowledge construction in scientific practices. As described in section 3.5 in the literature review, the literature as a whole tends to quantitatively present how teachers use different types of teacher questions but lacks data about the reasons behind teacher questioning. This indicates that teachers' views about open and closed questions and teacher tensions when using questions need to be explored.



Note: Percentage=number of open questions in one lesson/total number of four types of questions in one lesson

Figure 5.1 Top five lessons with a high proportion of open questions

Five lessons stood out from the rest in that they had a high proportion of open questions (see Figure 5.1). The top four were polished lessons that colleagues observed before discussing how to improve the teacher's classroom teaching. Zachary's lesson 2 was not a polished lesson; however, he had 26 years of teaching experience. He told me that he taught several classes in the same grade and adapted his teaching every year until he was satisfied. Overall, the percentages of open questions within the six polished lessons and 12 lessons that were not polished were 7.0 percent and 1.9 percent, respectively (see Table 5.2). Managing discussion questions (e.g., Anything to add?) 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. The result is not surprising as polished lessons were refined based on collective lesson observations and discussions and teachers tried to use their questions to draw students' ideas out. However, it is still worth exploring the reasons behind this because little is known about why teachers engaged in such activities, for example, the impact of policies on polished lessons and how they affect teachers' work practices and classroom behaviour. This also highlights the detailed process of polished lessons and the teachers' experiences that need be explored further: for example, how teachers improved teacher questioning in the polished lessons, how much effort they made, and what the motivation behind the polished lessons was.

	Polished lessons	**Non-polished lessons**
Closed questions	63.8%	69.0%
Open questions	7.0%	1.9%
Rhetorical questions	21.6%	25.9%
Managing discussion	7.6%	3.2%

Note: Percentage=number of a certain type of questions in six polished lessons (or 12 non-polished lessons)/total number of teacher questions in six polished lessons (or 12 non-polished lessons)

Table 5. 2 A comparison of question types between polished lessons and non-polished lessons

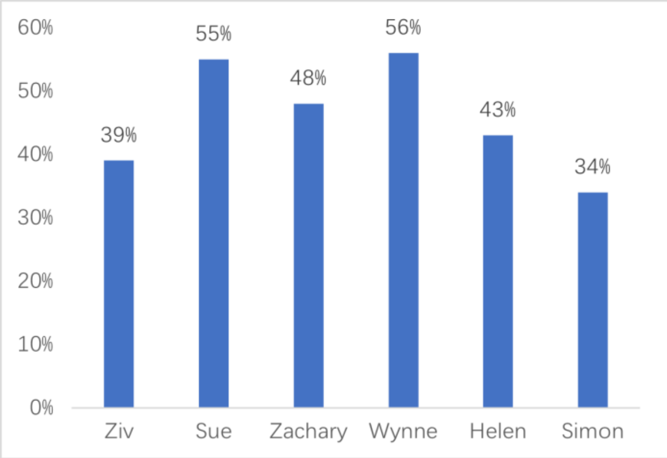
There are also differences in the way the six teachers used different types of open questions. As there were only a few open questions in each lesson, I present both their number and proportions in Table 5.3. As can be seen from this table, Wynne asked more open questions in her three lessons than the other teachers did, not only using open divergent questions but also paying attention to open evaluative questions. Wynne also posed the largest number of open evaluative questions. Her three lessons were all polished lessons. Zachary, who worked in the same school as Wynne, posed six open evaluative questions, which was a higher number than teachers in the other schools posed. As stated above, Simon and Helen used open questions the least. Note that Simon asked only two open questions, though both were open scenario-based questions, which were not used by the other teachers. As described in section 4.7.1.1, open scenario-based questions help students think from another perspective: for example, "Imagine you are the scientist Sutton or Morgan…?" Science teachers often present abstract and complicated arguments and explanations; for example, the eye colour of fruit flies is controlled by genes located in X chromosomes. Using such questions might help students focus on the scientist's situation and use experimental data to generate convincing conclusions.

	Ziv	**Sue**	**Zachary**	**Wynne**	**Helen**	**Simon**
Number of open questions	16	16	17	23	3	2
Open divergent	14	13	11	12	2	0
Open evaluative	2	3	6	11	1	0
Open scenario-based	0	0	0	0	0	2
Percentage of open questions	7.0%	3.6%	4.4%	9.1%	0.6%	0.7%

Note: Percentage=number of all open questions in three lessons/total number of four types of questions in three lessons

Table 5. 3 Differences in teachers' use of open questions

Figure 5.2 presents a description of the percentages of closed memory questions among the total number of closed questions in each of the teacher's three lessons. For example, of all the closed questions in Ziv's three lessons, 39 percent were closed memory questions that asked students to recall factual knowledge. In other words, 61 percent of questions in his lessons were classified as closed other. It can be seen from the data that Simon and Ziv had the lower proportions of closed memory questions (34 and 39 percent, respectively), which means they focused more on reasoning, comparing and other higher cognitive levels. Wynne and Sue posed slightly more closed memory questions than closed other ones.



Note: Percentage=number of closed memory questions in three lessons/number of closed questions in three lessons

Figure 5.2 Differences in teachers' use of closed memory questions

5.3 Summary

In this chapter I have sought to provide a full picture of how teachers used different types of teacher questions based on an analytical framework adopted from Blosser's (1975) QCSS. Some findings provide discussion points upon which the rest of the research has been built, involving the following:

- Closed questions were used significantly more than open questions.
- Polished lessons enabled more open questions.
- Scenario-based questions were used by Simon.

The related reasons behind the questioning practices and how teachers and students talked about scenario-based questions will be discussed in later chapters.

Chapter 6 Research Findings of RQ 2

RQ 1 provided an overview of how teachers use different types of teacher questions quantitatively. The intent of RQ 2 is to qualitatively look at teacher questions and provide a detailed account of their purposes: What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?

This chapter is divided into three sections. Section 6.1 uses data to give a detailed description of the analysis process in order to increase transparency. Section 6.2 presents analysis results, including how purposes employed during the lessons relate to scientific practices, which is the focus of RQ 2. The section also shows the other themes that emerged in the data. These expert teachers' examples of questions and the explanations for them can encourage other teachers to reflect on their question purposes and lead to improvements in questioning practices. A summary is then provided at the end of this chapter.

6.1 Analysis of purposes of teacher questions

It was possible that a question was planned but the teacher did not have an intended purpose. It was also possible that the teacher made a quick decision and asked a question spontaneously according to the student responses and did not have an intended purpose. However, relatively speaking, teachers' questioning practices were purposive.

As described in section 4.7.2 in the methodology chapter, I used both lesson and interview data to explore the purposes of teacher questions. For each teacher, I first coded the purposes of their questions in the lesson data, then coded the interview data, before comparing the two strands of coding and, finally, generating categories. I show the details of how I analysed three of Ziv's lessons and three of their interviews below. I analysed the data of the other teachers in the same way. Therefore, in section 6.1.1, I show the details of Ziv's background, the three lessons, and how I developed the question purposes through employing the lesson and interview data. I then shifted to the overall comments regarding the use of different datasets to look at purposes of teacher questions in section 6.1.2.

6.1.1 Details of how I analysed Ziv's data

Ziv, the biology teacher who participated in my research, worked in a famous private junior secondary school in Xi'an City, which was built about 25 years ago. It had a clear advantage in scoring because it was far ahead of the other schools in the city in terms of the results of the high school entrance examination. In addition, "it attaches a lot of importance to the development of students' comprehensive literacy, not judging students purely on grades" (Ziv_IV1). Ziv had 21 years teaching experience, and he was a city-level teaching expert. He had a society class, the Science Micro Video Society, where he guided students in carrying out open inquiry about once a week. He led students to participate in national competitions and won amazing prizes for his school: for instance, the Soong Ching Ling Award for Children's Invention. The classes that I listened to were composed of 56 students, aged 12 to 13 years, including a wide spread of student abilities: that is, including both inquisitive students who had "a thirst for knowledge" and those who were very "passive in learning" (Ziv_IV3). Lessons 1 and 2 were recorded with the same class, while lesson 3 was recorded with a different class.

6.1.1.1 Ziv's three lessons

I listened to three lesson recordings of Ziv (see Table 6.1). The first two lessons investigated the role of the mouth (saliva, teeth, and tongue) in digesting *mantou* (Chinese steamed buns). In his first 40-minute lesson, students conducted experiments in the lab. In Ziv's second lesson, students analysed the results in the classroom. Ziv only recorded 30 minutes because after finishing analysing the experiment, he spent the last 10 minutes teaching another topic about structural features of how the small intestine had adapted to absorb digested food. The aim of both lessons was to understand that saliva, the chewing action of teeth and mixing with the tongue affect food digestion in the mouth; that is, these three conditions are essential for the process of decomposing starch in the steamed buns into maltose. Students carried out experimental tests that involved placing the steamed buns in test tubes, presenting each test in a different set of conditions (steamed buns with saliva plus grinding and mixing; steamed buns without saliva; steamed buns without grinding and mixing).

The third 40-minute lesson discussed what a healthy diet was and how to ensure food safety. This lesson was directly related to student life and Ziv chose it for a polished lesson. As elaborated in detail in section 3.6.3, a polished lesson is a planned and structured classroom teaching activity that is open for a specific group, including school leaders and other teachers. About 25 people, including school leaders, biology teachers and teachers who taught other subjects, watched the lesson at the back of the classroom. Some teachers worked in the school and some were from other schools. It was an opportunity for Ziv to demonstrate his teaching skills as a municipal expert teacher and exchange experiences with colleagues, and he was well prepared for this lesson. For example, he bought physical models of the online food guide pagoda so that two students could have a model in the classroom. He tried his initial lesson plans in other classes, listened to the biology teachers' opinions and changed his lesson plans accordingly. One student who attended the polished lesson told me during the student interview that he was proud that his biology teacher Ziv was an expert teacher and his class had been chosen to demonstrate this lesson.

Overall, the first two lessons, in which students carried out experiments, and analysed and interpreted data, focused more on scientific practices than in the third lesson. For example, in lessons 1 and 2, Ziv asked students how to create a 37°C environment for test tubes and why three test tubes should have an equal mass of steamed buns, then helped students to predict the experiment results. In this way, he focused on planning and carrying out investigations. Reporting inconsistent findings and analysing in which test tube the starch was broken down and what the reasons were was related to analysing and interpreting the data. The students' group discussion at the end of lesson 2, which involving the roles of teeth, tongue, and saliva and the differences and connections between them, was related to obtaining, evaluating, and communicating information. However, only a small part of lesson 3 paid attention to one of the scientific practices, using models. It involved observing the model of the food guide pagoda, analysing its composition, and using it to explain why a meal was healthy and balanced.

6.1.1.2 Episodes used when interviewing Ziv

From the transcriptions of three lessons, I selected seven episodes in which the devised format included students engaging in scientific practices (e.g., analysing data) or his questions. I sent the transcripts to Ziv at least one day ahead of the second and third interviews. For the second interview, two episodes were selected from lesson 1 and two episodes from lesson 2 (see Table 6.1). For the third interview, three episodes were selected from lesson 3 (see Table 6.1). These were selected by the researcher. In addition, before the interviews, I told Ziv that one interview question would ask him to describe what he thought went well in these recorded lessons, with the aim of giving him an opportunity to talk about what he valued most in his teaching. Therefore, Ziv drew upon two episodes in the second interview and one episode in the third. All the episodes that he thought went well were those I selected (see Table 6.1). Two examples of these episodes can be seen in Appendix 15.

Lesson	**Topic of the lesson**	**Duration of class (min)**	**A polished Lesson? (Yes/No)**	**Episode**	**Who selected the episode?**
Lesson 1	Investigation of *mantou* digestion in the mouth (I)	40	No	Episode 1: how do you know it is starch?	The researcher
				Episode 2: analysing and interpreting data	Both
Lesson 2	Investigation of *mantou* digestion in the mouth (II)	30	No	Episode 3: a typical controlled experiment	Both
				Episode 4: communication	The researcher
Lesson 3	Healthy diet and food safety	40	Yes	Episode 5: could we eat instant noodles too much?	The researcher
				Episode 6: using the model food guide pagoda	Both
				Episode 7: is your food safe?	The researcher

Table 6. 1 Details of three lessons (Ziv)

6.1.1.3 Ziv’s question purposes

I now move to examine the purposes of Ziv's teacher questions. As stated earlier, I developed Ziv's question purposes based on two strands of data: lessons and interviews. When I analysed lessons, I focused not only on each teacher question, but also a sequence of questions. Because questions are linked, rather than isolated, I need to zoom out to get a broader perspective.

The following is a list of question purposes developed based on Ziv's three lessons (see Table 6.2).

Focusing on each teacher question		Focusing on a sequence of questions
★Eliciting	★Applying	☆Opening up the problem
★Probing	★Linking	☆Checking student understanding
★Extending	★Refining	☆Explaining the model
★Clarifying	★Inferring	☆Applying the model
★Prompting	★Checking	☆Understanding concepts
★Challenging	★Reporting inconsistencies	☆Engaging with current affairs
★Reinforcing	★Contradicting	☆Connecting content to students' lives
★Explaining		☆Predicting experimental results
		☆Analysing and interpreting experimental data
		☆Identifying the variables and understanding controlled experiments

Table 6. 2 Codes for purposes of teacher questions in the lessons (Ziv)

The following is a list of question purposes developed based on the interviews (see Table 6.3).

Scientific practice-specific	Scientific practice-general
★Mastering the principles of scientific inquiry ★Clarifying the experimental aim and design ★Reporting inconsistent findings ★Analysing experimental data	☆Framing ☆Laying the foundations for future learning ☆Enlightening students ☆Forming appropriate emotions, attitudes, and values ☆Checking whether learning objectives were achieved ☆Enabling students to explain phenomena in their lives ☆Going back to the textbook ☆Reviewing ☆Reaching a consensus ☆Using precise and scientific language ☆Opening up the problem ☆Activating classroom climate ☆Warning

Table 6. 3 Codes for purposes of teacher questions from the interviews (Ziv)

I developed Table 6.4 after combining, deleting, and categorizing codes in Tables 6.2 and 6.3. In this table, I showed the codes, their descriptions and examples that included question examples and interview extracts.

Code	Description	Example
Mastering the principles of scientific inquiry	To identify the variables; to design a control group and an experimental group; to understand reproducibility	That is, among the three test tubes, which test tube is the control group, which two test tubes can form a control group and an experimental group? It is very important to understand this principle of the design of a controlled experiment. This is also the core scientific inquiry ability that we require students to master in inquiry-based practical work. (Ziv_IV2)
Clarifying the experimental aim and design	To clarify what the aim of practical work is and why it is designed in this way	Let students understand the experimental design. What do the three test tubes simulate respectively in this practical activity? Why use three test tubes? Why do we design in this way? (Ziv_IV2)
Predicting experimental results	To predict the outcome of a practical activity	Ziv: What do you think the colour will be when iodine solution is added to the No. 1 test tube after [covering the test tube with hands to keep it warm for] five minutes? (Ziv_L1)
Reporting inconsistent findings	To investigate the findings that are inconsistent with those of the textbook	I had talked about the experimental procedures. In theory, if students followed the steps strictly, their results should be the same, but in practice there were some inconsistent findings because students did this practical work for the first time, after all, and no doubt they made some mistakes during the process: for instance, the amount of iodine solution dripped or the reaction time. So, it is necessary to get such feedback. Let the students see that there were all kinds of results, but what was the result that most students got? Collect the data. Then, other students could think about why their results were different from those of most people and what the reasons were. (Ziv_IV2)
Analysing experimental data	To analyse and interpret experimental data	Let students learn to analyse experimental results, learn to analyse because it was just a simulation and this simulated practical activity finally needs to reflect digestion [in the mouth], and go back to [the topic of] digestion. (Ziv_IV2)
Using models	To explain the model (the Food Guide Pagoda for Chinese Residents) and apply	Ziv: Which food group should we consume the most of each day, according to the model? (Ziv_L3)

	it to solve daily life problems	Ziv: Why is this lunch healthy and balanced based on the model of the food guide pagoda? (Ziv_L3)
Understanding concepts	To understand a concept; to grasp the main points of the definition; to ask students to name a concept	[Ziv stated that a healthy diet is a concept referring to a comprehensive and balanced diet] Ziv: A comprehensive diet is about having the six major nutrients and dietary fibre in the diet. What does a balanced diet mean? How about the ratio of the six essential nutrients? (Ziv_L3)
Using a precise and scientific language	To articulate ideas with a precise and scientific language	Ziv: Could you please give me one term that describes the functions of tongue and teeth in the breakdown of starch? (Ziv_L2)
Implementing social responsibility	To engage with current affairs; to enable students to explain phenomena in their lives	For example, when you swim, explain why people suddenly feel breathing is particularly laborious after they go into the water… Let them go back to life and explain this phenomenon. Then they will understand the concept, and they will take the initiative to apply it. Naturally, we want to cultivate students' scientific literacy. They will use these concepts to explain the phenomena in their lives. (Ziv_IV1)
Forming appropriate emotions, attitudes, and values	To have appropriate emotions and attitudes and see the worth of something; to warn students not to eat junk food	This lesson has a teaching objective about emotions, attitudes, and values. That is, wild animals should be protected. We sometimes eat them, try new food, but these wild animals cannot be eaten. First, they should be protected. Second, they might carry some bacteria and some viruses. So, I talked about this here. In fact, this is to achieve the objective of [appropriate] emotions, attitudes, and values. (Ziv_IV3)
Framing	To use questions to structure a lesson	When I prepare lessons, I like doing this; I pre-plan a sequence of questions to structure a lesson. As for this class, from simple to complex, I use a sequence of questions to link different parts of the lesson. (Ziv_IV2)
Drawing out	To elicit or open up the problem; to probe; to prompt; to elicit a group discussion	The nutrition [in instant noodles] is not comprehensive: too much salt, too much fat, mono diet. It is unhealthy and it is unbalanced. Therefore, the purpose is to pave the way

	topic; to link different parts of a lesson and create coherence	for a healthy diet: that is, to lead to the topic of a healthy diet. (Ziv_IV3)
Clarifying	To clarify the characteristics, relationships or functions of something	Ziv: What is the role of teeth and tongue in [eating] sweetened steamed buns? (Ziv_L2)
Checking	To check student understanding; to check whether learning objectives were achieved; to check how many students successfully finish practical work	The last question is mainly to connect to life. Chewing food and eating slowly, what are the benefits? Do students really understand it? If they can explain the reasons, it means they understand it. Then I have achieved my learning objectives. I just want to check if my learning objectives have been achieved. (Ziv_IV2)
Reinforcing	To highlight an idea; to reach a consensus	Ziv: The colour doesn't change when iodine solution is added to the No.1 test tube, right? (Ziv_L2)
Refining	To correct or make modifications	Ziv: What do you think the colour will be when iodine solution is added to the No. 1 test tube? Ss: Dark blue. Ziv: Dark blue? Ss: The colour won't change. Ziv: If it turns blue after iodine solution is added, what does it mean? (Ziv_L1)
Going back to the textbook	To pay attention to what the textbook says	The description in the textbook is very simple, but very precise. When students analyse their problems, they go back to the textbook. They can use the knowledge of the textbook to understand what their problems are during the practical activity, or how to describe the conclusion of this practical work more accurately. (Ziv_IV2)

Challenging	To push students to higher levels of thinking; to enlighten students	Ziv: The normal oral temperature is 37° C. That is to say, for these three test tubes, we must create… Ss: 37° C. Ziv: How do we create a 37° C environment? (Ziv_L1)
Activating the classroom climate	To create a lively learning climate	Crush the steamed buns, put them in the test tube, and then let the student drop the iodine solution. He saw the colour change himself... This is to active classroom climate. (Ziv_IV2)
Laying the foundations for future learning	To gain knowledge that will form the basis for future learning	The concept of digestion is to change substances that cannot be absorbed into those that can be absorbed: that is, to change large molecules into small molecules, which is a chemical change. Nevertheless, junior secondary students, they haven't actually learnt chemistry. They don't study chemistry in the first year of junior secondary school, and start to learn it in the third year of junior secondary school... Developing this concept will be helpful for them to study chemistry in the future. (Ziv_IV2)
Recalling	To recall what students have learnt	Ziv: What is the beginning of the digestive tract? (Ziv_L1)
Inferring	To infer	Ziv: In which test tube was the starch broken down? (Ziv_L2)
Explaining	To give reasons for something	Ziv: Why was the starch broken down? (Ziv_L2)
Managing discussion	To ask students if they agree or if they have anything to add	Ziv: Does anyone agree with their analysis? (Ziv_L2)

Table 6. 4 Codes for purposes of teacher questions (Ziv)

6.1.2 Reflections on the use of different datasets to look at purposes of teacher questions

I used the lesson data and interview data to analyse the other teachers. In this section, I compared what these two datasets told me about the purposes behind teacher questions. The rationale for why I did it this way is that studies tend to explore purposes of teacher questions or utterances by looking at classroom teaching and lack teachers' reflections on their purposes for doing this, as described in section 3.4 in the literature review.

(1) As described in section 4.7.2.2, coding the lessons is I used the lesson data to infer purposes of teacher questions from an external perspective, which is different from coding the interviews that show the inner voices of teachers and their reflections on purpose.

(2) Teachers did not talk about every question in the interviews, but I coded every teacher question in the lesson transcriptions. Therefore, codes for lesson data could be added to the whole coding set. For example, I developed the purpose of paying attention to experimental materials based on the lesson transcription.

(3) In terms of their consistency, sometimes teachers spoke proudly about what they intended to do during interviews (e.g., "I did my best to make students experience the fun of inquiry." (Helen_IV3)), but they did not actually do it during their classroom teaching.

(4) There was usually one purpose for one teacher question when I coded the lesson transcriptions. The teachers sometimes gave me a few purposes for their questions during interviews. For example, I used one code for the teacher question "Where do you inject a mouse?" when analysing the lesson, whereas I generated five purposes for this question when analysing Simon's interview: laying the foundations for future learning; realising the importance of standard procedures; activating classroom climate; learning to respect and love; and use of scenario-based questions.

(5) I focused on questions during analysing lessons when teachers might talk about the purposes of a lesson, rather than limiting purposes to a question or a series of questions in the interviews. The purposes behind teacher questions clearly matched the purposes of the lesson

more broadly. Sometimes, when analysing the lesson, I assumed the teacher asked a question to simulate interest or to recall knowledge, but a different and unexpected answer was given during the interview (e.g., “Different pieces of knowledge should fit together into a web” (Sue_IV3) and “I ask this question to implement a big idea of biology: structure determined function” (Wynne_IV2)). Teachers might look at questions from a broader angle. What they said and what I listened to and noticed complemented each other.

6.2 Six teachers’ purposes of teacher questions

My inductive qualitative data analysis identified five themes, which are presented in the following subsections: (1) how purposes through the lessons relate to scientific practices; (2) use of questions to emphasize social responsibility; (3) use of questions to support understanding ‘big ideas’ in science; (4) use of questions to form appropriate emotions, attitudes, and values; and (5) questions used for pedagogic purposes. One teacher question might serve multiple purposes and different types of purposes are sometimes intertwined. For example, one question was not only related to scientific practice but also served a pedagogic purpose. I applied the following criteria for the selection of these themes: (1) how they relate to scientific practices that are my thesis focus; (2) whether they can help me develop original contributions to existing research literature; for example, using scenario-based questions to serve a pedagogic purpose is not strongly evident in other similar studies; and (3) whether some purposes can be linked to RQs 1 and 3 to explore reasons: for example, why Wynne asked more open questions and how this purpose was affected by personal, internal, and external factors.

The significant differences and similarities between teachers, or some of them, were discussed for each theme. Significant means here that the focuses are worth highlighting with extracts or examples of very sophisticated use of questions. To some extent, the similarities and differences between the purposes seen in the data were framed by the topics of each lesson. For example, the lesson Investigation of *Mantou* Digestion in the Mouth involved control variables that are not seen in most lessons. As Helen and Simon taught the same lesson on

Where Genes Are Located on Chromosomes, they showed the same purpose lay behind their questions: paying attention to scientific methods.

6.2.1 How purposes through the lessons relate to scientific practices

The sections below present and exemplify nine purposes related to scientific practices and developed based on the analysis of lessons and interviews. Each purpose was illustrated and elaborated below using a selection of extracts from lessons or interviews.

6.2.1.1 Learning to control variables

Here, I explain how Ziv and Simon used questions to help students learn control variables, a purpose which was not mentioned by the other teachers. Ziv put an emphasis on learning to control variables for grade 7 students in his first two lessons of Investigation of *Mantou* Digestion in the Mouth. Specifically, learning to control variables involves identifying the variables, and inferring which test tube was the control group and which was the experimental group among the three test tubes.

> That is, among the three test tubes, which test tube is the control group, which two test tubes can form a control group and an experimental group? It is very important to understand this control of variables in the design of a practical activity. This is also the core scientific inquiry ability that we require students to acquire in the inquiry-based practical work. (Ziv_IV2)

Simon similarly emphasized the importance of control variables for grade 10 students, aged 15-16 years, when teaching Griffith's experiment in his lesson 3:

> Simon: …If they do not inject mice with live R-type bacteria [not virulent] and they only inject with live S-type bacteria [virulent], the mice die. Do they need to inject mice with that culture solution?
>
> Ss: No.
>
> Simon: Think again.

Ss: Yes.

Simon: If there is no group 1 in which mice are injected with R-type live bacteria, is it necessary to add a group where mice are injected with the culture solution?

Ss: Yes.

Simon: Yes. Was it the soup without rice or the rice that killed the mice? The injection of the culture solution with live S-type bacteria made the mice die. Was it the injection of the live bacteria or the culture solution that made the mice die? So, if they don't have group 1, they have to add a [control] group. Of course, there is group 1, so they don't need to add one. (Simon_L3)

Griffith's experiment had four groups (see Figure 6.1). In the first group, mice infected with the R strain lived, while in the second group, mice infected with the S strain developed pneumonia and died. When Simon finished discussing the first group and talked about the second, he asked students to suppose if there was no group 1 and there was only group 2, would it be necessary to add a control group to test which killed the mice: S-type bacteria or their culture solution. His questions were intended to check if students understood control variables.

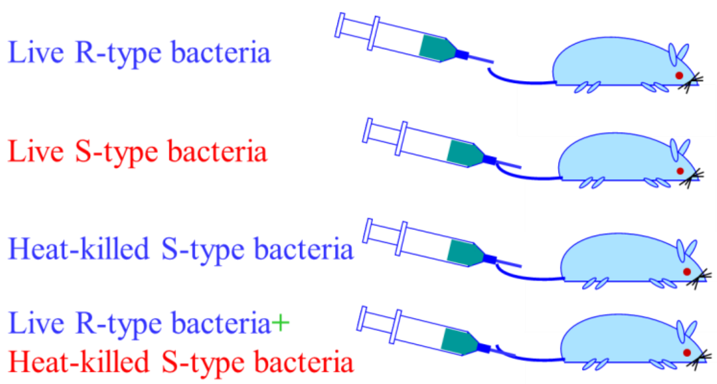


Figure 6.1 Griffith's experiment (from Simon's slides)

6.2.1.2 Paying attention to experimental materials and procedures

Both Simon and Helen focused on experimental materials: in this case, why Thomas Hunt Morgan selected fruit flies as experimental materials in the lesson Genes are Located on

Chromosomes. Helen focused on what fruit flies were and their characteristics in Morgan's fruit fly experiment:

> Helen: Morgan: which experimental material did he use?
>
> S: Drosophila.
>
> Helen: Look, this is a fruit fly. If you throw the banana peel in the bin and don't take out the rubbish, you will see little bugs flying around a few days later. They are fruit flies. What are the characteristics of fruit flies? (Helen_L2)

However, Simon paid attention to help students understand the advantages of using the fruit fly as a key model organism by comparing it with an elephant. Simon also paid attention to the appropriate and standard procedures for injecting mice in Griffith's experiment:

> Because in all the pictures, including the picture in the book, the butt of the mouse is used as an injection site. In fact, this is very unscientific…This should be explained explicitly to students and let them know the correct method of subcutaneous intramuscular injection. Otherwise, some students always think that the butt is the injection site. This is obviously unscientific. (Simon_IV3)

According to Simon, all the pictures about Griffith's experiment he saw conveyed misinformation about the injection site of mice (see Figure 6.2) and it should be corrected. He attempted to let students know and follow the correct experimental procedures: intramuscular and subcutaneous injections.

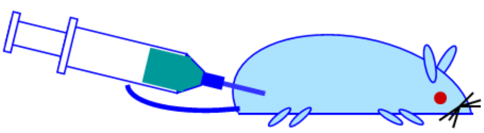


Figure 6.2 Misinformation about the injection site of a mouse (from Simon's slides)

6.2.1.3 Paying attention to scientific methods

Of the six teachers, Helen and Simon most strongly emphasized the purpose of paying attention to scientific methods, including inductive approach, hypothetico-deductive method, and analogical reasoning. For example, Simon considered analogical reasoning a crucial research method:

> Sutton's analogical reasoning, this, this scientific research method is quite important. It also provides the inspiration for our later students, scholars, and scientists... So, the first important thing is […] students should know what analogical reasoning is, why they can make an analogy or reason, what the two analogies are, how to make an analogy or reason. This is a crucial, an extremely important scientific research method in this lesson. (Simon_IV2)

Simon taught analogical reasoning in this way:

> Simon: …Then I ask you, Sutton states that […] genes are on chromosomes and genes and chromosomes have a parallel relationship. Which method did he use?
>
> Ss: Analogical reasoning.
>
> Simon: It's called analogical reasoning. Don't get it wrong [...] look at it now, sound can be reflected and refracted, and it travels in straight lines; light also has these three characteristics. Sound is a kind of wave, you say; how about light?
>
> Ss: It's possibly a wave.
>
> Simon: Yeah. You are making an analogy: light is also a kind of wave… (Simon_L1)

Here I used two different data types when assessing the teacher purposes. In the classroom, Simon asked a question ("Which method did he use?") to emphasize the scientific method of analogical reasoning. His second question ("How about light?") asked students to infer the properties of light based on the similarities between the two analogies. Different types of data are used to strengthen my analysis, checking whether the purpose mentioned in the interview was achieved in the classroom teaching, whether there was a slight exaggeration in the interview, and if there was any inconsistency.

6.2.1.4 Experiencing the process of inquiry

Experiencing the process of inquiry means asking questions to make students engage in inquiry practices, such as asking a question, making a hypothesis, testing the hypothesis, describing a phenomenon, and analysing data. Wynne was the only teacher who emphasized that she asked a series of questions to guide students through the process:

> This question is about how the bones and muscles cooperate with each other to complete the movement. Then, it lets students go through the process of inquiry, that is, ask a question, make a hypothesis, and then test the hypothesis. (Wynne_IV2)

6.2.1.5 Dealing with inconsistent findings

Ziv asked questions in order to report inconsistent findings during the lesson on Investigation of *Mantou* Digestion in the Mouth. In this practical activity, after adding iodine solution to three test tubes, the ideal colour changes from tubes No. 1 to No. 3 are no change, blue, and light blue, respectively. He attempted to investigate any students' findings that were inconsistent with the standard colour changes in his slides.

> I had talked about the experimental procedures. In theory, if students follow the steps strictly, their results should be the same, but in practice there were some inconsistent findings because students did this practical work for the first time, after all, and no doubt they made some mistakes during the process: for instance, the amount of iodine solution dripped or the reaction time. So, it is necessary to get such feedback. Let the students see that there were all kinds of results, but what was the result most students got? Collect the data. Then, other students could think about why their results were different from that of most people and what the reasons were. (Ziv_IV2)

Ziv made students' inconsistent findings explicit and public and then explored this issue more fully. Of the six teachers, Helen was the only other teacher who asked questions to help students realize the gap between theory and practice: that is, to make students realize that it is possible that the actual experimental result is inconsistent with the ideal experiment result.

> Why is there still a small amount of radioactivity at the top in the group where radioactive phosphorus-32 was used to label the DNA? Why is there a small amount of radioactivity at the bottom in the group where radioactive sulfur-35 was used to label the protein? It is to let them know that there is a gap between theory and practice. (Helen_IV3)

6.2.1.6 Fostering rigorous scientific thinking

Fostering rigorous scientific thinking means thinking in a comprehensive, thorough, and disciplined way. It is a type of scientific thinking that is one of the four core literacies mentioned in the national biology curriculum standards. In Simon's view, rigorous scientific thinking is like 1+1 equals 2 and 1+1 cannot be equal to 3. For example, he asked students to return to the Sutton era, go back to the scientist's knowledge background, and think of all the possible claims that the scientist might make based on the evidence at that time. These claims should not be limited to the sole correct conclusion in the textbook.

> How do students draw conclusions from the current experimental findings? Students need to develop their scientific thinking. To be rigorous or objective, like 1+1=2 and 1+1 cannot be equal to 3… Sutton has concluded that genes are on chromosomes. In fact, if let students do this experiment, at least, they should draw three conclusions, even if there are incorrect conclusions. These three are that genes are on chromosomes, chromosomes are on genes, and genes are chromosomes. (Simon_IV2)

6.2.1.7 Understanding that scientific ideas are subject to change

Simon was the only teacher who was explicit in his intention to help students develop a world view that scientific ideas are subject to change. From Gregor Mendel's principles of inheritance to Thomas Morgan's fruit fly experiment, from the Avery experiment that demonstrated that DNA is the substance that causes bacterial transformation to the Hershey–Chase experiment that confirmed that DNA is a genetic material, Simon tried to make students understand scientific knowledge is constantly modifying, improving, and developing:

> Let students understand... the change in Morgan's attitudes towards Mendel. He did not understand or support Mendel at the beginning but agreed with him and supported him strongly later. This is the research mentality of a scientist. Also, it is a process of inheritance, modification, and development. (Simon_IV2)

> At that time, in terms of Avery's purification method, [with] the purification method, even when the DNA concentration was the highest, there was 0.02% protein. Therefore, this 0.02% protein brought many scientists a topic for further study. 'To be continued'. . . Suspicion is actually good. Why? It can promote the continuous modification, improvement, and development… modification, improvement, and development of the views of science and technology. (Simon_IV3)

6.2.1.8 Learning to observe

Of the six teachers, only Wynne and Zachary placed emphasis on close observation of animal characteristics and behaviour in the process of inquiry. They used questions to direct students' attention during the observation. For example, when students were observing a lizard, Wynne asked,

> Wynne: Does it have scales on its skin?
>
> Ss: Yes.
>
> Wynne: Can it turn its head?
>
> Ss: Yes. (Wynne_L1)

6.2.1.9 Using physical models

Sue, Ziv and Helen were three teachers who put a high value on physical models. Physical models mean physical objects that represent microscopic, macroscopic, or abstract things in science, such as an animal cell, the biosphere of Earth, or population growth. Sue used physical models to help students understand what the structure of a neuron was and why it had this structure. The physical models she used were special: hands, arms, and a school uniform. She stated that her purpose was to tell students to use their bodies to understand science knowledge involving several complex structures, such as a nucleus, a cell body, an axon, a nerve ending, a sheath, a nerve fibre, and a nerve.

> I thought about what a neuron looked like. The neuron is like an outstretched hand, right? Then, if you draw a red dot on the palm of your hand, is it like a nucleus? Is the palm like a cell body? Are fingers just like dendrites? Are the arms like an axon? If two arms are stretched, is the other hand at the end like a nerve ending? Yeah, then I told them, I asked, look, there were electrical signals on this. Just like a wire, will it leak electricity if it's not surrounded by anything? The students said yes. Then I found a school uniform and put it on. I said the school uniform was called a sheath. After the 'sheath' is put on, this is called a nerve fibre. Then, I asked what you usually saw was one wire or a bundle of wires. The students replied it was a bundle of wires. I said right. I said a bundle of nerve fibres was called a nerve. (Sue_IV3)

The interview extract below shows how Sue asked questions in an interesting and impressive way. She commented that it would make students understand and memorize things easily.

> For example, when I teach about the small intestine, I use a cloth. I took a piece of cloth and then I told the students that this was the small intestine because there are intestinal microvilli on the cloth. I folded the cloth. Didn't the cloth wrinkle when folded? I asked what this was. I let the students read the book. They said it was a fold…When I reviewed this in the next lesson, I took the rag; I asked what it was, and the students answered the small intestine. "Go and wipe the blackboard with the small intestine," I said. Then, the student wiped the blackboard. In this way, they will remember more clearly. They find it very funny every time. They said, "I will go home and clean my bowls with the small intestine today." (Sue_IV2)

Similarly, Helen intended to make students' thinking visible and make abstract and microscopic things visible through building physical models (see Figure 6.3): "I asked students to build physical models to show what I had taught just now so that their thinking could be visualized. Of course, I read some literature called making thinking visible" (Helen_IV3). Ziv used physical models (The Food Guide Pagoda for Chinese Residents (see Figure 6.4)) with an emphasis on explanation and application of the model. Students were required to explain its shape (e.g., why is the bottom big and why is the top small?), illustrate what each layer represented, and use the model to organise a healthy and balanced lunch.

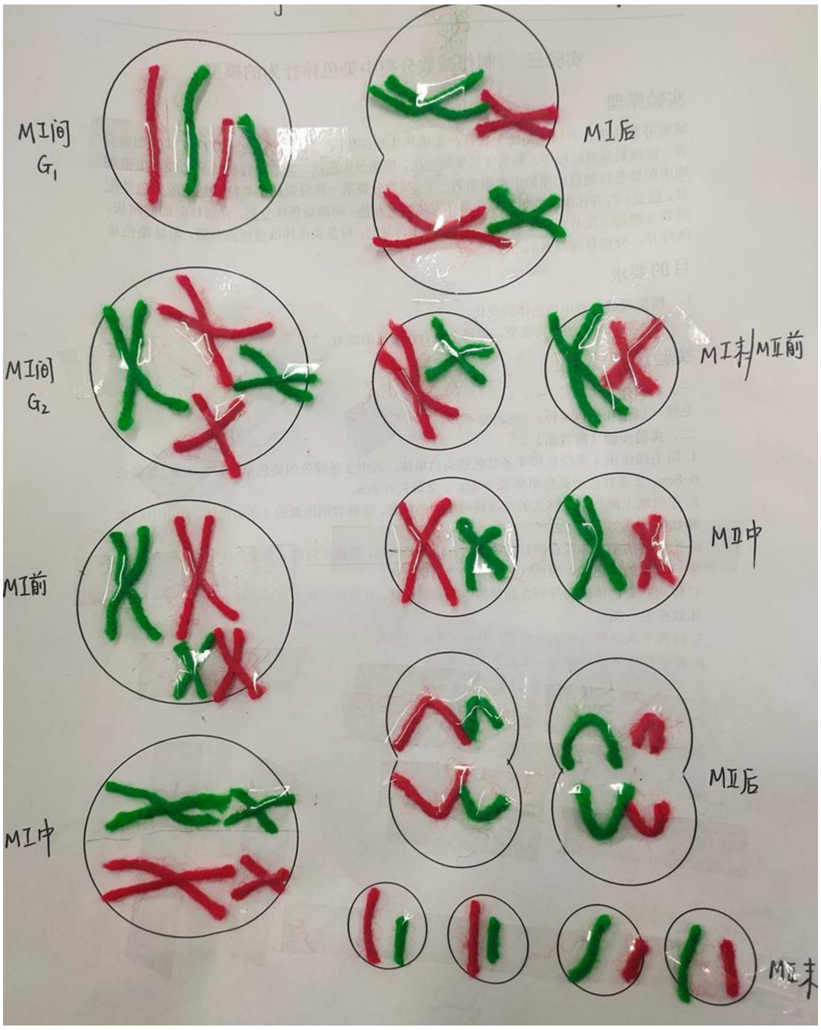


Figure 6.3 Students' physical model of meiosis in animal cells

Figure 6.4 The Food Guide Pagoda for Chinese Residents

6.2.2 Use of questions to emphasize social responsibility

In the Chinese national biology curriculum standards for senior secondary school (2017 edition), social responsibility refers to the expectation that students should pay attention to social issues, get involved in discussing and making rational explanations for them, and consequently oppose superstition and pseudo-science. Moreover, the standards suggest that students solve their daily life problems and advocate a healthy and civilized lifestyle. I include this section for two reasons: (1) teachers are encouraged to consider social responsibility in their teaching according to the curriculum standards, and the six teachers talked about it; and (2) it is directly related to the teaching of socio-scientific issues, an important pathway for the development of students' understanding of scientific practices, as described in section 3.2.1 in the literature review. I do not consider this to fall within the section on scientific practices because, as shown in Figure 2.1, social responsibility and scientific practices are different components of the core literacies in the biology curriculum standards (MOE, 2017b).

In the following example, Ziv tried to enable students to explain various phenomena in their lives. He used the term scientific literacy to refer to the biological science concepts and scientific inquiry capabilities required for a person's participation in society, economic activities and personal decision-making, including understanding the relationship between science, technology and society, understanding the nature of science, and forming scientific attitudes and values (MOE, 2011). He used the same term as appeared in the curriculum standards, which was also mentioned by Simon and Wynne.

> For example, explain why people suddenly feel breathing is particularly laborious after they go into the water… Let students go back to life and explain this phenomenon. So, they will understand the concept, and they will take the initiative to apply their knowledge. Naturally, we want to cultivate students' scientific literacy. They will use these concepts to explain the phenomena in their lives. (Ziv_IV1)

To engage with current affairs, Sue asked questions in her lesson about how to fight a locust plague. She talked about her purposes:

> Look at the students. In my opinion, they are students right now, but they will grow up in the future. When they grow up, they may be leaders and they may be involved in solving these problems. When they encounter these difficulties and each solution has its own advantages and disadvantages, how do we select an appropriate solution? This is social responsibility… I remember the Dianchi lake was polluted by water hyacinth one year. Regarding how to control water hyacinth in Dianchi, I remember it seemed that there was a professor or a doctor, but I don't remember very clearly. Anyway, someone suggested draining the Dianchi Lake. I think it's too stupid. (Sue_IV2)

Thus, Sue went beyond the question. Her purpose was to enable students, who are potential future leaders to make informed and reasonable decisions when they were involved in public affairs. She hoped that students would not make irrational suggestions: for instance, draining the Dianchi lake to control the spread of water hyacinth. Another example was about opposition to non-scientific views. Sue aimed to help students engage critically with science-related issues:

> In the 1970s, or in the 1960s in our country, in Shanghai injecting chicken blood into patients happened. People believed that they had vitality after the injection. So, at that time, there was a saying: "It seems like you have been injected with chicken blood". You see, the problem is that it's more than 100 years after Karl Landsteiner [who identified three major blood types]; there were so many hospitals, but there was this kind of anti-intellectual thing, and injecting chicken blood, surprisingly, became a national obsession… So, I said to my students, I asked you about studying biology and what you were studying for. I asked if it was just to take the test. I definitely said it's not the answer. I said you learnt this lesson and at least you wouldn't be deceived. At least my students wouldn't do such anti-intellectual things. I asked, "What would you do if someone wanted to inject you with chicken blood?" The students said they wouldn't do it. (Sue_IV2)

As another example, Ziv warned students not to eat wild animals. There was a saying that the origin of the new coronavirus was that people were infected with the virus after eating wild animals. Ziv helped students develop the correct understanding of the role of wild animals and protecting wild animals by not eating them.

> This lesson has a teaching objective about emotions, attitudes, and values. That is, wild animals should be protected. We sometimes eat them, try new food, but these wild animals cannot be eaten. First, they should be protected. Second, they might carry some bacteria and some viruses. So, I talked about this here. In fact, it is to achieve the objective of [appropriate] emotions, attitudes, and values. (Ziv_IV3)

6.2.3 Use of questions to support the understanding of 'big ideas' in science

The 'big ideas' in biology are one of the four core literacies in the national biology curriculum standards and it is required that they are implemented through classroom teaching and exam assessment. All the teachers emphasized the importance of the big ideas in biology lessons, including those lessons focusing on scientific practices, and they highlighted that they asked questions to help students understand: to give two examples, the theory of evolution by natural selection and how structure determines function. As Wynne states, "My teaching involves not only knowledge, but also the big ideas of biology". For example, when she asked the question "Look at this picture, what are the differences between these birds?", she aimed to improve students' divergent thinking and implement one of the big ideas of biology, which is that structure determines function.

> For example, they [birds] have different leg lengths, right? Some have webbed feet, and some don't. Some birds' feet are claw-shaped, and some are webbed. That is to say, when you want students to sum up these things from various aspects, you should ask divergent questions. I want to let students summarize that the structure of a bird is adapted to its environment; so, I ask, "What do you think the differences are?" (Wynne_IV1)

Wynne was very explicit about the purpose of her question. She used the term *divergent question*, which means a question that encourages students to think from different perspectives, rather than open questions. A possible reason is that she has related pedagogic knowledge of questioning regarding how to make students' thinking convergent or divergent, but she did not know the exact terminology. In the following example, she used questions with the purpose of helping students to understand the big idea of evolution. She tried to help students develop the idea of evolution by constantly comparing and experiencing. For example, she asked, "What's the difference between animals with necks and those without necks when they move on land?" Then she asked one student to act out the differences between having a neck and not having a neck in front of the class. Taking a different approach, Helen stated that she developed the big idea of heredity and evolution by telling students two facts: (1) the number of chromosomes is reduced by half in meiosis and returns to normal through fertilization, which means the number of chromosomes remains constant from generation to generation; and (2) the crossover of homologous chromosomes can increase genetic variation and diversity, which may help organisms adapt to the environment.

6.2.4 Use of questions to form appropriate emotions, attitudes, and values

Students need to not only acquire science knowledge, inquiry skills, and epistemological knowledge but also develop emotions, attitudes, and values. Positive science-related attitudes (e.g., an interest in science and enjoyment of science) can enhance students' engagement in scientific practices. Previous studies have examined the influence of teacher feedback or scientific practices on students' science-related attitudes both quantitatively (e.g., Chi et al., 2021) and qualitatively (e.g., Rivera Maulucci et al., 2014). Insufficient attention has been given to how teachers talk about their intentions to develop the science-related attitudes embedded in their questions during the process of scientific practices. In this study, all the teachers used questions to help students form appropriate emotions and attitudes and see the value of something. For example, Simon mentioned that he hoped that students would show respect to the laboratory animals that suffer a lot and would treat these living beings with kindness and sympathy, and these sentiments were behind his question "Where do you inject a mouse?"

> So, teach them to understand life, at least respect life. Since mice have been used as laboratory animals and they have dedicated their lives to science, students need to be sympathetic towards them. Have a kind heart, being kind to life, this kind of quality, this kind of literacy... Maybe someday some people are just in a position where they can decide the life and death of other lives. If they think of the things the teacher told them, they will have a kind of care for other lives. A kind of care, a kind of sympathy and a kind of understanding. This kind of care, sympathy and understanding makes it possible for all beings in the world to live in harmony. (Simon_IV3)

It is shown below that Simon encouraged students to learn from the S-type bacteria, which could survive in difficult situations, which reflects his philosophy of biology. In the fourth group in Griffith's experiment, the combination of heat killed S-type bacteria (virulent), and live R-type bacteria (not virulent) was able to kill mice. Simon explained the paradox in an interesting and novel way: the DNA of S-type bacteria lost its home, lived in difficult conditions, met the live R-type bacteria, then succeeded in entering the body of R-type bacteria and started a new life. In addition, Simon hoped students could show respect and admiration for the scientist when talking about the design of Griffith's experiment.

> Is it possible to teach students not to give up hope when they are in harsh environmental conditions and when they hit a low point in life? ... Look at S-type bacteria, it reflects the essence of this living world, the life philosophy in this living world. I think this is the life philosophy in the biological world. (Simon_IV3)

> So, in fact, here I asked students to talk about the fourth group of the experiment. I hoped they were full of admiration for Griffith. Griffith, how could he think of it? How could he think of mixing live R-type bacteria with heat-killed S-type bacteria? I always feel that Griffith had a dream during the night or he must have had a feeling that DNA is genetic material. That is to say, in terms of how genetic information is passed from parent to child, Griffith should have this kind of, this kind of scientific insight, or this kind of scientific predictability, or this kind of, that is, sixth sense. (Simon_IV3)

I see a focus on the spirit of scientists (e.g., their dedication and insightful ideas), the philosophy of biology of survival in a harsh environment, and attitudes to lab animals. These things have not received sufficient attention in the previous literature on scientific practices.

6.2.5 Questions used for pedagogic purposes

This section examines the pedagogic purposes of teacher questions relating to the teaching of scientific practices. The purposes of teachers' framing and use of scenario-based questions were selected because they not only helped teachers reflect on how to ask questions, but also linked directly to teachers' views about pre-planned questions and students' interviews in the next chapter.

6.2.5.1 Framing

Framing means teachers use a sequence of planned questions to structure a topic, a discussion, or a lesson; for example, Ziv remarked:

> When I prepare lessons, I like doing this. I pre-plan a sequence of questions to structure a lesson. As for this class, from simple to complex, I use a sequence of questions to link the different parts of the lesson. (Ziv_IV1)

These questions may be in a form of a table that requires students to fill in the blanks. They could be in the lesson plans, slides, and student handouts, which mirrors the findings of Chin (2007), who stated that questions presented in this way could attract students' attention and make teacher questions and discussion tasks clear. However, this study adds to Chin's findings by arguing that pre-planned teacher questions are not limited to physical presence and might be in teachers' minds. The following evidence suggests the teachers had different degrees of framing; teachers may ask questions according to plan or in a flexible way and according to student responses, rather than strictly in accordance with what they planned.

When Helen taught the concept of homologous chromosomes, she devised a sequence of eight questions in her lesson plan and slides (see Figure 6.5). In the lesson, she asked students to read the textbook about the definition of homologous chromosomes, to think about her questions in the slides, and then to answer these eight questions in order. Helen stated that these questions were directly connected with the definition of homologous chromosomes in the textbook and had their own internal logic. For example, they were developed based on the number, size, shape, origin, and behaviour of chromosomes. These closed questions enabled Helen to follow her careful planning strictly and helped students to construct conceptual knowledge.

1. How many chromosomes are there in a pair of homologous chromosomes?

2. Are homologous chromosomes necessarily the same size?

3. Do homologous chromosomes have the same parental origin?

4. Do homologous chromosomes pair up during mitosis?

5. What is the pairing of homologous chromosomes during meiosis called?

6. What is the name of the four chromatids in a pair of homologous chromosomes in synapsis?

7. How many chromosomes does a tetrad have? How many pairs of homologous chromosomes? How many chromatids? How many DNA molecules?

8. How many tetrads form in a human cell during meiosis? What about during mitosis?

Figure 6.5 A sequence of questions in Helen's slides

However, Sue had different attitudes to the use of slides.

> I basically don't use PPT… because once I've used PPT my teaching will be from this to this, to this, to this, but in fact students won't respond the way I would expect. Students are human beings, and they have no procedures. When I ask a question, they may talk about something in this slide, but it's very likely that they talk about something on the latter slide. It's embarrassing anyway. (Sue_IV1)

Sue did not like using slides because it limited her teaching. Her questioning strategy was so flexible that she adapted her questions and teaching according to students' responses. She gave students opportunities to express ideas, respected those ideas and used them to lead her teaching to some extent.

6.2.5.2 Use of scenario-based questions

Simon asked scenario-based questions: for example, "Imagine you are the scientist Sutton, what conclusions can you make from the data?" The student can pretend to be a scientist, plant, animal, or object to think from another perspective:

> In the process of teaching and learning, tell students to imagine they are in a particular situation, that is, students are in the situation that another person, plant, animal or object is in to think about their teacher's question. (Simon_IV3)

As mentioned in section 5.2 in the last chapter, Simon is the only teacher who used scenario-based questions. He talked about this type of teacher question many times in the interviews. I argue that such questions are helpful for the implementation of scientific practices. In some fundamental science theories and experiments – for instance, Sutton's chromosome hypothesis that genes and chromosomes have a parallel relationship – teachers usually ask students to reason how scientists drew their conclusions based on data. However, scientists may live in a different era and the data may be boring. This kind of question allows students to imagine that they are in the era and in the situation of scientists and then make judgments, which can bring students and scientists closer and help students think actively about the question and data.

6.3 Summary

This chapter presents five main purposes for the teacher questions. Some categories relate to the requirements of biology curriculum standards that emphasize the four dimensions of the core literacies: the 'big ideas' of biology, scientific inquiry, scientific thinking, and social responsibility. Participant teachers purposefully implemented curriculum standards in their classrooms and used these ideas to explain their behaviour. Scenario-based questions can be used to ask students to think from the perspective of a scientist and help them engage in scientific practices. Only Simon used this question type in these lessons, as described in Chapter 5, and his students commented on it in Chapter 8. Teachers used questions to frame their lesson but planning too many closed questions might lead students along the pathway the teacher planned. This chapter also reveals how teachers focused on bodies, physical models, and other resources when they talked about their questions, which will be discussed further in the final chapter. The complex reasons behind teacher questioning, involving institutional practices and external policies, are explored in the next chapter.

Chapter 7 Research Findings of RQ 3

This chapter addresses RQ 3 – What are teachers' reflections on factors influencing teacher questioning strategies? – and seeks to provide a deeper insight into the context that led to more sophisticated use of questions. Teachers' teaching is not only influenced by their personal attributes but also structured by the context inside and outside school. Thus, as detailed in section 3.6.1, I will use the framework offered by Ryder (2015) and categorize those factors into three levels: personal, internal, and external. The personal level includes the teacher's subject knowledge, pedagogical skills, personal biography, beliefs, and teaching goals. The internal level includes the impact of students' different backgrounds and aspirations, textbooks, subject department working practices and school priorities. The external level describes how the national college entrance examination, national curriculum standards, time constraints, and Chinese traditional culture influence teachers when they use questions. My findings may add new elements or make some changes to the fully comprehensive set of 27 influential factors listed in the framework. Nevertheless, more importantly, I aim to present factors behind teachers' use of questions to sketch out teachers' understanding of questions and the complex reasons behind their questioning practices.

In this chapter, I use the personal, internal, and external framework to create an overview of teachers' reflections on factors influencing their questioning practices (see Table 7.1). I then elaborate on key factors across the three analytical levels. The interactions of external, internal and personal factors are also discussed. Here interactions mean that factors are not separate things. Some are pushing the teacher in opposite directions – for example, teachers experiencing tensions – while others are pushing in the same direction.

7.1 The coding scheme

Table 7.1 provides a summary of the external, internal and personal factors that teachers mentioned as influencing their teaching or use of questions. The analysis included factors that influenced teaching more broadly rather than just focusing on factors mentioned only in the context of questions. Reasons were listed as follows: (1) sometimes when teachers talked about a whole range of influences – for instance, government policies, local school priority and personal biography – they sensibly focused on teaching, not just teacher questions; and (2) as questioning and teaching are intertwined, factors influencing teaching not only affected teachers' use of questions, but also provided a context through which to understand their questioning practices. For example, Zachary mentioned that because biology became a subject in the high school entrance exam two years ago and he needed more time to prepare for the exam, the observation of frogs in small groups was cancelled in his classroom. This background information helped me to understand his teaching and the difficulties he faced in carrying out scientific practices. Moreover, this policy change definitely affected his use of questions. When his teaching was changed, his questions were changed accordingly.

The table has parts that relate to teaching in general marked with *general*, but occasionally codes that were specific to questions are marked with *questions* in red. When codes were about scientific practices (SP), they are labelled *SP* in blue. This is valuable as an overview of the contexts of the coded content. For example, when the content was about an external influencing factor like the national college entrance exam, (1) if it was explicitly about scientific practices, the code would be *3.2 The high school entrance exam or the national college entrance exam - SP*; (2) if it was explicitly about questions, the code would be *3.3 The high school entrance exam or the national college entrance exam - questions*; and (3) if it was very general, it would be coded as *3.1 The high school entrance exam or the national college entrance exam - general*. The following example was coded *The high school entrance exam or the national college entrance exam – questions* because Helen mentioned that her question about how to label bacteriophages was affected by the national college entrance exam:

> The national college entrance exams often test this: that is, how to label bacteriophages. They are actually testing that bacteriophages are viruses, and they can only parasitize in living cells. They are testing this knowledge… (Helen_IV3)

More than one code might be applied to the same content. For example, if the coded content was about questions and within the context of scientific practices, it would be coded twice. Original codes were in Mandarin and translated into English in Table 7.1. In this table, the number of teachers represents how many teachers talked about a code and described it as one of the factors influencing teacher questions. The number of occurrences represents how many sections are coded; for example, one coded section was one occurrence.

External	**The number of teachers**	**Occurrences**
1 Chinese characters (e.g., explain why a Chinese character is used to name a structure) – questions	2	3
2 National policy: the first, second and third classroom (e.g., a policy of developing core literacy by developing school-based curricula and extracurricular activities)	1	1
3 The high school entrance exam or the national college entrance exam		
3.1 The high school entrance exam or the national college entrance exam – general	5	20
3.2 The high school entrance exam or the national college entrance exam – SP	2	3
3.3 The high school entrance exam or the national college entrance exam – questions	4	4
4 The role of polished lessons – external		
4.1 Demonstration lessons in the city (a requirement of the *three-level and three-category* policy)	1	1
4.2 Guidance from teacher developers	1	1
4.3 Participation in inter-school teacher networks	1	4
5 Teaching schedule requirements	1	1
6 Curriculum standards		
6.1 Curriculum standards	4	13
6.2 Big ideas in the curriculum standards	2	7
6.3 Social responsibilities in the curriculum standards	1	1

7 Teachers' views about how the research had impacted on their teaching and questioning practices	2	4
Internal		
1 Physical teaching spaces (e.g., laboratory and classroom) – SP	1	1
2 Colleagues		
2.1 Guidance from the school expert teacher or mentor teacher		
2.1.1 Guidance from the school expert teacher or mentor teacher – General	3	11
2.1.2 Guidance from the school expert teacher or mentor teacher – questions	1	3
2.2 Negative comments about their colleagues	3	7
2.3 Peer discussion		
2.3.1 Peer discussion – general	6	17
2.3.2 Peer discussion – questions	2	3
3 Engagement of teachers in professional development training	1	3
4 Students' intake quality	2	8
5 School policy of class grouping	3	4
6 Students		
6.1 Adapt teaching to students' needs		
6.1.1 Adapt teaching to students' needs – general	6	35
6.1.2 Adapt teaching to students' needs – SP	2	3
6.1.3 Adapt teaching to students' needs – questions	4	14
6.2 Common mistakes students make due to their incorrect subject knowledge – questions	3	4
6.3 Seizing teachable moments and adjusting instruction in the moment		
6.3.1 Seizing teachable moments and adjusting instruction in the moment – general	1	1

6.3.2 Seizing teachable moments and adjusting instruction in the moment – questions	1	2
7 Parents' engagement – SP outside school	1	2
8 Learning objectives		
8.1 Learning objectives – general	3	9
8.2 Learning objectives – SP	1	3
8.3 Learning objectives – questions	2	2
9 Textbooks		
9.1 Textbooks – general	6	19
9.2 Textbooks – SP	2	6
9.3 Textbooks – questions	4	9
9.4 Go beyond textbooks and use them flexibly	5	8
10 Exams at school – questions	1	1
11 School ethos and priorities		
11.1 School ethos and priorities	6	12
11.2 Requirements for classroom discipline		
11.2.1 Classroom discipline – general	1	2
11.2.2 Classroom discipline – SP	3	4
11.3 Financial support from the school – SP	1	2
11.4 Teacher assessment	5	6
12 Large class size		
12.1 Large class size – SP	4	5
12.2 Large class size – questions	1	2
13 The role of polished lessons - internal		
13.1 Sharing slides in biology department after polishing lessons	1	2
13.2 The role of students in polished lessons	3	12

13.3 The process of polishing a lesson	1	3
13.4 Observations of lessons with feedback	4	9
13.5 Polished lessons are different from normal lessons	3	6
14 Time constraints to cover the prescribed curriculum content		
14.1 Time constraints – general	5	15
14.2 Time constraints – SP	3	6
14.3 Time constraints – questions	2	3
15 Teaching content – questions	1	1
16 Resources		
16.1 Pictures, tables and videos	2	6
16.2 Physical objects and physical models	1	5
16.3 Experimental materials – SP	3	10
16.4 The role of body language	4	5
16.5 Resources – questions	3	7
Personal		
1 Personal role in polished lessons		
1.1 Personal role in polished lessons – general	3	12
1.2 Personal role in polished lessons – questions	1	2
2 Subject knowledge		
2.1 Subject knowledge – general	1	2
2.2 Subject knowledge – questions	1	1
3 Beliefs about how students learn	4	10
4 Views about teacher questions		
4.1 Views about pre-planned questions and spontaneous questions	5	17

4.2 Views about teacher questions	5	10
4.3 Views about the openness of teacher questions	5	13
5 Beliefs about biology education and science education		
5.1 Beliefs about biology education and science education	5	27
5.2 Beliefs about how science develops – questions	1	1
5.3 Views about how scientists do their research	1	2
6 Views about SP	6	19
7 Personal identity and the identity of their lessons	3	9
8 Reflections after teaching and changes in slides	2	4
9 Pedagogical knowledge		
9.1 Visible thinking	1	2
9.2 Pedagogical knowledge – general	3	16
9.3 Pedagogical knowledge – SP	1	3
9.4 Pedagogical knowledge – questions	5	34
10 Years in teaching		
10.1 Years in teaching – general	3	9
10.2 Years in teaching – SP	1	1
10.3 Years in teaching – questions	1	1
11 Personal biography		
11.1 Personal biography – general	4	13
11.2 Personal biography – SP	2	4
11.3 Personal biography – questions	3	7

Table 7. 1 Summary of external, internal, and personal factors influencing teacher questions

7.2 Key factors influencing teacher questions

I selected and elaborated on the key factors presented below for the following reasons: (1) I gave priority to those factors and examples specific to scientific practices and teacher questions that were the focus of my thesis; (2) some factors might not have been clear to people outside the Chinese context – for example, the hierarchy of the *three-level and three-category* teacher professional development path; (3) some factors were revealing about teachers' experiences of polishing a lesson and teaching scientific practices – for example, most questions were pre-planned, according to some teachers; and (4) some factors highlighted original contributions to the existing literature – for instance, detailed illustrations of changes or development in classroom teaching over time, especially the adjustments teachers made when they taught repeated lessons. As discussed in section 3.6.1 in the literature review, many studies on teacher development focus on how teachers develop through professional development programmes designed to enhance classroom practice and do not take a detailed account of a school's organisational conditions (van Driel et al., 2012). However, in my research, these teachers talked about how their teaching changed over time in their workplace contexts. This reflection over time – including how they use questions and how they think about their responses to students – was a theme running through many of these selected sections. Based on these selection criteria, I will present the selected elements: students, the role of polished lessons, views about teacher questions, and views about scientific practices.

7.2.1 The role of polished lessons – External, internal and personal

As discussed in section 3.6.3, teachers work together to improve or polish a lesson after classroom observations. I selected the role of polished lessons according to four criteria. First, some extracts focused on teacher questions or scientific practices, as detailed below. Second, the way that polished lessons affected teaching or teacher questions involved external policies and teachers working practices within the school, which might not be clear to people outside the Chinese context. Third, it was revealing that, for example, Wynne worked so hard at developing specific teaching approaches to seek external validation, as detailed in section 7.2.1.3. Finally, it should make some contribution to the knowledge of how teachers improve lessons in their school settings. In the process of polishing lessons, the teachers' classroom practice was influenced by external, internal and personal factors. Hence, I present teachers' comments on these issues together in this section.

7.2.1.1 The *three-level and three-category* policy, the role of teacher developers and inter-school teacher networks

The external factors in this section included the policy of *three-level and three-category* backbone teachers that requires teachers to demonstrate school-level or city-level public lessons, guidance from teacher developers, and participation in inter-school teacher networks. These factors are described in detail below.

Sue was a provincial expert teacher. She was asked to demonstrate a city-level public lesson with many significant strengths according to a provincial policy. In 2013, the government of Shaanxi Province issued the *Opinions on Strengthening the Construction of the System of Primary and Secondary Backbone Teachers* and launched a *three-level and three-category* project (see Table 7.2). "Three levels" refers to the hierarchy of three administrative divisions of China as detailed in section 2.3: provincial-level, city-level and county-level. The three categories included the hierarchy of three titles given to backbone teachers: prestigious teachers, who represent the highest level; subject teacher leaders, who show the potential to be leaders in a subject in a networked community; and expert teachers. Every administrative level included the three categories of backbone teachers and candidates entering the higher level would be recommended from those who awarded the title of backbone teachers in the same category in the lower level. For example, there were provincial expert teachers, city-level expert teachers and county-level expert teachers and it was expected that provincial expert teachers would be selected from city-level expert teachers. Only some teachers were backbone teachers, with about 2 percent of teachers awarded an honorary title of provincial expert teacher every year. These backbone teachers played a role in demonstrating outstanding lessons and fostering good quality teaching in the teacher community (e.g., with public lessons).

Provincial prestigious teachers	Provincial subject teacher leaders	Provincial expert teachers
City-level prestigious teachers	City-level subject teacher leaders	City-level expert teachers
County-level prestigious teachers	County-level subject teacher leaders	County-level expert teachers

Table 7. 2 Professional development of backbone teachers: three-level and three-category

(Arrows mean that teachers of one tier can go to a higher one)

When Sue polished her public lesson, she tried to improve it with the help of her colleagues and a teacher developer. As described in section 2.3, the teacher developers working in the local Education Bureau played an important role in providing a bridge between curriculum standards and actual classroom practice in the basic education curriculum reform through organizing public lessons, group discussions and lectures. They could be mediators of curriculum reform (Ryder, 2015) but they were not employed within schools. In this event, the teacher developer was not only an organizer but also a classroom observer who gave Sue helpful suggestions:

> I taught that lesson three times in total [before my city-level public lesson]. After the first lesson, some teachers from the biology department... discussed it and I listened. For the second time, a teacher developer came over, observed it and gave some suggestions to improve it. For the third time, I had a school-level public lesson. Lots of the experienced teachers in my department came. All the old teachers came this time. I can tell you that the lesson was criticized from beginning to end. My mentor teacher talked about the drawbacks first. They told me immediately that they did not want to speak about any advantages and only focused on my disadvantages and problems. They said there was a problem here in this lesson, there was a problem here, here and here. Oh, well, you know. We discussed one class period. When the discussion was almost finished, you know, the headmaster finally said this lesson was really good, quite good and asked, 'Why didn't you talk about its advantages?' My mentor teacher then replied that they must find out what the problems were because it would be a public lesson at the city level. So, my mentor teacher discussed my weak points the whole time. When I had the public lesson, it was particularly good and I was highly praised by the teacher developer. (Sue_IV3)

The final lesson was open to teachers sitting in the class and observing the expert's teaching carefully. It was this public lesson that made it possible that a diversity of people to work together to affect Sue's teaching and improve her lesson in terms of cooperation, including the senior teachers, her mentor teacher, the headmaster and the teacher developer. Sue tried three lessons before the formal activity itself to improve the quality of her teaching and learning. According to Sue, her mentor teacher and colleagues focused only on significant areas for improvement after the lesson observation because they thought this city-level public lesson was important and they aimed to demonstrate an outstanding lesson. Students were not mentioned in this quote. However, elsewhere in her interview, the teacher focused more on students, rather than the feedback from colleagues. An essential feature of the public lessons was that expertise could be modelled so that teachers could learn how to implement curriculum standards in the classroom by watching an expert's teaching.

When Helen was polishing her school-level public lesson, teacher networks outside of her school affected her teaching. She had just moved to the city and requested to have a demonstration lesson as a provincial expert teacher at the new school. When polishing her lesson, she talked with a special-class teacher that was an advanced and professional title set up by the Ministry of Education specifically to commend particularly outstanding primary and secondary school teachers. This special-class teacher was her own high school biology teacher. Helen was proud of her teacher's teaching: "It was because I liked her lessons that I studied biology in the university. I really enjoyed her lessons at the time. She was a goddess." Helen needed some advice for her polished lesson:

> I asked that teacher, I said, "What did you think the key points were in the lesson on meiosis?" She then told me that she felt that it was important to make the behaviour of a tetrad clear to students. I felt inspired then. (Helen_IV4)

In terms of the key points in the lesson on meiosis, the special-class teacher's reply was about the behaviour of a tetrad, and this changed Helen's teaching. She initially asked students to make physical models to show what happened to two pairs of homologous chromosomes during meiosis, but after listening to her teacher's advice, she decided to work towards figuring out what happened to a tetrad in meiosis before talking about two tetrads.

As discussed in the literature review, Wallace and Priestly (2011) identify a factor from a group of science teachers that had interschool informal meetings regularly during the year to share their teaching strategies to external reforms and that demonstrated no hierarchy. Nevertheless, in my study, Helen built a strong interschool network with a special-class teacher because they had known each other for many years. Moreover, the special-class teacher had a higher status than the provincial expert teacher and Helen took advantage of her expertise as a resource, shared her expertise, and allowed it to direct her own teaching.

7.2.1.2 Teachers' working practices

This section discusses how teachers' working practices affected their teaching, including weekly group meetings during which teachers collectively prepared for lessons, made observations on lessons with feedback, and shared slides in the biology department after polishing their lessons. Interviews extracts in this section were directly related to teacher questions or scientific practices (see below).

During one weekly group meeting, biology teachers in Ziv's school collectively prepared for a lesson and there was a keynote speaker. They discussed a lesson plan that scheduled specific plans for what and how to teach in a lesson according to the learning objectives set out:

> Ziv: When preparing for the lesson, we were, let me see, in the discussion, we discussed which was better, asking students to design lunch recipes or order a meal? Oh, we agreed that ordering a meal was better. In fact, when preparing for the lesson, we discussed it. This lesson, the keynote speaker was …
>
> April: What do you mean by a keynote speaker?
>
> Ziv: The keynote speaker prepares for a lesson. Specifically, we prepare for a lesson collectively and we are a group of six people. Every time we prepare for a lesson, there is a keynote speaker. For example, if I

teach the heart, that is, the keynote speaker will talk through the learning objectives of the heart, teaching materials, the teaching process, key teaching points and difficult teaching points. After the keynote speaker finishes, the teaching materials are clear and the lesson plan is described explicitly. We then focus on this lesson and discuss, for example, if there are any good ideas or if there is anything to improve. (…) That is, one of the purposes of our collective lesson preparation is to have the same learning objectives and difficult teaching points, but everyone may have their own teaching methods and styles. Everyone teaches their own lessons based on the keynote speaker's preparation, largely similar but minor differences remain.

April: Could you please explain why ordering a meal is better than designing lunch recipes?

Ziv: 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 life experience. They have more life experience around eating out. (Ziv_IV3)

Although designing lunch recipes was a suggested activity in the textbook, Ziv and his colleagues discussed its shortcomings in a collegial setting. They thought the question asking students to order a meal worked better because students had more experience of ordering a meal in restaurants. Another working practice was observing lessons and giving feedback. Sue, who worked at the same school with Ziv, talked about how she changed the way she tried to reach her affective objective in her public lesson through lesson observations with feedback. Colleagues suggested talking about a small thing, rather than saying empty words:

Many people place emphasis on emotions, attitudes and values, especially for a public lesson. Yet this affective objective is not easy to achieve. When I taught this lesson initially, I taught at my school, I said animals played a great role so we should protect them, and so on. This kind of teaching was a bit empty, without any real meaning. So, my colleagues suggested talking about a small thing at the time. Then, I thought the smaller the point was, the greater power it had. I thought about how to do it and then I just achieved it by [discussing] ants. So, students could feel that the grassland was so big, the biological relationship was so complicated, and that, although the ants were so small, they could do so many things. (Sue_IV2)

Similarly, in the next department, Wynne and Zachary emphasized the positive impact that working together to polish a lesson had had on their teaching and use of questions. For example, Wynne changed her lesson introduction by using three drawings by a student and a sequence of questions (e.g., “Can frogs live in this environment?”, “Why can frogs not survive in water-scarce terrestrial environments?”) rather than only having students recall their prior knowledge:

> For example, I initially introduced this lesson by recalling amphibians, a review of amphibians. Later, after I had a public lesson, a teacher gave me a suggestion that I should draw a few pictures. (…) In terms of how to introduce this lesson, he/she thought the important thing was to develop the idea about biological evolution that couldn’t be told students directly. (…) In the first picture, recall the characteristics of amphibians, a picture of their living environment. In the second picture, an amphibian goes to the desert. So, it encounters problems. Then, present the third picture. It is a lizard [in the desert]. It has overcome those difficulties encountered by a frog. How does it overcome them? Let the students observe and think about this question. (Wynne_IV2)

Zachary stated that he used slides that his colleague made when she had a county-level public lesson on earthworm observation, as they shared slides after the public lessons within their biology department. He thus used sequences of questions and teaching ideas in the slides. He commented that his lesson was improved significantly – for instance, using questions to support students in scientific practices:

> 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. Let students think, think about these questions before doing it. In the past, I overlooked these things. (…) [After the changes,] students’ purposes were very clear in the process. When they finished, they were particularly confident about the results they had. (Zachary_IV2)

It is clear that individual teachers can improve specific questions greatly by working together and utilizing the collective intelligence when polishing a lesson (e.g., slides) in a way that can be shared among every biology teacher in the department, which may have an impact on everyone’s classroom implementation of scientific practices.

7.2.1.3 Personal role in polished lessons

There is growing interest in how students use materials to engage in scientific practices from the perspective of multimodality (e.g., Prain and Tytler, 2022; Tang, 2022). However, relatively little research has examined how teachers select and adapt teaching materials or resources that influence their questioning and scientific practices. This section shows how teachers themselves made great efforts to support their teaching by polishing teaching materials. For example, Helen adjusted the hand and finger exercises (see Figure 7.1) which were first added at the end of the lesson and then used in the middle.

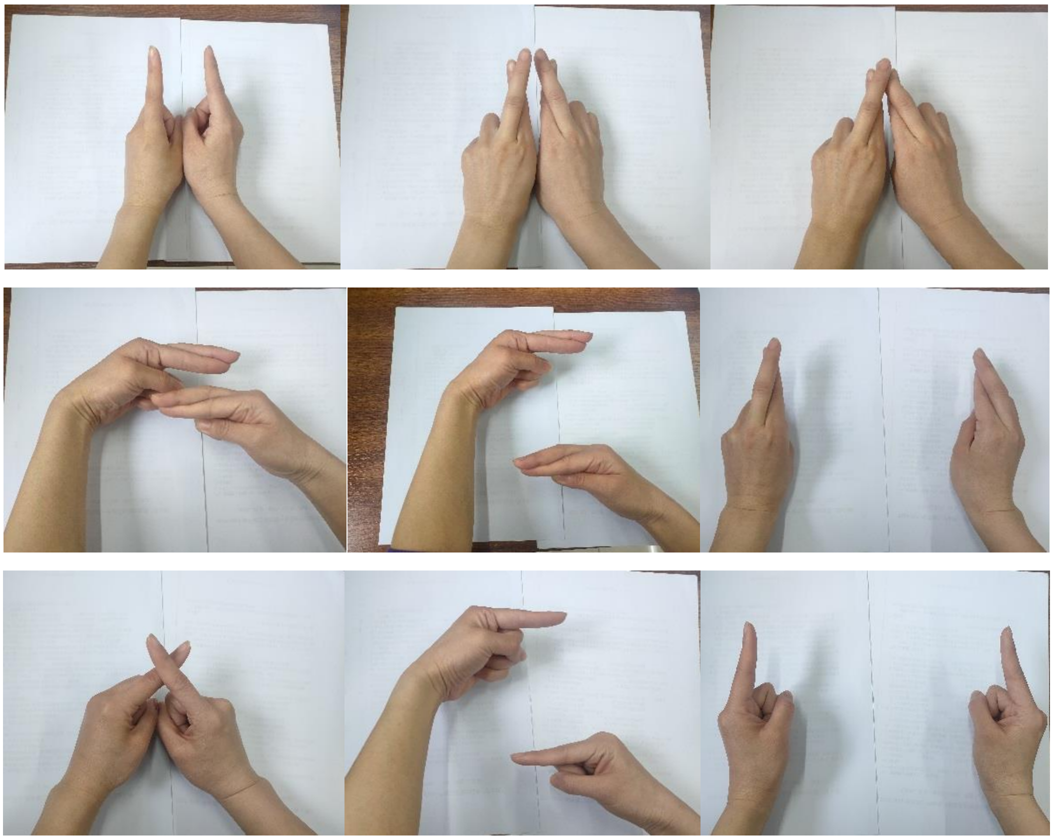


Figure 7.1 Using hand and finger exercises to show what happens to a pair of homologous chromosomes in meiosis

> Helen: (…) I taught this lesson four times. It's different every time, you know? The first three lessons were taught in one day. I made adjustments in every lesson. (…) In terms of the hand and finger exercises you asked about just now, it was in the second lesson that I thought whether I needed to add them. Then, students were very excited at the time and they were very interested. In the fourth lesson, I asked two students to build [the physical models of homologous chromosomes] on the blackboard while the rest did the hand and finger exercises…

April: When did you add the hand and finger exercises?

Helen: In the second lesson. They were added at the end of the lesson. In the third lesson, I realised that they could be used in the middle of the lesson. I was adjusting gradually. (Helen_IV4)

Helen prepared the lesson about one month in advance. She spoke of the importance of polished lessons; the appraisal of teachers was partly based on an assessment of her teaching performance in polished lessons. She tried to teach in a way that was intended to gain acceptance and attract admiration as a provincial expert teacher. She had an initial inspiration: using hand and finger exercises. She then kept adjusting this activity, which affected her questions. Helen finally asked a sequence of questions while students did hand and finger exercises in the middle of the lesson. For example, in the top left image in Figure 7.1 in which each index finger represents one of a pair of homologous chromosomes, Helen asked students to stretch out their left and right index fingers and asked what each one originated from.

The following teacher polished important experimental materials to help students carry out investigations. She tried, modified and tested her teaching materials many times in the laboratory:

You know, in terms of how to make a lesson more innovative, in its early days, I had to practice and modify many times to get a high-quality lesson. (...) For this lesson and these materials, I was in the laboratory at the time. I thought of the teaching materials, how to use them and how to improve them. I did experiments in the laboratory, oh, for half a month. Finally, they were polished to their current version. They looked very simple, but students could grasp the knowledge immediately. (Wynne_IV2)

Wynne put a great deal of time and effort into developing her lesson on animal movements because she was preparing to participate in a national competition hosted by the Department of Basic Education at the Ministry of Education between science experiments in primary and secondary schools. Her motivations can be inferred from the congratulations she received on her school website for her achievement in the competition. The editor-in-chief of the junior secondary biology textbooks printed by People’s Education Press commented that Wynne and her students were implementing STEAM practices in the process of building the physical models to demonstrate the movement of bones, muscles and joints; she thought the lesson on animal movements designed by Wynne was a major innovation in teaching and teaching materials in junior secondary biology, which enacted the Core Competencies and Values for Chinese Students' Development. Wynne was thus known for her excellence in teaching, which would prove beneficial to her promotion and career development. Wynne's strong personal motivation is partly supported and reinforced by such external validation. Although the title of this section focuses on the personal factor, it is clear from the study of Wynne, for example, that she worked hard at developing specific teaching approaches to seek external validation. This represents one of these interactions between factors in the framework that I will discuss in a later section.

Ziv also focused on how to modify his materials to support his questioning:

> When I taught this lesson initially, I used the stickers on the blackboard and the figure in the textbook. (…) It wasn't as good as I expected. (…) When I was preparing this lesson, I thought about how to modify. So, I thought I could search the internet and order a batch of models of food guide pagodas for students. (…) I searched later on Taobao. Oh, I found this, it was very cheap, one cost only 1.5 yuan, and then I bought a batch. So, I guaranteed that two students could have one physical model. Then, after it was unfolded, it was three-dimensional. The [classroom] effect was immediately different. (Ziv_IV3)

According to Ziv, the figure was very clear but "far away from the students" (Ziv_IV3). He therefore replaced them with physical models. He described how using physical models was different in that students could hold them in their hands, and it was easier for them to cooperate and discuss things with their classmates.

7.2.2 The high school entrance exam or the national college entrance exam – External

Because biology was not included in the high school entrance exam in the city before 2019, teachers were able to create biology exam papers within their schools. However, in 2019, biology became an exam subject and test papers were designed by the province. Although the biology score was not included in the total score for the high school entrance examination in 2021 when I interviewed teachers, students were still required to pass this externally set exam. If they did not, they could not get a junior secondary school diploma. Zachary described how these changes influenced his teaching attitudes and behaviours:

> We try to finish this textbook [for Grade 7] as soon as possible and will teach the textbook for Grade 8 at the end of this semester. We're facing pressure from the high school entrance exam. Also, the pressure of time (…) 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)

There were four biology textbooks in the junior secondary school. Teachers taught one textbook per term before 2019. After the exam changes, teachers accelerated their teaching schedule so that they had a few months at the end to review the content of the four textbooks and prepare for the exam. Thus, less time was given to carrying out scientific practices. For example, in the lesson students were only given a few minutes to observe a bullfrog at the front of the classroom. There was one bullfrog for a whole-class observation, and it was possible that the students at the back could not see it clearly. However, in the past, a group of four students were given an opportunity to observe the characteristics that bullfrogs had adapted to survive in their environment in detail:

> Students working in small groups observed bullfrogs two years ago. 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)

The new curriculum standards advocated carrying out scientific practices – for example, observation and practical work – and encouraging students to participate in experimental design, observation and data records. When the amount of time dedicated to scientific practices was drastically reduced, it appeared to become difficult to meet these requirements as set out in the curriculum standards. In the following example, Ziv changed a small group practical activity into a whole-class teacher demonstration:

> For example, I've been teaching Food Energy recently. This is a practical activity in which students investigate the energy content of peanuts by burning them. (…) In the past, I divided students into small groups and let students measure the energy content of peanuts. I choose a demonstration rather than letting students work in groups this year. In fact, the reason is I want to accelerate my teaching progress. (Ziv_IV1)

When asked, "How much time was saved?" He answered, "A demonstration only took ten minutes, whereas conducting small group activities took about 40 minutes. Oh, about half an hour." (Ziv_IV1). The above examples indicate that teachers were under assessment pressures and spent less time on scientific practices. The findings were consistent too with other research (Kim et al., 2013) that found teachers had difficulties in implementing scientific practices because of lack of class time, assessment conflicts and heavy curriculum content. My study also relates specifically to the way in which changes in exam policies have transformed teachers' enactment of scientific practices.

7.2.3 Influence of teachers' involvement as research participants – External

All teachers mentioned that participating in this study had a positive influence on them. Specifically, Zachary pointed out that when preparing his lessons that were selected for my project, he started to pay attention to his questions, reflected on his questions, and developed sequences of questions to improve students' thinking. For example, he developed a sequence of questions in his slides to help students understand how amphibians breathe: (1) Although the honeycomb-like structure of the frog lung increases the surface area for gas exchange, the oxygen it obtains cannot meet the needs of daily life activities. How to remedy it? (2) What are the reasons for your answer? (3) Which type of animal also uses this structure to exchange oxygen and carbon dioxide with air?

> Didn't you say that your thesis was about how to ask good questions in the classroom? Right? To be honest, I didn't consider this issue initially. I thought later, "Hey, this was in fact the aspect that I should pay attention to in class, right?" Firstly, I ask questions that are appropriate for students' level of existing knowledge, and secondly, I ask questions to improve students' thinking and help them connect new

> knowledge to things they already know. When I was preparing for this lesson, I paid more attention to questions. (…) I think your project is helpful to me, and I have adjusted my slides. After the adjustment, either the students' thinking or other things have been improved. (Zachary_IV3)

In another example, Simon remarked,

> I feel like I have made a little progress by communicating with you in this way, just that kind of feeling, because I have never calmed down and thought about my teaching before. In fact, this process is actually beneficial to me, and it is definitely beneficial to my teaching. (Simon_IV3)

Only Zachary laid great emphasis on the impact of research participation on his questions. Other teachers mentioned a little bit about the influence of their involvement as research participants. However, it may be typical for participants to provide such comments. I suspect it is unlikely that their participation had any significant impact on their planning.

7.2.4 School policy on teachers' involvement in open inquiry – Internal

Leading students to participate in competitions is directly related to assessments of teachers' performance including, to give two examples, teacher promotion and application for an honorary title. Ziv helped students take part in many national or international competitions in which students conducted open inquiry since 2003, and the meaning of open inquiry and its relevance to scientific practices have been discussed in section 3.2.1 in the literature review. In addition, he encouraged students to pose questions they were interested in (e.g., Are your water bottles clean?) and facilitated student-centred inquiry in his society class, which was about 100 minutes every week. His active participation and enactment affected his understanding of scientific practices:

> I think guiding students to carry out open inquiry has had quite an impact on my teaching. (…) One of the biggest advantages is that I am aware of what the students don't know, I know what their problems are, and I understand the level and ability of students in this age group. (…) Another advantage is (…) improving students' scientific literacy. I think scientific literacy includes many, many things and the most important thing may be question awareness. That is, they can ask questions, use their disciplinary thinking

> to analyse questions, and eventually solve problems. These three – asking questions, analysing questions and solving problems – are interlinked, and they are a kind of scientific inquiry. (Ziv_IV3)

When asked to give an example of the influences he mentioned, he answered,

> For example, we have a lesson about measuring peanut seeds and exploring the biological variation in the textbook. (…) Some variation is heritable, that is, different sizes of different species of peanuts are caused by different genes. Some variation is the result of differences in the surroundings. (…) Before leading students to do open inquiry, I just measured [the size of peanuts] and gave students these two conclusions when I taught this lesson. However, after doing open inquiry, I felt that (…) in fact, a meaningful or high quality inquiry activity should to be combined with mathematics. The inquiry question and the method are valuable only when it's data-driven based on evidence. (Ziv_IV3)

Ziv initially focused on drawing conclusions rather than collecting and analysing data, and therefore focused more on acquiring content knowledge and less on developing process skills. He was the only teacher who mentioned that his experience of engaging students in scientific practices in extracurricular activities made him reflect on the importance of using mathematical thinking and data to support a claim. His change provides insights into how teachers' involvement in open inquiry in a school setting influences their attitudes and behaviours towards scientific practices.

7.2.5 Students – Internal

In Simon's words, "if a teacher teaches the same lesson a second time, it is not necessarily the same as the previous one because students are different". Therefore, I examined teaching as a process that not only pays attention to students and but also develops over time. In this section, I will present how students' academic performance influenced teaching and how teachers adapted their teaching according to students' classroom responses, personal confusion, and life experiences when polishing lessons.

Simon and Helen taught Grade 10 biology in a senior secondary school that assigned students to classrooms according to the assessment of their academic attainments. Note that the other four junior secondary teachers taught mixed attainment classes because it was not allowed to classify students according to their academic performance while in the compulsory education stage. Senior secondary students were put into different pathways in the province, some on a science pathway and some on a social science one. They all studied science, but the social science pathway students were tested in history, political science, and geography in the National College Entrance Examination. In Simon's school, students choosing natural sciences were divided into different classes: key and regular. Students in the key class had a higher score than those in the regular. Some students were in the social sciences class. Students remained in their classes at all times for all lessons. Because of the students' different levels of academic performance, Simon used different teaching methods and taught different knowledge:

> In the key class, I could spend a lot of time guiding students (…) In the regular class, I asked students to confirm an X chromosome location for the eye colour gene. Is the eye colour gene in the XY pairing region or in the differential region of the X? I wanted to let students know that there was a question here but I told them the answer directly. That is, when you design experiments to rule out alternative possibilities, just try to select recessive individuals with two similar sex chromosomes and red-eyed male fruit flies with a pair of dissimilar sex chromosomes. (...) As for this question, I didn't let them discuss it and I just told them the answer in the regular class. (…) If I teach this lesson in the social sciences class, oh my god, don't mention this. Even if I tell students the conclusion, they can't understand it. (Simon_IV2)

These students had different levels of learning attainment, which resulted in different help being afforded them. For example, in terms of how the scientist Thomas Hunt Morgan designed experiments to confirm the location of the eye colour gene and rule out alternative possibilities, Simon divided students into small groups to discuss the issue in the key class, gave students the right answer in the regular class, and did not even mention it in the social sciences class. He mentioned he had a distressing teaching experience due to low motivation and the negative learning attitude of students in the social sciences class:

> I often lose my temper in the social sciences class because students in this class are very stubborn (…) They are so naughty and difficult. They fall asleep in class. OK, forget about it. I wake them and then they go to sleep again. There's nothing I can do about this. (…) They think they like to nap in the biology lesson.

> It’s not the main subject, and they won’t take a biology exam in the college entrance examination; so, they don’t even listen to my lesson. (Simon_IV3)

Simon also illustrated the importance of students’ needs and responses in the process of polishing a lesson:

> Yet there are many influential factors, including the number of lessons I tried. In other words, the students help me a lot to polish my lesson. When I polish a lesson, I may take a few lessons in advance of the final demonstration lesson. In this process, I know, oh, it turns out that students had different thoughts on this question, they understood it or they didn’t know as much as I thought they did. (Simon_IV1)

The idea of trying lessons is noteworthy here. Trying out a few lessons before the final demonstration lesson is to test the feasibility of a lesson plan and discover how effective or suitable teacher questions or activities are by observing students’ responses. A similar emphasis on students’ needs and a detailed example is given by Wynne:

> I gave students animal pictures in advance. That is, I cut them, printed them in colour, gave them to students, and then asked students to draw an environment that could make animals alive. In the past, I asked students to draw an animal by themselves, but they hesitated. Also, they were not confident of their drawing skills, so they didn’t want to present in front of so many people or in front of their teacher. (Wynne_IV3)

Wynne initially asked students to draw a favourite animal by themselves, but they hesitated before drawing and it took longer than expected. Considering the students’ hesitation and their lack of confidence in their drawing skills, she decreased the difficulty by giving students animal pictures. The following example shows how students’ confusion helps Wynne reflect on the disadvantages of the experimental material (see Figure 7.2) in the textbook and change her way of teaching to help students understand how muscles work. She tried different materials in the lab as described in section 7.2.1.3, and finally used a frog’s hind leg with a preserved nerve to engage students in scientific practices.

> There is a sentence in the textbook, that is, muscles can only pull bones, but they can’t push them back to the original position, so they work at least in pairs. How to explain this to students? I used to tell them this

> was how it worked, or I took a chicken wing, pulled a bone, and said, eh, look, I pulled the bone, but muscles... In fact, it was far-fetched that I could pull a bone, but those muscles couldn't push it back. A student doubted when muscles contracted. He/she said, look at my arm, look at my arm, the muscles were hard but why they couldn't push a bone back. It was real. I think I was telling them just remember it and that's it at the beginning. I used dead muscles that can't react to stimuli; so, it's difficult to make students understand how muscles work. (Wynne_IV2)

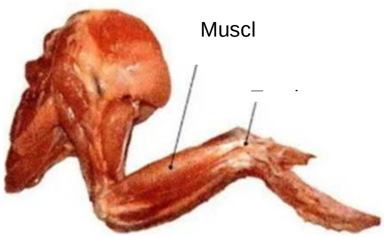


Figure 7.2 A chicken wing with some skin removed (from the biology textbook by People's Education Press)

Ziv mentioned he polished a question in response to students' life experiences. He changed the content of his question, using crispy noodles instead of instant. A small thing that was happening to students was used to change the content of his question to resonate with students.

> The textbook used instant noodles, but I used crispy noodles because students, most students had the experience of eating crispy noodles when they didn't have lunch at the restaurant. I didn't know it before, and I found that students liked to eat this later. So, I just changed my question in the third lesson. I adjusted. I used crispy noodles, rather than instant noodles. So, it is relevant to students' life. (Ziv_IV3)

Overall, six participant teachers placed importance on their students. They considered students' high or low academic performance, responses, difficulties, and life experiences. In the following sections, I will present the personal factors, including views about teacher questions, views about scientific practices and pedagogical knowledge.

7.2.6 Views about teacher questions – Personal

Helen stated that, “after the lesson preparation was done and the slides were ready, I felt tired, lay in bed and went through the lesson silently by heart, just like rehearsing a movie” (Helen_IV1). She silently rehearsed what she would ask in her demonstration lesson. She described a sequence of questions as a ladder or a spiral road that helped students climb a peak.

> In terms of the sequence of questions, I feel it is like, like students climb a peak and the road is spiral. Why a spiral road? Because it can’t be very steep. In that case, can you imagine that it is very laborious for students to go up? (…) My role is to inspire students through recalling their prior knowledge. Like this, just providing scaffolds to support learning. It’s just like providing a ladder. (Helen_IV2)

Ziv describes it as an upward arrow:

> The sequence of questions is like, like an arrow, like an arrow. This arrow points to the conclusion, and it is an upward arrow. (Ziv_IV2)

There are two common features here. First, both teachers were focusing on teachers’ guidance and scaffolding. Second, students went along a question pathway designed to reach conclusions. These features made me consider two related issues with regard to teacher questions: how much control do teachers have when using questions to achieve their objectives, and how much open space is left for students’ thinking? In the following sections, I will present teachers’ views about pre-planned and spontaneous questions and their views about the openness of questions.

7.2.6.1 Views about pre-planned questions and spontaneous questions

Simon highlighted the need for spontaneous questions. In his view, teaching was continuously changing and developing. For a fleeting opportunity, teachers should have made judgements quickly and asked spontaneous questions:

> Classroom teaching is dynamic and may change at any time. It is necessary for teachers to write down their questions in lesson plans, especially some very important questions, which is forward-looking. Yet teaching is continuously changing in the classroom; so, teachers may ask questions at the right moment

> according to the actual situation, students' responses, etc. Some spontaneous questions, acting as a reaction to the actual situation, are really needed in the process of exchanging ideas between a teacher and students. (Simon_IV2)

Although Simon emphasized the immediacy of teaching, he stated that most teacher questions were planned. Here planned questions constituted not only what teachers wrote out in their lesson plans or slides, but also what they had in their heads but had not actually scripted in advance. According to Simon, the reason why most questions were planned was because textbooks containing canonical science knowledge (e.g., prokaryotes organisms have ribosomes) determined the teacher questions:

> April: May I ask to what extent questions are pre-planned and to what extent they are spontaneous?
>
> Simon: No doubt most of them are pre-planned. Most of them contain the difficult teaching points, key points in this chapter, and what can inspire students to think. Most of them are determined by textbook knowledge. (Simon_IV3)

Similar views were offered by the other teachers. Here is an example:

> April: To what extent do you think questions are planned?
>
> Sue: To what extent are they pre-planned? A lot of them, yes, a lot of them. (Sue_IV3)

The reason given by Sue for pre-planned questions was to help students get the subject matter knowledge by thinking and reasoning:

> The reason why I pre-plan questions is because I basically don't tell students knowledge directly when I teach. You have listened to my lesson; so, you can feel it. (...) I don't like asking what this is, what this is, what this is, and what this is used for. A very important reason why I don't give them knowledge directly is because I can use questions to help students to reason. That is, I hope that my students can reason like this. (Sue_IV3)

Elsewhere in Sue's interview, she talked of *the sense of design*: "Questions are planned step by step. It is a bit like, when I teach, it is a bit like the escape room where every step is actually designed by others." (Sue_IV2) In an escape room, all the puzzles and riddles are planned and players need to solve them to escape. For example, when Sue taught the subject knowledge that mature red blood cells in mammals do not possess nuclei, she planned it as follows. She said a red blood cell was like a truck. She then drew a truck with a trailer, a cab, and a driver on the blackboard. In the trailer, there were some cubes representing oxygen. She asked how this truck could load more, and some students answered "Put cubes in the cab". So, she wiped the driver off the truck and put cubes in the cab. She then stated this car had no driver and asked which structure mature red blood cells did not have. Students finally realised that red blood cells did not have the nuclei to release their oxygen load. The content and sequence of her questions were devised to help students understand and construct new knowledge. This is why I have focused on 'episodes' and sequences of questions, not just isolated questions, to answer my second RQ. The following teacher aimed to use a sequence of questions to elicit and obtain deep thinking:

> I think many questions are thought-provoking, like a few sequences of questions I asked here. Why should the blood transfusion be less and slower if you get blood from a different blood type? Can the person with blood type AB receive from a donor with blood type O directly? No, a blood cross-matching test is required. You see, if students really want to understand these questions, they need to think deeper. The students find these questions a bit difficult; so, they may be more motivated to learn biology. They don't have a feeling that biology is too simple and easy. (Zachary_IV2)

7.2.6.2 Views about the openness of teacher questions

As elaborated in detail in section 5.2, open questions were used significantly less than closed ones. Sue talked about the reasons – for example, getting off track and the time constraints on covering the prescribed curriculum content:

> If I want to encourage divergent thinking by asking broad questions, it will be very likely to get off the track. (…) When I plan questions, I always plan sequences of questions. I then try my best to improve

> students' divergent thinking, but the divergence of their thinking is limited. I cannot digress from my lesson because you know that the lesson has teaching schedule requirements for teachers. It seems inappropriate if there is too much divergent thinking but I don't explain. Yet if I explain, my teaching task will not be completed. (Sue_IV1)

Sue stated that, "When I plan questions, I always plan sequences of questions". This supported my focus on episodes rather than the questions in isolation. She captured the struggle she faced when deciding openness of teacher questions and viewed asking open questions as a way to make 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. This mirrored Biggers's (2018) claim that investigation questions are overwhelmingly provided by teachers, materials or other sources and students are not given the opportunities to ask their own questions that they carry out investigations to answer, because teachers are pressed for time and teaching requirements. Ziv mentioned that compared with his society class, less open questions were used in the normal lessons:

> April: You just said that you often used open questions in the society class. So, why are open questions used more? What are the differences between the society and the normal class?
>
> Ziv: One is that there is no…I don't have curriculum standards. 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 same objective. Also, fewer people. If I have fewer students, I can use more open questions.
>
> April: How many people in your society?
>
> Ziv: 36 [in the society]. There are 56 students in my normal class. (Ziv_IV2)

Ziv used more open questions in the society class because there were fewer students, no learning objectives about subject matter knowledge and no teaching schedule requirements. In the normal class, his desire to use more open questions conflicted with his duty to support 56 students in acquiring prescribed subject knowledge. 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: the sternum of birds is very extensive.

> I found that when I asked this question, the students' thinking was very divergent and it was from different directions. It was because the question I asked was not specific enough. I then reflected on it after the lesson and revised it. (…) When I taught birds a few years ago, I asked such a question, that is, the sternum of birds is very extensive and has become a plate. Isn't it a plate-like thing called a keel, right? When I taught this lesson, I asked: "What do you think are the characteristics of bird bones?" In fact, my question was to let them notice the sternum was extensive. Yet, my question was not specific; so, the students didn't know how to answer it, and they didn't know what I wanted. 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)

Sue focused on the degree of difficulty of the teaching content. When the subject knowledge in the whole lesson was easier and there was no right or wrong in some cases, she used more open questions:

> It has something to do with the knowledge objectives, because teachers need to teach knowledge. That is, for example, there are many open questions that don't have standard answers in the ecosystem lesson. Just like burning straw, there are no right or wrong answers to it. To be honest, there are no right or wrong answers because burning straw has its advantages. Another example, the initial idea of killing wolves was actually reasonable. So, these questions have advantages and disadvantages and the knowledge objectives are easy to achieve. The knowledge is not so difficult. So, the main purpose of this lesson is to improve thinking skills. (Sue_IV2)

This is also an example of the socio-scientific issues discussed in the literature review. Sue claimed that this context of socio-scientific issues enabled more open questions. In the literature, Day and Bryce (2011) have similar view: teachers may pose questions that allow students to look at the same socio-scientific issue from multiple perspectives. Even though Ryder and Banner (2013) discuss a tension between the teaching of social-scientific issues and the teaching of traditional subject knowledge, open-ended social scientific issues are still the ideal context for open questions when the knowledge objectives are easy to achieve in a lesson. The openness of questions was also determined by the objectives, according to Wynne:

> If I want to make a question broader, like birds, different kinds of birds have different shapes, I will ask, ah, look at this picture, what the differences are between these birds. Here the question is not specific because I want to improve students' divergent thinking. For example, they [birds] have different leg lengths, right? Some have webbed feet and some do not have. Some birds' feet are claw-shaped and some are webbed. That is to say, if I want them to sum up these things from various aspects, I will ask divergent questions. I want to let students know that the structure of a bird is adapted to its environment; so, I ask what do you think the differences are? (Wynne_IV1)

For the same subject knowledge, teachers might ask questions with different degrees of openness: for example, "What do you think are the characteristics of bird bones?", "What are the characteristics of a bird's sternum?" and "What is the shape of a bird's sternum compared with a reptile's sternum?" A question can be located on a column between closed on the one hand and open on the other (see Figure 7.3). 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 teaching large class sizes, etc. In the literature review, van Booven (2015) argues that teachers negotiate a tension between authoritative and dialogic sequences of questions and it is necessary for them to find any middle ground given their diverse learning objectives and students' needs. It is thus more helpful to consider balance rather than tension.

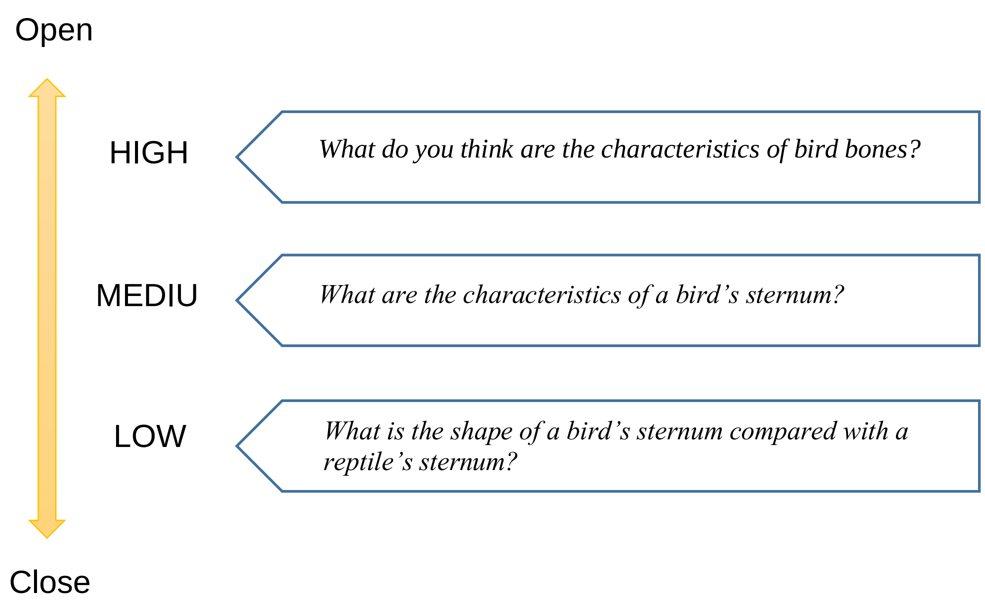


Figure 7.3 Degree of openness of teacher questions

7.2.7 Views about scientific practices – Personal

The participant teachers had different understandings of the definition of scientific practices. Sue stated that the term applied to almost everything and used some key words to describe what they were and what were included: idea, method, skill, broad, practical work, observation, and survey. For example,

> In my opinion, it [scientific practices] is an idea and it doesn't necessarily mean doing practical work. In fact, it's an idea that applies to many things. (…) For example, which is better in terms of straw management, burning straw or feeding cattle and sheep? It's actually a kind of inquiry. (Sue_IV1)

In contrast to Sue, Simon defined it in the following way:

> …help students to pose questions about life phenomena in the real world (…) and then lead students to observe, pose questions (…) design an investigation and carry out their investigation, facilitate small group discussion at the end, and help them communicate and discuss their results. (Simon_IV1)

According to Simon, scientific practices included the activities of students: for instance, posing questions, planning investigations and communicating explanations. His definition of scientific practices was similar to that found in the national biology curriculum standards. Simon only focused on how scientists work and the nature of science, while Sue had quite a broad usage of the term. The other teachers' understandings lay in between; for example, Wynne paid more attention to what scientists do but she also included the teaching of science concepts.

Zachary mentioned that the scientific practices in the curriculum standards were not practical because,

> In fact, in terms of many investigation questions provided [by the teacher, the curriculum or other sources], students have already know the answers, know the final results (…) It doesn't include much true inquiry.

> (…) When students do practical work about microorganisms (…) it is true inquiry because they don't know which environment has more microorganisms. They make a real hypothesis and finally come to their conclusions through investigation. I think, in the entire two-year junior secondary biology study, this is probably the only real inquiry because students do not know the final results. (Zachary_IV1)

Similarly, Simon did not perceive the textbook to be very inquiry-oriented because sometimes the titles (e.g., Genes Are Located on Chromosomes) in the textbook tell students the answers:

> The title tells them the scientific conclusion. (…) It's really annoying when I teach this part. I need to make it clear to students that it's not easy to come to the conclusion that genes are located on chromosomes. It is gained by the collaborative efforts and experimental tests of scientists. (…) I try my best to let students not only know the conclusion in the textbook, but also find out all the other possibilities, that is, how scientists develop these possibilities and how they rule out incorrect hypotheses. (Simon_IV2)

This was concerned with the level of the openness of inquiry in the textbook and the alignment between textbooks and curriculum standards. If textbooks and other curriculum resources are not inquiry oriented, this will obstruct the implementation of scientific practices. In addition, teachers' different understandings of the definition in the curriculum standards might be caused by the simple descriptions in the curriculum standards and misunderstanding in journal papers. In the literature review, I discussed there was no consistent and explicit definition of scientific inquiry, which led to teachers having different understandings. I will discuss the implications of this in the final chapter.

7.2.8 Pedagogical knowledge – Personal

This following example was selected because it highlights original contributions to the existing literature. As mentioned in the literature review, teaching and learning science are a multimodal process and draw on many representational and communicational resources: for instance, drawings, diagrams, gestures, body position, teaching materials and resources (Mortimer and Scott, 2003; Wilmes and Siry, 2021). This example contributes to how a teacher selects and adapts gestures to support their questioning rather than just focusing on the use of language in a specific context. In this example, Sue was explaining ecological balance, that is, how grass and sheep live in balance and their populations remain relatively stable. If there are more sheep, then the grass population would decrease and eventually the population of sheep would decrease due to a lack of food. In the past, Sue used a graph (see Figure 7.4) to help students develop the concept of ecological balance, but she later used gestures:

> I was teaching [ecological] balance at the time (…) I was thinking about what the balance was. Isn't it like a seesaw? If I use gestures, it is like a seesaw, one side up and one side down. In the past, when I first taught this lesson, (…) a kind of curve [studied] in high school was drawn. A kind of wave with two peaks and two valleys, right? I gradually found out that students actually didn't understand that kind of curve. Even though they understood it, it's still difficult (…) because it involved data analysis. Using my body language can make a difference to students. I used my hands and said this was going up. Students then said that it was going down after that, then going up this way, going down this way... They understood these things well. In this case, I asked if it was going up and down around this level in the middle. The students said that's it. I then asked what this was called. The students replied balance. (Sue_IV2)

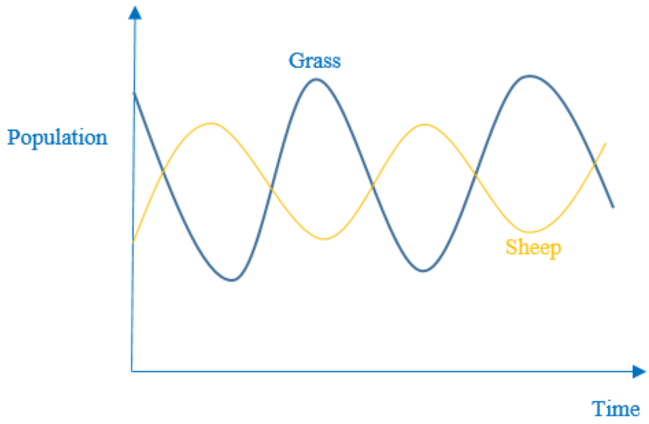


Figure 7.4 Population dynamics between sheep and grass

According to Sue, this graph involved complex activities: for instance, reading a graph, interpretating a graph and effectively summarising information. Thus, it was not appropriate to use a more difficult thing (a graph) to explain a difficult concept to junior secondary students. Using seesaw gestures was different. Previous research has argued that graphs play a dominant role in scientific practices and reading, and interpreting graphs is an important skill (Glazer, 2011), and teachers tend to use graphs to teach the concept of ecological balance. However, this finding does not support the previous research because Sue suggested graphs might be an obstacle when junior secondary students were learning about abstract matters.

In this example, Sue's gestures made reference to the visual image of a seesaw and replaced a curve that showed the population dynamics between sheep and grass but was more difficult to interpret. They revealed implicit knowledge and assisted students in thinking about her questions and learning the concept of balance expressed in speech at a later point.

7.3 The interactions of personal, internal, and external factors

The previous sections identified multiple factors influencing teacher questions and teaching. In this section, I explore the interactions of these external, internal and personal factors, some of which are pushing in the same direction and some of which are tensions.

Simon summarized the three basic stages of polishing a lesson (see Figure 7.5) through which it can be seen how his teaching was affected by external, internal, and personal factors moving in the same direction: implementing curriculum standards and motivating students to engage in scientific practices.

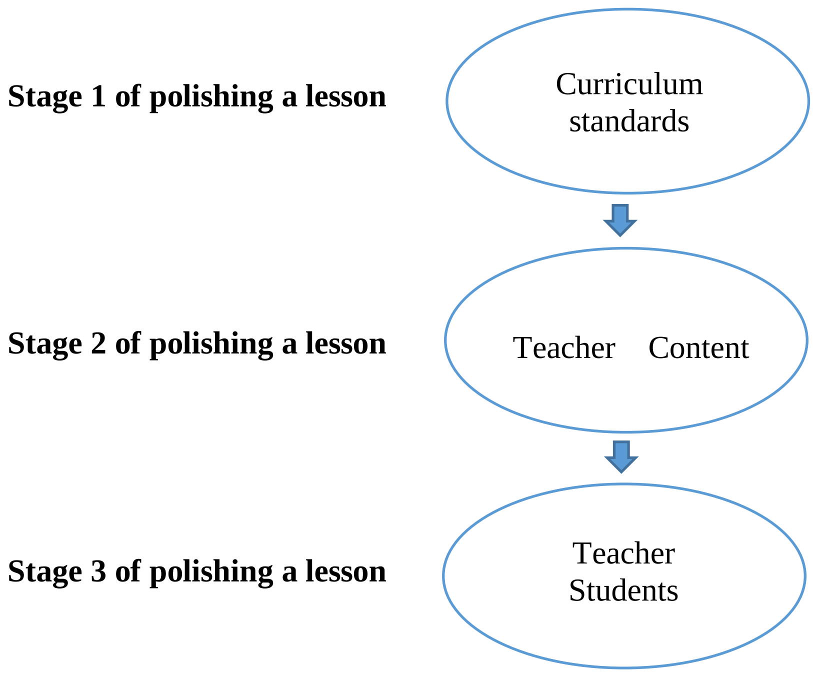


Figure 7.5 Three stages of polishing a lesson (Simon)

Polishing a lesson is a complex activity and closely related to curriculum standards, content, and students. According to Simon, the initial stage involves studying curriculum standards and knowing what students are expected to acquire in terms of four aspects: big ideas of biology, scientific inquiry, scientific thinking, and social responsibilities. Simon stated that the next stage was reached when teachers integrated themselves into the teaching content; for example, integrating a teacher as a living thing into the biology subject that studied the natural processes of living things. He also described a need to be familiar with the content, describing it as like "a proficient driver knows full well that how to avoid an incident, how to turn around, how to change lanes safely, and how to control the speed on the highway" (Simon_IV2). In the final stage, he considered the teacher, content, and students as aspects of the whole, which meant teachers putting their heart and soul into their students, exchanging ideas with them and motivating them to conduct scientific practices with great interest.

The following example shows how the external factors (e.g., curriculum standards and teacher developer) and internal factors (e.g., a student's confusion and group discussions where colleagues worked together to polished lessons) resulted in teachers' personal development. Wynne was encouraged to take part in a national competition; she selected a lesson about animal movements. According to the junior secondary biology curriculum standards, students were required to learn in this lesson how the movement of the human body is controlled by the nervous system and produced when the muscles pull on the bones around the joints. However,

> …our biology teachers thought this sentence was very simple and did not see this knowledge as a key teaching point of this lesson. What was treated as a key teaching point instead? The components of the musculoskeletal system and the structure of the joints. (…) They spent a lot of time on these. (…) When I studied the learning objectives [in the curriculum standards] again, I found that they mistook the key point. (Wynne_IV2)

According to curriculum standards, the national guidance for classroom teaching, Wynne identified the key teaching point of the lesson: that is, how muscles, bones and joints produce movement. She also received help from a teacher developer. When they were discussing how to improve the materials used to show how muscles move a bone (see Figure 7.2), the teacher developer gave her a piece of advice; could materials (muscles, bones, and joints) move automatically to show how to produce movement? This suggestion made Wynne think: chicken muscles are dead; they cannot react to stimuli. So, how can we innovate with the materials? From the students' angle, as I mentioned earlier, one student after this lesson told Wynne he/she was still confused about how muscles, bones and joints worked. The students' confusion also helped Wynne reflect on the disadvantages of the experimental material in the textbook and change her way of teaching. She thought of the classical practical work she did when she studied a Master's degree, which she then refined and used in her lesson. That became an important experimental material to help students investigate how to generate movement. External, internal, and personal factors were interacting with each other towards the same direction: implementing curriculum standards and helping students draw a conclusion based on results.

However, in other cases, these external, internal and personal factors were pushing the teacher in opposite directions. For example, in the lesson about Griffith's experiment, in which mice were injected with living type S virulent bacteria, living type R bacteria, heat-killed type S bacteria, and living type R bacteria and heat-killed type S bacteria, Simon valued opportunities to involve students in scientific practices to foster their inquiry skills. He reflected on his question, "What was the conclusion of Griffith's experiment?"

> I should encourage students to compare and analyse the first group, the second group, the third group, and the fourth group in Griffith's experiment and give students an opportunity to draw a conclusion. (Simon_IV3)

However, he felt this was undermined by time constraints. He finally asked students to find the conclusion in the textbook, rather than giving them time to argue and reach a conclusion. He explained,

> I sometimes find that (…) what the student says is not what I expect to hear. Some students are even completely unaware of time issues. They don't know the answer but they are ashamed to say they don't know. (…) One student stood up, dawdled and thought [for a slightly longer time]. You know, a lesson is only 40 minutes 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)

He added,

> Students are more likely to make mistakes here, that is, [they think Griffith concluded that] DNA was genetic material. I asked them to read the textbook carefully. Griffith came to the conclusion that there was a transforming principle, but he didn't know what it was. (Simon_IV3)

Making common student mistakes explicit and clear had the priority over analysing experimental results, discussing and making conclusions at the time. It appeared that the teacher was faced with exam stress, as Simon mentioned, "Our school is very concerned about test scores, so that more students can go into top universities, such as the number of students admitted to Tsinghua University and Peking University" (Simon_IV1). The school had a policy of separating teaching and examining in that the examiners should be teachers teaching the same subject but not in the same grade and they should not be those who have been responsible for the teaching. The school compared the average score for each class after the school exams.

Elsewhere in his interview, Simon stated, "students pay too much attention to test scores, too much attention to exercises" (Simon_IV2). These students managed very good grades in the high school entrance examination and were admitted to an excellent senior secondary school, and Simon illustrated junior secondary students' recruitment context:

> We have cooperative schools, and my school took over two or three [junior secondary schools] last year. (…) If the number of schools for three-year junior secondary school increases, my senior secondary school can select some students who have (…) excellent academic achievement. (Simon_IV1)

Simon was referring to a considerable growth in junior secondary branch schools that were operated and managed by his main school over the previous few years, but the number of senior secondary schools did not increase accordingly. This led to more intense competition between students who wanted to attend top senior secondary schools. It is worth considering to what extent such a competitive educational environment, in which lots of students were screened out, affected students' attitudes towards examinations and scientific practices, and how much it affected classroom teaching.

7.4 Summary

In this chapter I presented teachers' reflections on factors influencing teacher questions from three aspects: personal (e.g., teachers' views about the openness of teacher questions), internal (e.g., students and school policy on teachers' involvement in open inquiry) and external (e.g., the high school entrance exam and the *three-level and three-category* policy). The role of internal and external factors cannot be ignored. For example, the policy shift on the high school entrance exam was so impactful that it dramatically changed the use of teacher questions and implementation of scientific practices. A school policy encouraging teacher involvement in open inquiry changed Ziv's attitudes towards scientific practices and he realized the importance of collecting and analysing data rather than just focusing on drawing conclusions. These factors sometimes aligned to push teacher professional development; for example, polished lessons made personal, internal and external factors work together to demonstrate a more sophisticated use of questioning. This explained why polished lessons enabled more open questions as described in RQ 1. However, in other cases, different levels of factors led to teacher tensions: for example, the personal desire to use more open questions conflicted with the time constraints and exam stress. The use of episodes enabled teachers to reflect in a broad way that highlighted the role of teaching materials, gestures, and resources in teacher questioning.

Chapter 8 Research Findings of RQ 4

In the last chapter, I illustrated teachers' views on the factors influencing teacher questioning. In this chapter, I shift attention from teachers to students and investigate RQ 4: How do students perceive their teachers' questioning in class? I aim to present the student voice in order to advance our understandings of students' attention, interest and attitudes towards teacher questioning, and contribute to a wider use of questioning strategies and teacher professional development.

This chapter is composed of six sections. Section 8.1 presents my codes and the categorization scheme. The next two sections are about students' perceptions of teachers' questions, including their views about different types of teacher questions (e.g., open and closed) and what they notice about teacher questioning. I also compare how students and teachers talk about the same episodes. I used student drawings when interviewing students, and sections 8.4 and 8.5 analyse the students' drawings, which describe how their teachers work with them when they learn science knowledge, and show my reflections on students' drawings, respectively. The final section gives a summary of the findings.

8.1 Codes and categorization scheme

Table 8.1 provides a summary of the codes, descriptions and examples. Coding brings together myself, my data, and my RQ in an effort to generate interactions between them (e.g., I keep my RQ in mind and read interview transcripts in order to trial coding; I find a link between the data and my RQ through coding). It is complex and iterative because it involves combining codes, changing their names, deleting codes and adding new ones. For example, I combined three codes – 'focusing on small things', 'focusing on easily confused knowledge', and 'focusing on knowledge more likely to be tested in the exams' – into a new code, 'the content of teacher questions'. There were two reasons for doing that: (1) reducing the number of codes makes information easier to read and understand; and (2) the old code 'focusing on small things' only appeared very infrequently in the data set. However, whether a code is prevalent (e.g., a substantial number of students mentioned the code) is not crucial for my entire coding process. Coding depends on whether or not students talked about something important related to my RQ. Even though only one student might articulate a particular code across the whole data set, the code is still presented because it captures an important thing: for example, a student's views about the significant differences in Ziv's teacher questioning between the society and normal classes.

Code	Clarification (where needed)	Example
Students' views about open and closed questions		Is pneumococcus prokaryotic or eukaryotic? Yeah, this question was just to let us… because it was taught a long time ago (…) it is just a kind of recall something. The teacher was just checking in class. It's, like, just in case we forgot it. Recalling helped us remember it. (S1_Simon)
A student's views about questions in the society and normal classes	A student's views about how Ziv uses questions differently in the society and normal classes	His questions in the normal class were about learning knowledge and guiding our thinking but those he asked in the society were about practical problems we were facing. (S3_Ziv)
Students' views about scenario-based questions		It's his style. It's anthropomorphic, that is, he asked us what I would do if I were a cell. In this way, it helped me memorize things easily, rather than just mechanically memorizing knowledge. Also, I felt like I was in this scenario; I was a certain immune cell, and then I [as a cell] struggled to work [in this scenario]. (S1_Simon)
The content of teacher questions	Teacher questions focus on small and specific things, easily confused knowledge or knowledge that is	His questions are about small things. (S2_Simon)

	more likely to be tested in the exams.	
The pace of teacher questioning	The speed of asking sequences of questions	Then, in terms of teacher questions, that is, yeah, they can consolidate my knowledge. Also, it is like he is always pushing, pushing. It's pretty fast and furious. (S2_Simon)
Using materials or examples to support questioning	Using materials to support teacher questioning and using examples to relate to students' lives	In terms of teacher questions, what impressed me most was that the teacher brought a real heart for dissection. He took some parts of the real heart, and then came to ask questions. (S1_Ziv)
Increasing difficulty gradually	The teacher asks questions with increasing difficulty levels.	He would always ask some questions to review knowledge at the beginning of the lesson, but they were relatively simple and easy to answer. After that or in the middle of the lesson, he asked more deep and difficult questions. It's like he increased difficulty gradually. (S3_Simon)
Improving concentration		Her timing of asking questions is perfect. Sometimes some students there… sometimes the atmosphere was uninspiring or some students weren't concentrating, and then she would ask questions in time and help them focus on the lesson. If not, they couldn't get anything. (S2_Helen)
Increasing learning motivation	Teacher questions increase learning motivation; students become interested in the question, which develops a positive classroom climate.	The questions in this episode are fit for the teaching content, very interactive so they can increase students' learning motivation. (S1_Helen)
Developing inquiry skills	Teacher questions help students understand how scientists work and	There is also an issue of the material selection. Yeah, this has had a great influence on me, I think. In the end, after his lesson, I felt that the experimental equipment, like lab materials, could not be chosen

	understand a fair test.	indiscriminately. Their selection should be evidence-based, I think. (S2_Simon)
Developing critical thinking		For example, if he finishes explaining this theory, that is, he finishes explaining this theoretical system to us, he will ask if the theory is right and why. His questions improve critical thinking. (S2_Simon)

Table 8. 1 Codes about how students perceive their teachers' questions

My categorization grouped the codes as shown in Figure 8.1. I identified two main categories: students' views about different types of teacher questions; and types of students' attention to teacher questioning. Types of students' attention to teacher questioning represented what students noticed when they were asked to make comments on teacher questions. To show the relationship between the codes and present them clear and logically, 'increasing difficulty gradually', 'using materials or examples to support questioning', and 'the pace of teacher questioning' formed a sub-category: 'the pedagogic issues of teacher questions'. Similarly, I developed a sub-category, 'the effect of teacher questions' that included 'improving concentration', 'increasing learning motivation', 'improving critical thinking' and 'developing inquiry skills'. These concepts (shown in Figure 8.1) reflect my way of representing students' perceptions. Moreover, some concepts (e.g., the pace of teacher questioning) were based on what one student said and might not be generalizable across all students or even a larger sample.

8.2 Students' views about different types of teacher questions

In Chapter 7 I explored teachers' views about the openness of teacher questions and the reasons why Ziv used more open questions in the society class than in normal class. In Chapter 6, I also stated Simon used scenario-based questions to help students think from another angle. What are students' experiences and expectations about these questions? In this section, I first present students' views about open and closed questions, then go on to differences in the teacher questions for the society class and those for the normal class, before finally discussing their feelings about scenario-based questions.

8.2.1 Students' views about open and closed questions

Overall, there were not many comments from students explicitly about closed questions. In terms of a closed memory question that was used to recall factual knowledge, a student remarked, "In fact, this question is mainly used to review prior knowledge. It's not interesting." (S1_Simon). Although this did not mean that he disliked all closed memory questions, it

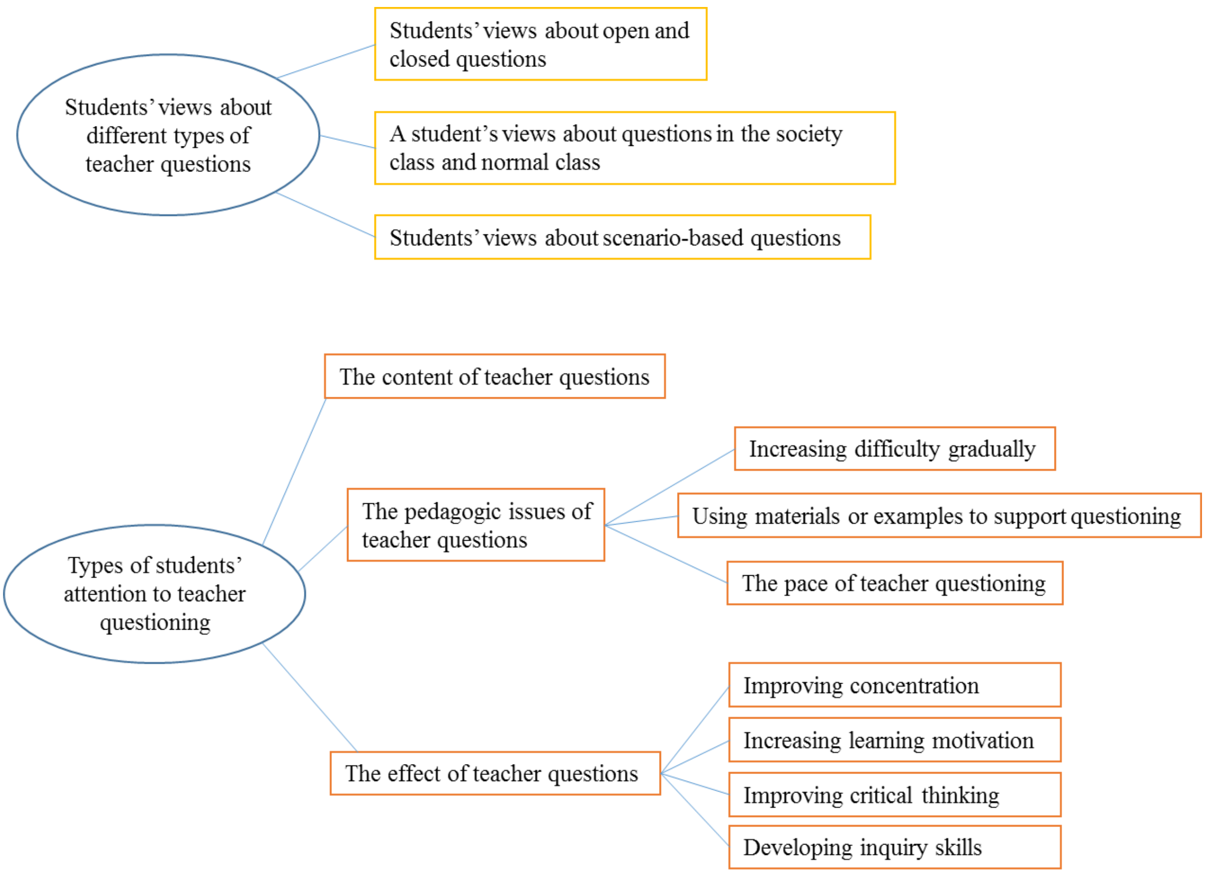


Figure 8.1 A categorization scheme, showing students' views about teacher questions

reflected how this student preferred more open questions to some extent. S1_Helen mentioned his response to closed memory questions:

> For a simple recall question, my thinking speed… at least in science subjects, my speed of thinking is relatively fast, (…) the time I need to think of an answer is relatively short, but I don't want to say it out loud. Generally speaking, if there is enough time, I will think about its related knowledge by the way. But I don't want to give an answer. (S1_Helen)

S1_Helen kept silent about closed memory questions, although he knew the answers. Elsewhere in his interview, when asked which questions he liked in the episode, he pointed out some closed other questions that required higher cognitive levels (e.g., predicting and comparing) than the closed memory questions, but they still had a limited number of right answers: for example, "If we use a blender and a centrifuge too early and bacteriophages don't have enough time to attach to their hosts, where will radioactivity be detected?" He explained "this type of questions requires me to consider many things" and "they involve some other knowledge, like the knowledge of isotopes; that is, they are very comprehensive questions that test and improve my ability."

In terms of open questions, S3_Simon pointed out that she liked an open question in an episode: "The behaviour of genes and chromosomes are parallel. Does that mean that genes must be on chromosomes? You definitely cannot say this is the only conclusion. What else can you draw?"

> I like that [question] better (…) he [Simon] asked if genes must be on chromosomes and if there is only one conclusion. So, there are some possibilities. I like it because I don't need to give a fixed answer and therefore have a feeling of divergence. (S3_Simon)

It is interesting to know how the student's views compared with Simon's. Simon also commented on this question in detail in Chapter 6. He suggested students draw conclusions based on the data, rather than focusing on the sole correct conclusion in the textbook. Simon's comments were more detailed and insightful; for example, he was concerned with broader aims and issues (e.g., students' development of scientific thinking), but S3_Simon's respond was limited to her thoughts and feelings about this question.

S1_Ziv remarked she liked the question "What are the difference and connection between the role of the teeth, the tongue and the saliva?" when compared with closed questions: for instance, "Which two tubes from test tubes 1, 2 and 3 can be a fair test?" She remarked,

> I like a type of questions that don't have very fixed answers. Similar to this one, that is, the difference and connection between the role of the teeth, the tongue and the saliva. I can use my imagination. I can say it out loud when I think of something, and then the teacher helps me summarize it. (S1_Ziv)

Students stated that because open questions did not have fixed answers, they could use their imagination, think from multiple perspectives and experience a sense of divergence. The next student was fond of open questions because she favoured arguing:

> It's just that I personally prefer this kind of open-ended questions that we can discuss because I like to argue with people (…) it's like a debate. I think perhaps there may be some people who agree on this issue and some people who disagree, and then we can discuss these ideas. (S3_Ziv)

A little later on, the conversation developed and S3_Ziv made this point:

> I have a friend who went to a school abroad. Sometimes I like having a chat with him/her. I asked about the learning experiences in his/her classroom and I'm very envious of him/her. He/she said that they sat cross-legged on the floor in class (…) the teacher sent a question to the iPad, a group of students sat in a circle, and everyone talked about their own ideas (…) Also, their teacher pointed out that students couldn't only have one answer and they must have at least two answers. [I think] it is possible that a student has an answer that may be right or wrong. (…) Even if the answer is wrong, it still has great value because students can learn and better understand [the question] by discussing why the answer is wrong. (S3_Ziv)

I could infer from S3_Ziv's fondness for the format in her friend's classroom of asking questions that whether there was one answer or multiple answers mattered to her. She also paid attention to the meaning of incorrect answers in that it showed students felt safe to make mistakes and they could discuss and learn from their peers' errors. In section 3.3 in the thesis, in which I reviewed the literature about typologies of teacher questions, one of the things that came out was tentative questioning (Oliveira, 2010), in which teachers ask questions to encourage students to give uncertain answers and engage in discussions around scientific practices. My study supports this argument in a specific context; that is, teacher questions are needed that have multiple answers, enhance peer interactions and provide a supportive learning environment. S3_Ziv also mentioned the context of teacher questions; that is, how questions were asked in her friend's classroom. Is the question raised verbally, presented in slides or sent to an iPad? Is the question for the whole class or small discussion groups? Do students sit in their seats or in a circle on the floor when they discuss the question? This student did not think teacher questioning was simply teacher behaviour. She expected that it involved multimodal interactions between a teacher and students, between an iPad and students, and between students and students. She valued the construction of social support in teacher questioning.

8.2.2 A student's views about questions in the society and normal classes

S3_Ziv joined the school Science Micro Video Society in which 36 students worked in small groups and engaged in their own open inquiry projects. (Note that she is the only student who experienced both classes.) In her small group in the society, they watched several advertisements that claimed the food made using air fryers was healthier than fried food; therefore, they did an experiment to compare the calories in air-fried and fried food. She mentioned the differences in teacher questioning she noticed between the society and normal classes:

> In the classroom in my school, it is 1:56 [teacher-student ratio] (…) However, in my society, the teacher is…There are four students in my group but one student left. So, it is 1:3 [teacher-student ratio]. (S3_Ziv)

First, the teacher-student ratio was 1:3 in her society class and 1:56 in the normal class and therefore Ziv's questions were only for a few group members in the society. Next, the student stated that the purposes of the teacher questions were different. According to her, teacher questions were used to help students learn science knowledge in the normal class but used to solve students' practical problems in the society lessons:

> In the classroom, we mainly take lessons: that is, learn the biology textbook. The teacher's questions are to get the knowledge: that is, ask us to think about his questions and better understand that knowledge. However, in scientific inquiry, (…) we say that there's no success or failure in scientific experiments and we may say that we haven't achieved our experimental objectives. This is what the teacher told us. (…) His questions in the normal class were about learning knowledge and guiding our thinking but those he asked in the society were about practical problems we were facing. So, they are different in essence... (S3_Ziv)

She also mentioned whether teacher questions were flexible:

> In the classroom, questions make us just go straight along a thinking path and we can't go back. So, this kind of thinking is very fixed. In the society, (…) even if our method is not good, (…) the teacher will help us investigate step by step and explore which method is the best. Then he'll suggest using this method. He offers support and advice. In the society, everything we do is optional. Our teacher, as he said, is a facilitator, and we make our own decisions. That is, we are free to choose between following his suggestions and rejecting them. I think we can have our own opinions. (S3_Ziv)

As illustrated in Chapter 7, Ziv perceived a sequence of questions in the normal class as an arrow that points to a conclusion. The student described her feelings when responding to these questions; it was like she went straight along a path and it was impossible to return. However, she found that students in the society could go back, for example, if they did not achieve their objectives. In Chapter 7 Ziv emphasized that he "only [has] an objective that is to instruct students to make movies" and he used more open questions because of a relatively small class size and no time constraints to cover teaching content in the society class. This indicates some agreement between Ziv and his student about the differences in teacher questions in the society and normal classes; both agreed on the impact of the number of students and objectives on teacher questions.

There was no right or wrong when students did experiments in the society class. According to S3_Ziv, students were given opportunities to try a method and modify it if it was not good; they could make her own decisions and the role of her teacher was a facilitator. Therefore, the teacher's power and authority shifted in the society lessons to teacher-student dialogue and negotiation. As discussed in the literature review, Chen et al. (2017) identified four roles of teacher questioning during argumentation: dispenser, coach, moderator, and participant. The participant role means students have the ownership of ideas and of activities, the teacher and students exchange ideas, and the teacher encourages students to do what they want to do in scientific practices. In my present study, Ziv worked as a participant in the society classes.

8.2.3 Students' views about scenario-based questions

Scenario-based questions were specific to Simon, and all three of his students were impressed by this type of question. For example, a student commented that "I think it's more immersive. I can think from another angle…" (S3_Simon). S1_Simon commented too on this kind of questioning:

> I think one of the most memorable things for me is that the teacher often asks us to imagine you are that cell or organelle, imagine you are a kind of creature, and you can imagine what you are going to do when faced with some of the work they do. In fact, when he teaches the knowledge in anthropomorphic ways in class, I think it's easier for us to accept these things and memorize them. (S1_Simon)

S2_Simon remarked on this question: "Imagine you are the scientist Sutton; why did you rule out the other two hypotheses?" Sutton proposed the chromosome theory of inheritance that states that the behaviour of genes is parallel to the behaviour of chromosomes. Students suggested three hypotheses in the classroom: genes are located on chromosomes, chromosomes are located on genes, and genes are chromosomes. Simon then asked students to rule out the incorrect hypotheses. S2_Simon spoke about his appreciation of this question:

> At first glance this is deeper than the previous [questions]. Also, it's from the perspective of this scientist. It seems particularly high-level. Specifically, it can stimulate students' thinking.

He later added as the conversation went on,

> I can clearly remember the moment when he taught about Mendel, [he asked] if you were Mendel; when he taught about Sutton, he asked if you were Sutton. (…) At the time, that scientist selected male fruit flies for his experiment. That is, for example, [the teacher asked] if you were the scientific researcher, why you wanted to select these [male fruit flies] that were so rare in nature. (S2_Simon)

Scientific practices aim to develop students' creative thinking and help students not only to know what scientists did but also know why they did it. As described in section 6.2.5.2, Simon claimed that he used scenario-based questions to help students imagine they were, for example, a scientist and try to think and make decisions from the scientist's perspective. Students stated this type of question supported such thinking. Teachers are encouraged to ask these questions, which make students completely involved in a situation and think from another perspective: for instance, "If you were Mendel…" and "If you were Sutton…"

8.3 Types of student attention to teacher questioning

Students' attention to teacher questioning refers to what they noticed when they talked about teacher questions. It fell into three categories: the content of teacher questions; the pedagogic issues around teacher questions that include increasing difficulty gradually, using materials or examples to support questioning, and the pace of teacher questioning; and the effect of teacher questions that includes increasing learning motivation, improving critical thinking, and developing inquiry skills.

8.3.1 The content of teacher questions

Students' attention relating to the content of teacher questions was divided into three kinds. First, S2_Simon and S2_Ziv stated that many teacher questions were about small and specific things; for example,

> In this episode, questions pay attention to many details; for example, how genes occur in a body cell, how chromosomes occur in a body cell, how genes occur in a gamete, and how chromosomes occur in a gamete. (S2_Simon)

The second arose when students did not know the subject matter knowledge and provided an incorrect answer, which was only mentioned by S2_Helen, who had good grades in biology. He commented on a question and mentioned his embarrassment after giving an incorrect answer:

> Do homologous chromosomes always have the same size? For me… In fact, when I replied to this question, I actually answered yes, because I didn’t remember that kind of sexual reproduction, that pair of homologous chromosomes XY. I was especially embarrassed at the time. (S2_Helen)

The third category was concerned with whether teacher questions involved the knowledge that was more likely to be tested in the exams:

> In terms of these two big questions, they are not written in the textbook so it is easy for them to be ignored by many people. However, when I take exams, examiners especially like to test this. For example, this question was tested in this final exam. (S2_Helen)

The two questions refer to those Helen asked after teaching the method of the Hershey-Chase experiments: “How does one label T2 bacteriophages with phosphorus-32 or sulfur-35?” and “Why was a small amount of radioactive phosphorus-32 detected in the lighter solution and why was a small amount of radioactive sulfur-35 detected in the heavier bacterial pellet?” Theoretically, there was no radioactive phosphorus-32 detected in the solution and no radioactive sulfur-35 detected in the solid pellet in the Hershey-Chase experiments. This student had an interest in these questions that may be exam questions. In the interview, Helen explained the three purposes of her questions. Firstly, they are to prepare for the national college entrance examination that tends to test these areas:

> How are bacteriophages labelled? The question is intended to test student knowledge; that is, bacteriophages are viruses, and they are parasites that require replication in living cells... In Jiangsu, Shandong, and Zhejiang province, they like using this kind of question in [college entrance] exams. (Helen_IV3)

Second, they are used to make students realize that there is a gap between theory and practice; and, third, these two questions are used at the end of the lesson to establish the framework of the experiments in the first half of the lesson and analyse a few details at the end, when asking both questions is crucial, according to Helen. Comparing the responses of the student and Helen, I concluded that both agreed on the importance of exams and the teacher considered the pedagogical issues around how questions fit in with the whole lesson.

8.3.2 The pedagogic issues of teacher questions

This section includes increasing difficulty gradually, using materials or examples to support questioning, and the pace of teacher questioning.

8.3.2.1 Increasing difficulty gradually

Four students noticed their teachers increased the difficulty level of teacher questions gradually. S3_Simon stated that questions in the middle of the lesson were more difficult than those at the beginning, while S2_Helen, S1_Ziv and S2_Ziv remarked that their teachers used a sequence of questions with increasing difficulty. For example,

> The teacher first asked some easy questions, such as this one I previously mentioned, how many chromosomes in a homologous pair. It is very easy to answer, right? She then asked some questions… I don’t know how to put it… not really difficult; that is, she asked what was likely to be neglected [by students]. Examiners especially like to test this kind of knowledge in exams, like the XY question [that is about whether homologous chromosomes are always the same size] that made me particularly embarrassed. (S2_Helen)

S2_Ziv commented that "teacher questions were like staircases going up layer by layer because questions helped us find answers step by step". This corresponds with Chin's (2007, p.837) view that a series of teacher questions is like a *cognitive ladder* that helps students to progressively reach a high level of knowledge and understanding.

8.3.2.2 Using materials or examples to support questioning

Two students paid attention not only to teacher questions per se but also the context: for instance, examples and materials. As S1_Ziv put it, "In terms of teacher questions, what impressed me most was that the teacher brought a real heart for dissection. He took some parts of the real heart, and then came to ask questions." Imagine a scenario in which Ziv points at a ventricle in a picture of the heart, rather than a real heart, and asks which blood vessel is directly linked with it. Perhaps this student would not be so impressed. S2_Ziv noticed interesting examples of what teacher questions were based on; for example, a quality inspector extracted more than 20 ml of oil from a pack of instant noodles:

> The teacher talked about some examples and then asked questions (…) He set the scene for the students, and we could relate to a kind of experience in our lives. My classmates might not notice this phenomenon in their lives but at least they have something to say. (S2_Ziv)

8.3.2.3 The pace of teacher questioning

The pace of teacher questioning was mentioned by S2_Simon, and it referred to the speed of asking sequences of questions during an episode, rather than focusing on a question or student response. Thus, it was different from the concept of wait time that refers to pausing after asking a question and after a student response. Simon purposely asked questions at a very quick pace to push students to think and respond faster:

> S2_Simon: …Then, in terms of teacher questions, that is, yeah, they can consolidate my knowledge. Also, it is like he is always pushing, pushing. It's pretty fast and furious.
>
> April: What do you think about the questions in this episode?
>
> S2_Simon: He often does this! That is, he suddenly asks a question, then suddenly asks a student to answer his question.
>
> April: You think it is sudden, right? Haven't you had time to react?
>
> S2_Simon: No, he is very fast. He teaches very, very fast… (S2_Simon)

S2_Simon went on to say how a fast pace of teacher questioning enabled him to concentrate:

> S2_Simon: I really like it… I have to give him my full attention and use my head in class. If not, I won't understand what he says. He asks some questions and he asks them once sometimes. If I don't listen to what he is asking carefully, I can't answer his question. (S2_Simon)

Based on the student's utterances and the classroom recording, the pace of teacher questions could mean the teacher talked very fast, asked a question, gave students a short wait time, invited a student to answer his question, then moved onto his next question and repeated this several times. This student used the terms 'pushing', 'fast and furious', 'suddenly', 'fast', 'give him my full attention', and 'use my head' to describe his feelings. He did not use the word 'pace'; however, this word reflects my understanding of a student's attention to teacher questions. It does not simply mean wait time but more than that: for instance, the speed of speaking, the focus on a succession of teacher questions, and an exciting classroom environment.

Contrary to many studies that find that slowing down and giving students more think time can produce more positive results (e.g., Rowe, 1986; Tobin, 1987), this student in my study got used to the fast pace of questions that made him concentrate the mind. However, considering that the school has a good reputation for students' academic performance, it is difficult to move from this particular student's view to a general one. Teachers may adapt their pace of questioning in accordance with students' different academic abilities and needs.

8.3.3 The effects of teacher questions

The effects of teacher questions, which include improving concentration, increasing learning motivation, improving critical thinking and developing inquiry skills, are discussed in the following sections. Simon is very prominent here because he used a wider range of forms of questioning and stressed the importance of critical thinking and inquiry skills.

8.3.3.1 Improving concentration

Four students from senior secondary schools focused their attention on improving concentration: S1_Helen, S2_Helen, S1_Simon, and S2_Simon. Subject knowledge in the textbook at this stage is more difficult to understand than that in the junior secondary school; therefore, it is challenging for students to maintain their focus. Students commented that teacher questions helped them think and concentrate. For example, S1_Helen remarked, "Questioning can activate our thinking, activate the classroom and attract our attention to the teaching content. That is, it can improve our learning efficiency and enhance learning outcomes." S2_Simon commented, "If a few students just sleep there in class and the teacher starts to ask questions, they will wake up. Just have a feeling, a task-driven feeling."

8.3.3.2 Increasing learning motivation

Four students – S1_Simon, S2_Simon, S3_Simon and S1_Helen – commented that teacher questions increased their learning motivation:

> Why can bacteria cause sepsis when they have capsules? It, it needs expanding thinking. It's not easy to answer this question… It allows me to discover something I didn't know before. So, I have a feeling of self-exploration. (S3_Simon)

> In fact, what I find really interesting is how to inject a mouse. What is the site of injection? This is really a blind spot for me. I have never heard of it. If I didn't listen to it, I just wouldn't know such knowledge. So, it sounded very novel at the time. (S1_Simon)

When talking about two questions – "Why can bacteria cause sepsis when they have capsules?" and "What is the site of injection [of a mouse]?" – students used words to describe their experiences like *expanding thinking, self-exploration, a blind spot* and *novel*. Both of Simon's questions involved subject matter knowledge that was not required in the textbook. Helen did not ask these two questions when she taught the same lesson. However, in the students' views, both questions not only broadened their minds but also maintained their interest.

I listened to the episode in the recording when Simon explained this question in the classroom: "What is the site of injection [of a mouse]?" I found he made it funny and interesting and therefore created a relaxed and enjoyable atmosphere. In the interview, Simon talked about the five purposes of this question: (1) lay the foundations for future learning because students will study animal cell culture engineering that involves subcutaneous injections in the third year of senior secondary school; (2) make students realize how important a standardized procedure is in the process of scientific inquiry; (3) create a positive classroom climate; (4) help students remember it; and (5) show compassion and respect to mice used as laboratory animals. The teacher considered more aspects (e.g., teaching strategies, scientific inquiry, emotions and attitudes) but students placed the emphasis on their interest and enjoyment.

In the next example, Simon used a question about how a scientist designed experiments to confirm the location of the eye colour gene and rule out alternative possibilities to engage students in discussion. This question was hard and challenging, but it motivated S2_Simon to learn:

> We were actively involved in this activity. That is, we worked hard, although we couldn't figure it out. Also, we were so annoyed we couldn't figure it out. Nonetheless, after listening to the teacher, we suddenly felt that everything clicked. It was this kind of discussion that made us enthusiastic about learning. (S2_Simon)

8.3.3.3 Improving critical thinking

Three of Simon's students mentioned critical thinking. When Simon managed to convince students that the behaviour of chromosomes and genes was parallel and genes were located on chromosomes, he suddenly asked if there were any other possibilities. He asked students to prove a theory, and then went back to disprove this theory. S2_Simon commented it was like demolishing a building immediately after it was completed:

> April: The behaviour of chromosomes was parallel to the behaviour of genes. Simon asked if you had any other conclusions besides the conclusion that genes are located on chromosomes. What do you think about his question?
>
> S2 _Simon: This? He asked us back suddenly. That is, it seemed that I became dazed at the time and I didn't know what he meant. I just kept thinking about it all the time. I wondered if there were genes in the cytoplasm and if... I was thinking other things.
>
> April: Were you dazed?
>
> S2_Simon: That is, he suddenly… I felt that he suddenly demolished a building that was completed just now. I just couldn't jump to conclusions. He often does this kind of things. (S2_Simon)

Elsewhere in his interview, S2_Simon mentioned that Simon's questions helped him develop his own critical thinking. He changed his attitudes to biology, and started to critique and pose his own questions:

> He asks us to look back critically. For example, if he finishes explaining this theory – that is, he finishes explaining this theoretical system to us – he will ask if the theory is right and why. His questions improve critical thinking. (…) In the past, when I learned biology, I found it very boring, because I just did the exercises all the time. (…) However, after I took his lessons and listened to his questions, I started to think on my own initiative and then went to explore something. For example, I especially like plasmids and I really want to learn more about them. (S2_Simon)

8.3.3.4 Developing inquiry skills

S1_Simon, S2_Simon and S1_Ziv mentioned developing inquiry skills. For example, S1_Simon mentioned teacher questions in an episode about the Hershey-Chase experiments and how Simon did not just want students to learn knowledge. He stated that students were expected to learn skills and develop a deeper understanding of how scientists work: for example, how to design an experiment and how to analyse and interpret data:

> In fact, in terms of this sequence of questions raised by Simon, I think he was analysing a process in which the scientist carried out his experiment and he wanted to stimulate students' thinking. I think one thing he really wanted us to learn was how to design experiments, rather than knowledge. I think this is very important. (…) He helped us to think if you were, you were a scientist at the time, how you would do this experiment, which step was needed, why, why you need this step, what would happen if you did it, what deviations might occur if you did not do it, or something else? (…) I think this is also a very important process. It is about the ability to analyse experimental results, which is also a must when we do scientific practices. (S1_Simon)

8.4 Students' drawings

Eight students were asked to provide a drawing showing how their biology teachers taught them science knowledge. The exact terms I used were 'biology teacher', 'teach', and 'science knowledge'. Drawing a science teacher provides a way of showing how teachers typically teach science knowledge from the students' perspectives. Through these drawings, and the related written or spoken explanation, I could see a more detailed and bigger picture that I did not see in interviews: for example, where the teacher's position is in the classroom, how the teacher uses science equipment, and how the teacher interacts with students.

As described in section 4.7.4, I analysed students' drawings based on the DASTT-C score sheet. The scores of five students are listed in Table 8.2. I then selected and presented S2_Helen's, S2_Ziv's and S1_Simon's drawings in the following paragraphs because their total scores were 9, 5, and 2, respectively, representing their teaching on a spectrum from teacher-centred to student-centred. The rest of students' drawings are attached in Appendix 16. I could not use the score sheet to analyse three students' diagrams because S1_Helen and S3_Ziv did not draw pictures, and S2_Simon's drawing showed the teacher working in different places and therefore could not be marked using this score sheet. I also analysed each drawing in terms of the role of the teacher, the role of the students, the learning environment and the relationship between the teacher and students.

Name	**S1_Simon**	**S3_Simon**	**S2_Helen**	**S1_Ziv**	**S2_Ziv**
Score	2	6	9	12	5

Table 8. 2 The scores of students' drawings

In the S2_Helen's drawing (see Figure 4.2 in section 4.7.4), the teacher Helen is standing on a small raised section in the front of the classroom and teaching or lecturing with a pointer in her hand. Students are sitting at their desks and listening. It appears that they are receiving knowledge. There is a distance between students' desks that are arranged in one row so that students are not working in groups. There is a big blackboard behind Helen and in front of the students. Helen is much higher than seated students. All these details may suggest the teacher is the sole authority and source of knowledge.

S2_Helen wrote a few sentences below his drawing: "When the teacher is teaching, she often asks questions when we are sleepy. We can wake up in time. Also, her questioning skill often makes me memorize the knowledge easily.” The student thinks that teacher questions play a role in focusing attention and memorizing knowledge.

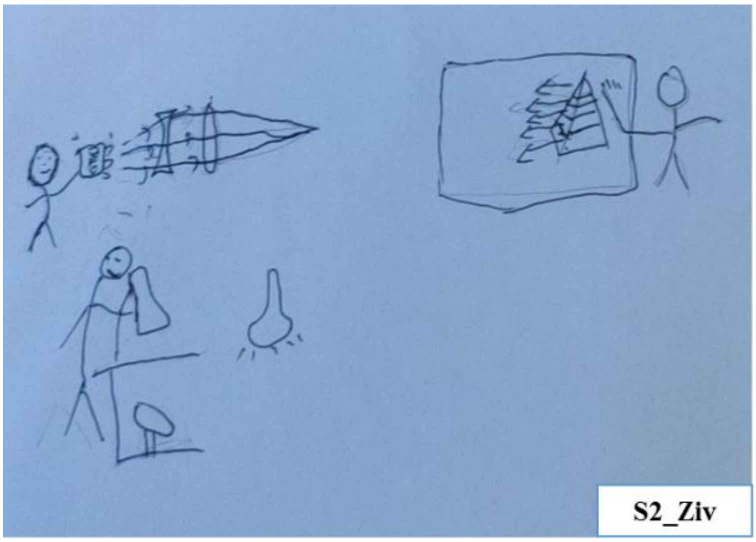


Figure 8.2 S2_Ziv’s drawing

In S2_Ziv’s drawing (see Figure 8.2), Ziv is standing and working in three different contexts. In the top-left picture, he is using teaching materials to explain how short-sighted persons need concave lenses to focus clearly on distant objects. In the top-right, he is using a pointer to point at a slide that shows a Food Guide Pagoda divided into five layers. In the bottom-left, he is demonstrating how to use a microscope. There is no student in the drawing, perhaps because of my emphasis on the teacher’s teaching when the student was asked to provide the drawing. The first picture shows three instructional tools – a light emitting three laser beams, a concave lens, and a convex lens – and these materials are used in the context of a classroom. The second drawing is also in the classroom and it shows a stick in Ziv’s hand and a slide where there is a picture of a Food Guide Pagoda. The third one is in a biology lab and shows two lab instruments: a light that allows a specimen to be seen by a person using a microscope, and a microscope with a mirror that reflects light to pass through the specimen. The size of the microscope has been exaggerated. These three pictures represent three different ways in which Ziv taught science knowledge: using teaching materials or resources to demonstrate something, using slides, and using microscopes in the lab. Thus, it shows the close interactions between Ziv and materials.

In S1_Simon's drawing (see Figure 8.3), Simon is standing, raising his right hand, and stretching out his left hand to show the way. S1_Simon used English for the image. Simon is encouraging students: "try and believe yourself!" Students who are close with each other are walking in Simon's direction. There is no environmental information. The teacher is larger than students but he is making students confident, rather than giving orders. Teacher authority is thus dissipated. There is an interaction between the teacher and students. In terms of the teacher-student relationship, S1_Simon explained:

> Actually, what I want to say in my drawing is when Simon is teaching, he is not a very old-fashioned teacher. In fact, he is like a friend. Or, precisely, he is more like a guide. Then, he often uses some… In fact, he uses some exaggerated, exaggerated language and actions to help us memorize and understand knowledge, some of which may be very boring. He is actually quite helpful when we study biology. (S1_Simon)

S1_Simon also translated some utterances Simon often said in the classroom into English at the top of his picture (see Figure 8.3). One of them was "If you forget something, please imagine that you are one of them. What will you do then?" It seems this kind of scenario-based questions was very typical. To some extent it was favourable and unforgettable, according to the student.

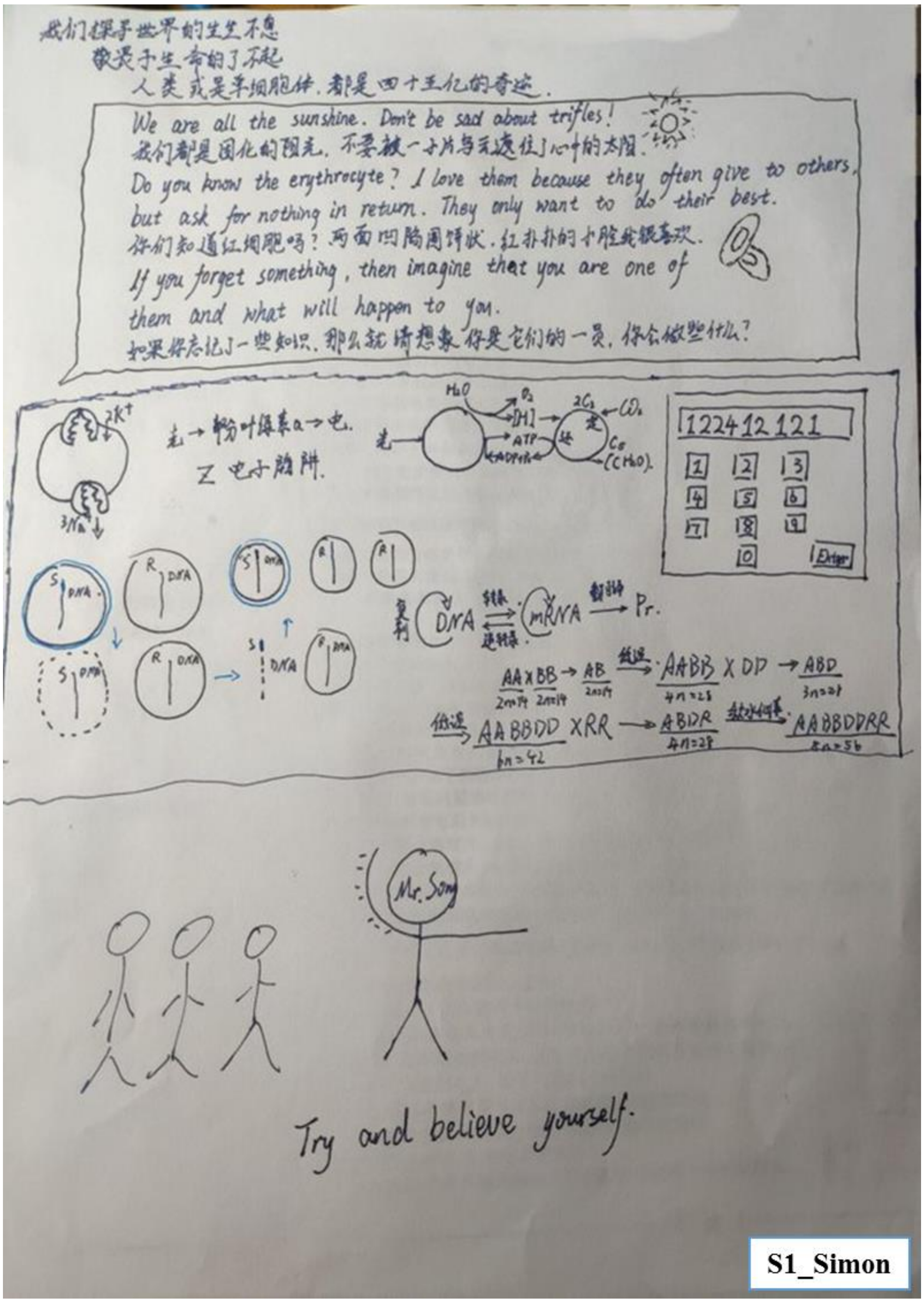


Figure 8.3 S1_Simon's drawing

8.5 Reflections on student drawings

All the student drawings lack illustrations of student cooperation, small group discussions and students' interactions with materials. Although Ziv is interacting with materials in S2_Ziv's drawing, students' interactions with materials are not shown. One possible reason was that I asked students to draw their teachers; therefore, they focused more on teachers' teaching, rather than students' learning. Moreover, it may have been difficult for students to draw students and their cooperation. Students tend to draw what they find easier to draw, rather than necessarily capturing their primary experience of learning science. However, to some extent, it appeared that when students are learning science knowledge student cooperation in small groups and interactions with materials was not as common as teacher demonstration.

There is a podium, a small raised section of floor, in S2_Helen's drawing, which has a specific name in Mandarin, '讲台', and this term is connected with the teaching profession. That is, when people see this term, they will know this refers to teaching as a profession. The height of a podium is about 10 centimetres. On the one hand, teachers have a higher position and therefore it is easier for them to see all the students in large classes, but on the other hand, it might increase the teacher's air of authority about science knowledge and classroom discourse.

S1_Helen used words and arrows to show his experience of learning science knowledge (see Appendix 16). Reading the textbook, doing exercises and reviewing are his main activities according to the diagram, which shows the student checking if his answers were correct after finishing the exercises. Science knowledge has authority, and it exists in the textbook and in the exercises. The diagram does not show any activities that help students engage in scientific practices. S2_Helen's image also shows that Helen is working at a blackboard and students are sitting and listening.

Students' drawings did not show students' perception of teacher questions. Nevertheless, they provided a context in which teacher questions were asked and teaching and teacher questioning were inseparable. Understanding students' views on teaching is helpful to understand their teacher's approach to teaching as a whole.

8.6 Summary

In this chapter, I have reported how students demonstrated sophisticated and thoughtful reflections on open and closed questions, differences in teacher questioning between the society class and normal class, scenario-based questions, and what students noticed about other aspects of teacher questions, although the student voice was not diversified (e.g., different views about open questions). In the next chapter, I will discuss the relationship between what students said and what their teachers said about teacher questions, and implications for teaching and learning and teacher professional development.

Students' drawings provide background information to help me understand their perceptions; for example, S1_Simon's drawing reflected that the teacher showed less teacher authority, which was related to the student's articulation of his fondness for open scenario-based questions. Messages in the drawings could be used to understand the teacher's question behaviour; for example, S1_Helen's diagram showed the teacher focused on the teaching of science knowledge, which appeared to be in line with Helen using more closed questions to structure a lesson. In addition, drawings were used to elicit students' ideas during the interviews, and more will be discussed about that in the final chapter.

Chapter 9 Discussion and Conclusions

I set out in this study to try to unpack how teachers use questions to engage students in scientific practices, the multi-level factors behind their questioning practices and how students perceive teacher questions. I address these RQs in section 9.1. In section 9.2, I clarify and summarize the following original contributions to the existing research literature:

(1) Teacher questions reflect teachers' responses to national curriculum reforms, influenced not only by individual characteristics but also institutional and national context. These influential factors are explored across three levels – the personal, internal, and external – differing from previous studies that have tended to consider factors from only one of those areas.

(2) Section 9.2.2 contributes to extending our knowledge of students' views around teacher questions. I was unable to find any literature that aimed at exploring students' views regarding teacher questions.

(3) This method of talking to teachers by using episodes gave me access to some distinctive insights into how teachers selected and adapted drawings, gestures, teaching materials or resources to support their questioning and scientific practices, as described in section 9.2.3.1. I also discussed the role of student drawings and teaching episodes in eliciting students' views about teacher questions, as described in section 9.2.3.2.

After elaborating these research contributions, I then go on to consider the implications for teachers, school leaders, policy makers, and teacher professional development in section 9.3. Finally, I discuss thesis limitations, focus on some questions that may be worthy of research attention, and reflect on my four-year PhD journey.

9.1 Key findings across the RQs

This section provides an overview of the RQs by summarizing key findings within each of them. I also give an indication of how each RQ interacts with the others and where the research contributions are.

9.1.1 Addressing RQ 1: What types of questions do teachers ask during teaching that encourages students' engagement in scientific practices?

I classified teacher questions according to Blosser's (1975) QCSS: closed, open, rhetorical, and managing discussion (e.g., "Anything to add?"). Consistent with previous studies on teacher questions (Eliasson et al., 2017), my study shows open questions were significantly less frequent than closed ones. These two types of questions indicated teachers' power and control over broadening or narrowing student thinking. Although previous literature has shown that closed questions do not always lead to triadic initiation-response-evaluation interactions and that open questions might limit students' thinking and do not always lead to long and multiple-perspective responses (Khoza and Msimanga, 2021), a balance between different types of questions is recommended as it relates to student thinking, student attitudes, and classroom interaction (Wilen, 1991). Chin (2004) suggests going beyond the use of questions to recall factual knowledge and using higher order questions (e.g., synthesis) to develop students' problem-solving skills and critical thinking. However, in this study, teachers used too many closed memory questions and students were not given more opportunities to practice the use of scientific language and open up their thinking, which might have resulted in the authoritative classroom talk suggested by Mortimer and Scott (2013).

In this study, Wynne had a higher proportion of open and managing discussion questions compared with the other teachers, while Simon was the only teacher who asked open scenario-based questions in the recorded lesson. He asked two open scenario-based questions: "Imagine you are the scientist Sutton, why did you rule out the other two hypotheses?" and "In terms of the third group in Griffith's experiment, imagine you are Griffith. Why did you kill the S strain and then inject mice with them? Is it necessary?"

Within the context of polished lessons, there seemed to be a higher proportion of open questions. For example, as described in section 5.2, five lessons included a high proportion of open questions, and the top four lessons were polished ones. Moreover, Wynne used more open questions than the other teachers and all three of her lessons were polished, and this finding confirmed the association of open questions and polished lessons. As mentioned in section 3.6.3 in the literature review, I provided an example of how a Chinese teacher changed a closed question ("When the final product (glutamate) is too much, it will inhibit the activity of glutamate dehydrogenase. Which type of regulation is it?") into an open one during a polished lesson. In Stigler and Stevenson's (1991) study, a Japanese teacher reported they spent a great deal of time discussing teacher questions (e.g., the wording) in order to develop student thinking and stimulate discussion when they polished a lesson, because they did not want to ask a question that only elicited a simple answer and did not promote deep thinking. However, previous studies lack a holistic exploration of the reasons behind polished lessons: for instance, external policies and organizational support.

RQ 1 provided a quantitative overview of how six teachers used different types of teacher questions. It identified an infrequent use of questioning related to scientific practices and not commonly seen in the literature – scenario-based questions – and that was worth exploring in terms of the related purposes in RQ 2 and students' views in RQ 4. RQ 1 also provided a key theme that was worth exploring in more depth in RQ 3: polished lessons enabled more open questions. This is important because previous research has tended to describe teacher questioning practices (Wilen, 1991) but did not include much data for exploring the reasons for questioning behaviours.

9.1.2 Addressing RQ 2: What are the purposes of teacher questions when teachers engage students in scientific practices in secondary biology classrooms?

I used the interview data and classroom observations to get access to the teachers' purposes when questioning, which involved teachers clearly explaining their goals in the interviews and my postulations about the intentions of teachers' classroom behaviours. This approach was a distinctive one because previous studies tended to rely on classroom observations to approach and interpret the purposes for teachers' questions, as described in the literature review. The purposes for teacher questions were developed based on the data, including purposes related to scientific practices, using questions to emphasize social responsibility, using questions to support understanding big ideas in science, using questions to form appropriate emotions, attitudes, and values, and questions used for pedagogic purposes.

This finding has shown that teachers used a wide variety of purposes, involving cognitive, affective, and pedagogical domains, and that they considered inquiry skills, scientific thinking, scientific literacy, and the nature of science. This works against the stereotype of China being a country which focuses on knowledge recall, closed questions, and exam success. These focuses are present but stand alongside focuses on open exploration, value education (e.g., sympathy and care for others), and the application of science ideas within society. For example, as described in section 6.2.1.5, Ziv's account of the use of questions to deal with inconsistent findings showed he gave students opportunities to present results that were different from the standard results in the textbook and think about the reasons behind it. Teachers also purposefully used questions to help students form appropriate emotions and attitudes (e.g., show respect to the laboratory animals) and develop their perceptions of scientists (e.g., have respect for a scientist's insightful ideas) within the context of scientific practices.

In this current study, according to Simon, the pedagogic purpose of scenario-based questions is to ask students to think in a particular situation. This finding mirrors Soysal's (2022, p.23) study, which proposes a type of challenging question – playing the role of Devil's advocate (e.g., "Then, according to you, water is a very small thing. If small particles come, it says, 'There is a gap inside me; come in, sit down, you can come in'?"). However, Soysal emphasizes the role of critiquing while Simon pays more attention to finding a way of encouraging students to go beyond the science knowledge in their textbooks and make sense of scientists' ingenuity to include the complicated journey through which they reasoned and ruled out alternatives before reaching their conclusions. As described in section 3.4, a sequence of teacher questions can be used as a *cognitive ladder* (Chin, 2007, p.837) to frame a lesson. However, planning too many closed questions might lead students along the pathway the teacher planned, which would indicate the need to plan open questions in order to expand students' verbal spaces and broaden their thinking.

Question purposes have evolved significantly over the 150 years or so. They reflect teachers' efforts to better implement scientific practices in the classroom and a shift towards the development of high-order thinking. Ross (1860) suggests two major types of purposes of teacher questioning: test students' understanding; and apply the knowledge. About 100 years later, Pate and Bremer (1967) conducted a survey and collected the views of 190 primary school teachers on three important purposes for teacher questions. Their findings show that more teachers focused on diagnosis and fact recall and only a small percentage considered high order thinking, like generalizing and making references. Possible explanations for this shift may include societal shifts, changes in requirements for the labour force, and the development in educational theories.

9.1.3 Addressing RQ 3: What are teachers' reflections on factors influencing teacher questioning strategies?

The teachers' reflections on the factors influencing their questions revealed that the questions were affected by external, internal, and personal elements. For example, in Chinese polished lessons, teacher questioning and teaching were directly affected by: (1) external policies – for example, the policy of three-level, three-category backbone teachers encourages teachers to polish, show and share lessons in public; (2) internal support – for example, the biology teaching research group demonstrated a long tradition of polishing lessons; and (3) personal motivation and effort – for example, Wynne made the most elaborate preparations for a lesson that then had an impact on her teaching appraisal and promotion. Therefore, it was reasonable that within the context of polished lessons there was a higher proportion of open questions. As discussed in section 7.2.2, when biology became an exam subject for the high-school entrance exam, Zachary was unable to conduct discussions in small groups to allow students to investigate how bullfrogs adapted to their environment and, therefore, he was unable to ask questions involving the characteristics of the heads and legs of bullfrogs. As discussed in section 7.2.4, the school policy that encouraged Ziv to carry out open inquiry in his society class resulted in the change of his views and behaviours around scientific practices. For example, Ziv emphasized the importance of collecting and analysing data, rather than focusing mainly on drawing conclusions, when students investigated natural selection in peanuts. Moreover, teachers' views about planned and spontaneous questions and their views about the openness of teacher questions affected their use of them. The reasons for using fewer open questions included time constraints, class types, teaching content, and teacher control, which are linked to RQ 1. These findings showed changes in classroom practices over time within the workplace context, which is distinct from previous studies that tended to focus on how teachers improve questioning through professional development, as described in section 3.6.1 in the literature review. The findings also provided key research contributions around factors from different areas, differing from previous studies that tended to consider factors from only one of these areas, as detailed in section 3.6.1. How these areas interacted was discussed in detail in section 7.3, that is, sometimes they supported teachers while sometimes they generated tension.

9.1.4 Addressing RQ 4: How do students perceive their teachers' questioning in class?

Students used a range of terms to describe their views on teacher questions: for instance, *challenging*, *interactive*, *developing thinking*, *paving the way for later learning*, *broadening knowledge*, *using the occasion to stop zoning out*, *focusing on easily confused knowledge*, and *increasing difficulty gradually*. These examples showed students' sophisticated and thoughtful reflections on the pedagogic role of questions. Another finding that emerged from this study was that using materials could support teacher questioning and create a compelling atmosphere: for instance, a real pig heart and a physical model. Furthermore, students focused on whether the content of their teachers' questions was associated with exams and the effect of the questions, including improving concentration, increasing learning motivation, improving critical thinking, and developing inquiry skills.

This study has shown that students valued questions asked in a way that showed less teacher authority and allowed more student engagement. This conclusion was based on the following three findings. First, students preferred open questions over closed ones. As discussed in section 8.2.1, S1_Helen kept silent in response to closed memory questions used to recall factual knowledge. Several students commented that open questions with no fixed answers could encourage them to think from different perspectives, inspire their imagination and creativity, and find a personal interest in the argumentation of theories. Second, as discussed in section 8.2.1, S3_Ziv highlighted the importance of a safe and relaxed questioning environment where teacher questions were not used as a tool to judge students' prior knowledge so that students could make mistakes and discuss and learn from peers' errors. This is consistent with previous studies that highlighted tentative questioning (Oliveira, 2010) and examined students' positive views about group work (e.g., Hume and Coll, 2008; Roychoudhury and Roth, 1996). The third finding, an original and important perspective, as detailed in section 8.2.2, was that a student remarked there were significant differences in teacher questions between the society class and other classes. For example, teacher questions appeared to be rigid and fixed during normal classes but more flexible in the society ones.

RQ 4 enabled me to explore the relationship between how students talked about teacher questioning and how teachers talk about it, which is an important research contribution, as detailed in section 9.2.2.2.

9.2 Research contributions

Having addressed the RQs, I will now move on to discuss my research contributions, as mentioned at the start of this chapter. I begin by arguing that understanding the complexity of teacher questioning is affected by multi-level factors, then go on to discuss students' perceptions of teacher questions and explore the relationship between what students and their teachers said. I also consider the contributions of the research design that were helpful for exploring teachers' and students' views about teacher questions without separating teacher questions from their context.

9.2.1 Understanding the complexity of teacher questioning

The most important finding was how teacher questioning was influenced by personal, internal, and external factors. This differs from previous studies that miss some important issues for teachers because they tend to consider factors from only one of those areas – particularly around personal knowledge (e.g., Carlsen, 1987; Hashweh, 1987), student responses (e.g., Chin, 2006; Roth, 1996), and teacher professional development (e.g., Oliveira, 2010) – rather than looking at other factors around the school and policy environments. My significant research contribution is reporting how teachers talked about the factors behind their questioning practices and tensions, because such data is rare in published studies and teachers talked about what they did in a fascinating, distinctive, and sophisticated way. I do not focus my attention on teacher knowledge and teacher beliefs, before looking at what they are doing in classrooms. The thesis is about curriculum policy enactment; therefore, I try to find out what else is going on in these teachers' lives and in their school environment, and how external and internal factors influence their classroom practices: for instance, the significance of polished lessons and curriculum policy.

I argue that to understand the complexity of teacher questioning, we should understand how: (1) teacher questions were affected by multi-level factors, including personal, internal, and external factors; (2) questioning practices were influenced from different angles, not limited to types of questions; (3) teachers experienced tensions when they asked questions in the context of scientific practices; and (4) the cultural context affected teaching and teacher professional development. These are discussed in detail in the forthcoming paragraphs.

9.2.1.1 Teacher questions were affected by personal, internal, and external factors

As argued earlier, use of questions cannot be dissociated with other teacher practices; therefore, any consideration of influences on teacher questioning needs to consider influential factors more broadly. Teacher questions are affected by factors that are personal (e.g., teachers' views about teacher questions), internal (e.g., students' and teachers' working practices), and external (e.g., the high school or the national college entrance exams). The results are consistent with the findings of Ryder (2015), who identified how a range of personal/internal/external contexts impacted on teachers' responses to externally driven curriculum reform, as described in section 3.6.1 in the literature review. However, as detailed in the following paragraphs, my findings demonstrate how external policy shift significantly affected teacher questioning practices and showed the impact of a teacher's relationship web and polished lessons on teacher questions with unique Chinese characteristics.

In this study, external factors are very influential. As shown in section 7.2.2, changing an assessment method leads to teacher pressure and much less time spent carrying out scientific practices in classrooms. For example, in the past students spent a long time observing and discussing how bullfrogs adapted to their environment in small groups; however, once biology became an exam subject at the high school entrance exam, the whole class had to observe teacher demonstration within a few minutes. Another example in section 7.2.2 showed how, because biology had become an entrance exam subject, Ziv faced time constraints and conducted a demonstration of how to investigate the energy content of food rather than asking students to work in small groups. This confirmed previous findings that show that assessment stress and time constraints hinder the implementation of scientific practices (e.g., Kim et al., 2013; Ramnarain, 2016) and contributes additional evidence on how the change of assessment policies makes teachers' enactment of scientific practices more difficult. This also reflects that external factors are important in delivering pressures in order to manage the performance of teachers (Ball et al., 2012). It is a further manifestation of global trends in education policy that aim to raise standards of a labour force and have become more competitive and assessment-driven (e.g., Organisation for Economic Co-operation and Development's Program for International Students Assessment; Rizvi and Lingard, 2010).

Teachers do not work alone, working rather with people in their environment: for instance, classrooms, schools, inter-school networks and administration. Figure 9.1 summarizes a teacher's relationship web, involving some internal factors (e.g., the mentor teacher, teachers in the biology department, and school leaders), representing in an oval shape, and external factors (e.g., teacher developers and teachers outside school), in rectangles. This is derived from the thesis findings. The context of polished lessons on the gold background enabled teachers to form a relationship and relate to a person or an organization around them, which then emerged in teachers' reflections.

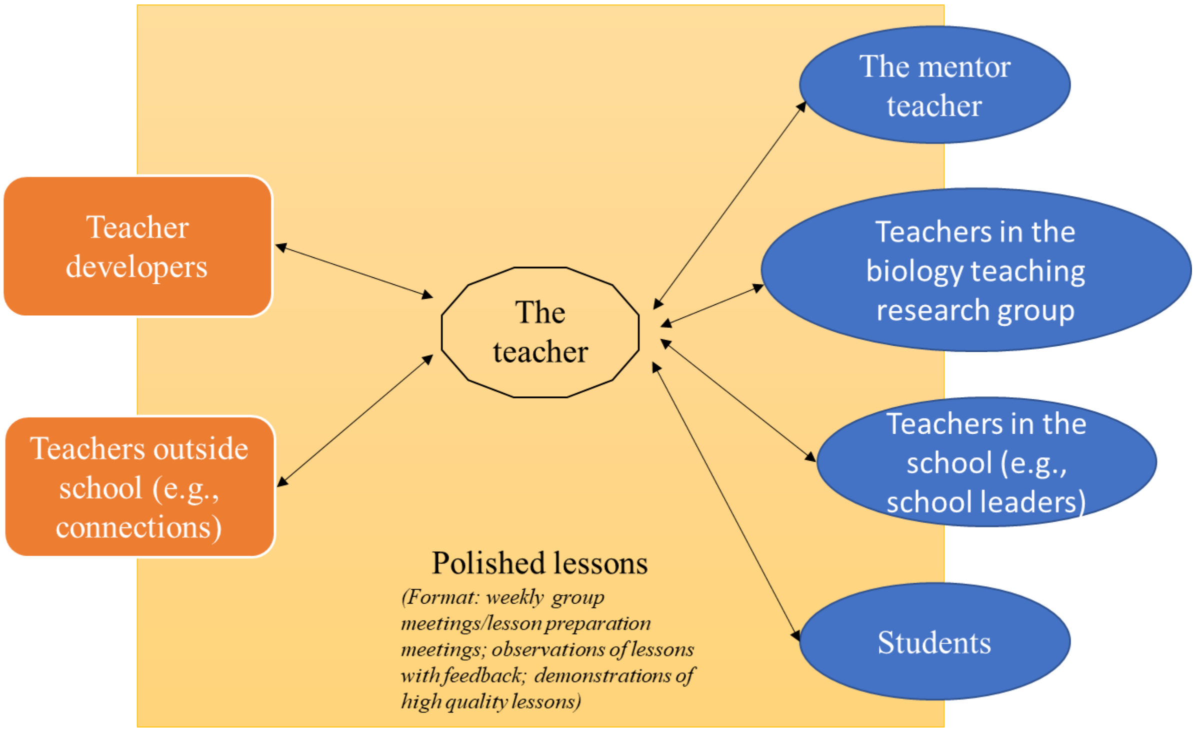


Figure 9.1 A teacher's relationship web

The mentor teacher, with many years of teaching experience and the reputation of being an expert teacher, could help colleagues recently graduated from universities to improve the quality of their teaching and adapt to the new working environment by mutual classroom observation, collective lesson preparation, and discussion and communication (Lee and Feng, 2007). For example, as described in section 7.2.1.1, Sue's mentor teacher gave her some helpful suggestions in terms of what needed to be improved in her polished lesson. The biology teaching research group was a small group of biology teachers that usually worked in the same office and worked together to polish lessons. Teachers within the school taught different subjects and school leaders were sometimes invited to observe polished lessons and give feedback. Teachers outside school involved the teacher's connections. For example, as described in section 7.2.1.1, when Helen polished a lesson, she asked for an expert teacher's suggestions that then changed her teaching; this teacher was one of her connections. As described in section 2.3, teacher developers worked in the local education bureau, monitoring the classroom enactment of curriculum standards, and promoting teacher development through several teaching research activities; for example, one teacher developer invited an expert teacher to demonstrate a polished lesson in public. Relationships in Figure 9.1 are represented with double -ended arrows because interactions are two ways; for example, the mentor teacher not only changed the teacher, but also worked to better understand the teacher's working context and motivations. The control lay with the school leaders and teacher developers, who played a role in monitoring and assessing teachers' classroom performance.

Having analysed the influences of external and internal factors, I will now move on to discuss how the use of teacher questions was affected by personal views. Although teachers highlighted the need for spontaneous questions, they stated they planned most of their questions because they need to use these questions to teach the canonical science knowledge in the textbooks, and they aimed to plan sequences of questions to help students learn the subject knowledge through thinking and reasoning. Teachers used fewer open questions because they were worried that students might lose track. In addition, the openness of teacher questions was partly determined by the learning objectives; for example, when Wynne wanted students to learn that the sternums of birds were very extensive, she used the question "What is the shape of a bird's sternum compared with a reptile's sternum?", rather than an open question like "What do you think are the characteristics of bird bones?" Teachers used different words – for instance, broad and divergent – to express what they meant by open questions.

When teachers used questions, they encountered complex or competing factors. These factors aligned in some cases, which resulted in teachers' implementation of scientific practices. For example, polished lessons could link personal, internal, and external elements, as shown in Figure 9.1, thereby joining personal/internal/external factors together, with their combined strength engaging students in scientific practices and greatly improving teacher questioning and teaching. Furthermore, the polished lesson could start with one teacher, then involve teachers within a subject department and then a school, and end with a demonstration in an interschool network, through which the implementation of curriculum standards in the classroom could be spread across teachers, rapidly and effectively. In one example, described in section 7.2.1.1, the teacher Sue and the mentor teacher, biology teachers, school leaders, and teacher developers worked together to polish a lesson that was finally shown to a large audience. However, in other cases, different levels of factors pushed the teachers in opposite directions, which led to tensions that will be discussed in section 9.2.1.3.

In addition, I see evidence that the internal factor has affected the personal factor, thereby helping teachers to better understand scientific practices. For example, as described in section 7.2.4, the school policy encouraged teachers to carry out open inquiry and to guide students to participate in related national competitions. Thus, Ziv began to engage students in open inquiry in his society class about 15 years ago. He reflected that this experience helped him realize the importance of data and evidence and, consequently, his questions focused more on data collection and analysis than on conclusions. Such analysis shows that teachers' understanding of scientific practices is changing and developing over time in these interacting contexts. It also reinforces the importance of longitudinal studies that capture these interactions and associated teacher development, which agrees with the findings of Ryder et al.'s (2014) study, in which many teachers were changing their views about the curriculum reform three years after their enactment of reformed courses, and Chen et al.'s (2017) findings that the roles of teacher questioning were changed significantly after the four-year implementation of argument-based inquiry, as described in the literature review. A long-timescale analysis of teacher changes was therefore needed.

9.2.1.2 Questioning practices were influenced from different angles

This section is an extension of 9.2.1.1 in that it looks deeper into the specific angles that influenced these teachers' use of questions. The findings are unique and distinctive because the literature tends not to look at specific teacher questions, perhaps because most people, quite sensibly, look at the teaching, not just the teacher questions.

As the teachers reflected themselves, different aspects of teacher questioning practices, including but not limited to types of teacher question, were influenced by personal, internal, and external factors. Which aspect of the questioning practices was influenced is detailed as follows: (1) the number of open questions and the openness of teacher questions – for example, as described in section 7.2.6.2, when Wynne aimed to draw students' attention to the extensive sternums of birds and adapted her question from an open question, "What do you think are the characteristics of bird bones?", to a closed one, "What is the shape of a bird's sternum compared with a reptile's sternum?"; (2) the people the questions are aimed at – for example, as described in section 7.2.5, Simon’s senior secondary school classified students, as according to academic attainments, and students were put into different classes and different pathways: science and literal, which meant Simon used questions differently in the social sciences class, such as not asking students whether the eye-colour gene of a fruit fly was in the XY pairing region or in a different region of the X; (3) the method of asking questions – for example, as described in section 7.2.1.3, when Ziv considered modifying teaching materials to support his questioning and replaced figures and stickers with physical models because using physical models enabled students to hold them in their hands and made it easier to cooperate and discuss with classmates in small groups; (4) deciding when to ask questions – for example, teachers considered asking questions at the beginning of the lesson, in the middle, or at the end; (5) the content of teacher questions – for example, as described in section 7.2.1.2, in a weekly group meeting of the biology teaching research group, teachers discussed which question was better, either asking students to order a healthy and balanced meal in a restaurant or designing a lunch recipe, and because students had more experience of ordering meals, Ziv finally selected the former question; and (6) the framework of questions in a lesson – for example, Zachary used his colleague’s slides after collectively polishing a lesson, then changed his question framework for the lesson, accordingly. These findings suggest that in general teachers adapted their questions from different perspectives. They considered student responses and colleagues’ suggestions and developed their questions over time as they taught repeated lessons. So, the teachers in this study typically used quite sophisticated rationale in their use of questions. Not just their personal knowledge but also the internal/external contexts influenced their use of questions.

9.2.1.3 Teacher tension

Teachers experienced tensions: for example, the 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 internal challenges (e.g., accountability and traditional textbooks that were not inquiry-oriented) and external stress (e.g., exam assessment). My study agrees with Wallace and Kang’s (2004) findings, which showed six American teachers who taught senior secondary science had two major competing belief sets when they carried out scientific practices: personal belief sets (e.g., inquiry could promote scientific thinking) and culturally based belief sets (e.g., students are lazy). As described in section 3.6.4 in the literature review, personal belief sets supported teachers while culturally based belief sets hindered the implementation of scientific practices. My findings, however, differ from their classification because I classified culturally belief sets into both the internal and external factors to make the source of influential factors clear. I also argue that not only have personal belief sets enhanced the classroom enactment of scientific practices, but I have also seen evidence of external and internal pushes: for instance, polished lessons and students' interest in scientific practices. The polished lesson within the Chinese context could support teachers to engage students in scientific practices to some extent – for example, a teacher considered curriculum standards and external validation to be priorities, rather than times constraints and exam assessment, when they demonstrated their public lessons. Generally, more open questions were used in the polished lessons.

Teachers need to balance these tensions (Kim et al., 2013). As discussed in sections 7.3 and 7.2.2, teachers were stressed and gave priority to science knowledge, rather than inquiry skills (e.g., drawing conclusions based on evidence) at the end of a lesson, and did demonstrations rather than small-group practical work. However, tension does not always lead to stress and being pulled in different directions might lead to generating positive and creative energy. For example, Sue devised a sequence of questions and classroom activities to make the best use of time. Teachers eased their tension by: (1) asking students to think about how the scientist ruled out alternative conclusions when students knew the conclusion from the title of the lesson in the textbook; (2) carrying out scientific inquiry that was not very open with students only engaged in some practices: for instance, making a hypothesis, analysing and interpreting data, and drawing conclusions; and (3) controlling and balancing the openness of questions that do not need to be as open as possible. Another way of reconciling tension is carrying out open inquiry activities in the society class and the teacher could ask more open questions, which is consistent with Wallace and Kang (2004).

9.2.1.4 The role of cultural context

Having discussed personal/internal/external factors, teacher tension and how questioning practices were influenced from different angles, I will move on to illustrate the role of cultural context in current teaching practices. The increasing popularity of polished lessons is rooted in Chinese traditional culture. Thus, understanding the culture contributes to the meaning-making of policies, teacher reflection, and the complexity of teacher questions.

As described in section 3.6.3 in the literature review, some features are noteworthy in polished lessons: for example, inviting colleagues to observe and give feedback and thereby dedicating significant resources to maximising the quality of lessons. Opening up the classroom is related to the tradition of academies (e.g., Yuelu Academy) that originated more than one thousand years ago during the Tang dynasty and belonged to the category of higher learning. Most academies were composed of famous scholars and their students, and one major type of academic activity was delivering the opening lecture (Gu, 2004). It was common for a famous scholar's lecture to appeal to many people from different regions and schools of thought (e.g., Confucianism), and the number of attendees could reach almost one thousand. Such kinds of open sermons and discussion can be seen as the origin of the flourishing tradition of polished lessons in China today. The classroom has long been regarded as a public open space (Yang and Yan, 2020), which differs from a culture that tends to consider the classroom as a private space and teachers "are sometimes reluctant to allow colleagues into their classrooms" (Richards and Lockhart, 1991, p. 1).

The intention behind peer observation and discussion during polished lessons is to learn from others. Confucius, a symbol of Chinese traditional culture, pointed out the universality of learning: "When I walk along with two others, they may serve me as my teachers. I will select their good qualities and follow them, their bad qualities and avoid them" (Wikiquote, 2023). He also emphasized the emulation and use of role models in education (Chen, 2017): "When we see men of worth, we should think of equalling them" (Wikiquote, 2023). In addition, Xueji is the earliest known literature that specifically discusses teaching and learning in the world and its famous saying is about observing and learning from each other (Yang and Yan, 2020). These cultural roots might explain why teachers are willing to be involved in polished lessons. Teachers can take a leaf out of an expert teacher's book and gain greatly from the suggestions colleagues and teacher developers make about teaching details immediately after the classroom observation.

As described in section 7.3, Simon explained his understanding of three stages of polished lessons: studying curriculum standards; interacting with the teaching content; and polishing to combine three aspects (the teacher, content, and students) into a whole. Here, teacher planning and classroom teaching are considered as a gradual process and teachers need to devote a great deal of effort to approach the highest level. This is similar to three stages of research according to Wang Guowei, who is known as the master of Chinese culture: (1) the first is to climb high and look out in the distance, to identify a goal, and to understand the general situation, which refers to laying the groundwork for further research; (2) the second demands so much concentration and hard work that one might have sleepless nights and even lose weight but feel no regrets; and (3) one must have determination and enthusiasm to reach the level where one will suddenly understand something, have an epiphany and achieve a positive result (Wang, 2016). This seems to mirror the process of polishing a lesson that requires careful planning, rehearsal, reflection, and repeated refinement (Stigler and Stevenson, 1991). Teachers invest significant amounts of time and energy into developing lessons and try to make a difference to the classroom.

Polished lessons were supported by the five-level teaching research system and directly related to teachers' reputations for high-quality teaching, teacher appraisal, and promotion (Yang and Yan, 2020). As discussed in section 7.2.1.3, Wynne spent about two weeks improving her experimental materials because of her participation in a national competition. Her personal motivation was partly supported and reinforced by external validation. Moreover, it is a matter of personal honour and awards. Teachers may not get financial support for polishing their lessons, but they consider polished lessons as a resource and opportunity with which to achieve respect, status, and recognition.

9.2.2 Students' perceptions of teacher questions

RQ 4 is a detailed account of students' perceptions of a specific teacher question, a sequence of questions or teacher questioning in general. As mentioned in the literature review, prior studies on students' views (e.g., the nature of science) tended to rely on questionnaires and, more importantly, I was not able to find any literature that focused mainly on students' comments about teacher questioning. A qualitative investigation of RQ 4 would therefore be distinctive and significant, extending our knowledge of the student perceptions of teacher questioning and serving as a base for future related studies. This section first discusses the findings that emerged from student interviews presented in the previous chapter, and then moves on to the relationship between what students and their teachers said in terms of teacher questions.

9.2.2.1 Students' views regarding teacher questions

One student presented an original perspective on teacher questions when they drew a comparable distinction in class types. As described in section 8.2.2, S3_Ziv was the only student who experienced two class types: the normal class, and the Science Micro-Video Society. In the society class, students were given opportunities to identify an inquiry question they were interested in and to engage in open inquiry projects. According to S3_Ziv, teacher questions were used to provide science knowledge in the normal class while they were invited to solve students' practical problems in the society class. She also stated that Ziv used questions flexibly in the society class: for example, asking questions according to students' confusions and difficulties. Teacher questions were to help students think about possibilities and options, rather than judging right and wrong, and students could make decisions on their own; as a result, teacher questions transmitted less knowledge and teacher authority in the society classes. It seems possible that teachers could ask more open questions in an environment in which they had different goals compared with when they are under assessment pressure to teach prescribed subject content knowledge. This finding not only contribute to the existing literature by providing the students' observation that the teacher used questions very differently in different class types but also present implications for policy and practice discussed in section 9.3.3. However, this is only a single case and I cannot extrapolate from this, which suggests future studies could explore this in more detail.

Overall, students demonstrated complex and sophisticated thoughts regarding teacher questioning, which supported Batten's (1989) demonstration that students were able to identify some aspects of teaching crucial to a lesson' success (e.g., student interest and clear instructions) and listening to students' voices was important to researchers, teachers, and teacher educators. More studies are needed to present the student voice in relation to teacher questioning. In this study, students preferred open questions compared to closed. They also preferred using materials (e.g., a real heart) to support questioning, creating a funny and interesting atmosphere, and being challenged, which agreed with Osborne and Collins's (2001) findings examining students' views about the role and value of the science curriculum, as described in section 3.7 in the literature review.

9.2.2.2 The relationship between what students and their teachers said about teacher questions

I conducted one-to-one interviews with a total of eight students taught by three teachers (Ziv, Helen, and Simon), and what students and their teachers said about teacher questions showed some consistency. However, they sometimes looked at teacher questioning from different perspectives, and students' comments were shorter than their teachers' detailed reflections, as illustrated in the following paragraphs.

As discussed in section 7.2.6, Ziv stated in the interview that a sequence of teacher questions in the classroom was like an upward arrow that pointed to the conclusion. Three of Ziv's students were interviewed, and while S1_Ziv did not make an analogy, S2_Ziv and S3_Ziv each drew a different analogy regarding teacher questions: staircases and a one-way path, respectively (see Figure 9.2). These analogies showed some similarities: (1) a teacher question or a sequence of teacher questions had a single direction, rather than various directions, which suggested that teacher questions were not divergent; (2) teacher questions were guided by knowledge; and (3) the teacher seemed to control his questions and students were not given opportunities to alter the direction. In summary, the teacher and two students showed a high degree of consistency.

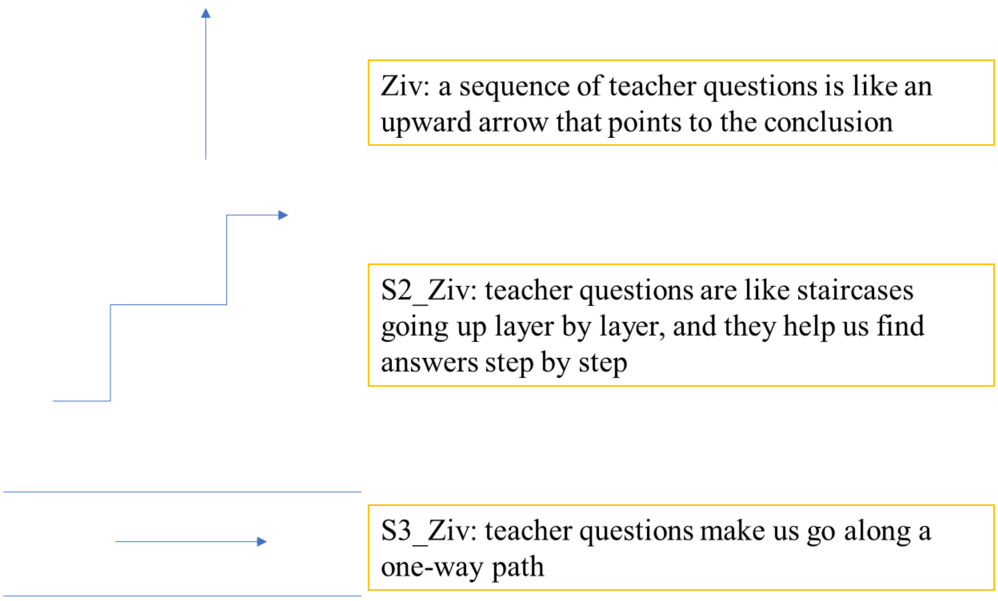


Figure 9.2 The analogies of teacher questions

Three of Simon's students were also interviewed, and what they said about scenario-based questions was highly consistent with the Simon's own statement. Students stated this type of questions (e.g., "Imagine you are the scientist Walter Sutton…") helped them think about the reasons why the scientist did what they did, which chimes with the idea of Simon encouraging students to think and make decisions from the scientist's perspective.

Regarding the differences between what students and their teachers said about teacher questions, the findings show that (1) teachers' views were more detailed and insightful than the students' short comments; and (2) students talked about one or two points while teachers offered more comprehensive thoughts about their questions. These findings mirror those of the previous studies that have examined teacher and student perspectives regarding a particular classroom experience (e.g., Batten, 1989; Brown and McIntyre, 1993). When Helen and S2_Helen commented on these two questions – "How to label T2 bacteriophages with phosphorus-32 or sulfur-35?" and "Why was a small amount of radioactive phosphorus-32 detected in the lighter solution and why was a small amount of radioactive sulfur-35 detected in the heavier bacterial pellet?" – they both mentioned that the questions were used to prepare for exams. Helen also considered a pedagogic issue – when should she ask these questions, in the middle of the lesson or at the end? As another example, in terms of the two questions "Why can bacteria cause sepsis when they have capsules?" and "What is the site of injection [of a mouse]?", Simon's three students tended to describe their personal feelings and responses (e.g., novel, interesting and expanding thinking) while Simon's reflections not only covered what the students said but also involved his complex purposes, the pedagogical design, and related ethical issues.

In addition, there was some evidence that suggested that what the teacher and students paid attention to were different. As described in section 8.2.1, S1_Ziv commented on the question "What are the difference and connection between the role of the teeth, the tongue and the saliva?" from the perspective of an open question. Ziv had linked the question with his learning objective, that is, he aimed to help students understand the difference and connection between mechanical and chemical digestion and to develop students' oral and written communication skills, because he stated what students thought, what they said, and what they wrote might be different things, and sometimes students could understand but might not be able to articulate their ideas explicitly and write their answers clearly during the exam.

9.2.3 Methodological contributions

A key idea in this thesis was that it is unhelpful to isolate teacher questions from longer sequences of teaching. For example, when I asked Joan about the purposes behind her questioning without showing episodes, she considered the purposes of teacher questions more broadly (e.g., students' interest) rather than being specific to a particular question or a sequence of questions. Using teaching episodes is a powerful interview technique that helps teachers recall their experience and identify teacher questions that they would like to discuss. It aims to stimulate ideas and find out what is important to teachers, what they try to convey to others, and what was going on in their mind while the episodes happened. It is related to previous studies on stimulated recall interviews (Dempsey, 2010) and interviews about instances that use specially selected cards to elicit student views about science concepts (Osborne and Gilbert, 1980). The methods used in the current study would be useful for future research that concentrates on the investigation of teacher questioning and may be applied to other topics (e.g., students' views about teacher feedback), other disciplines, and other countries in the world. In the following paragraphs, I illustrate that the use of teaching episodes revealed that teachers looked at teacher questions from a multimodal perspective and the use of student drawings and teaching episodes enhanced students' participation in the interviews.

9.2.3.1 Use of teaching episodes to look at teacher questions from a multimodal perspective

Using episodes and inviting teachers to talk about episodes provided a path toward teachers' feelings and a tool for encouraging teachers to interpret what was happening, what they were interested in, and what was not evident in the text (e.g., gestures and artefacts), but it was also important in terms of teacher questioning. I also collected some photos (e.g., a physical model) and documents (e.g., lesson plans and slides), which enabled me to look at the teacher questions more holistically. An important finding was that teachers stressed the importance of gestures, drawings, teaching materials or resources to support their questioning. As discussed in the literature review, previous studies on teacher questioning tended to take place within the sociolinguistic context and were more about, for instance, the cognitive level of teacher questions, teacher authority, the social function of teacher questions, and different types of teacher questions. However, teachers did not just consider the language per se. They considered, for example, using physical models to help students think about a question and using student drawings to ask a sequence of questions. As detailed in the following paragraphs, they did not separate questions from the context in which they asked them.

Teachers selected appropriate teaching materials through which they developed a series of questions to help students think, reason, explain, and draw conclusions. As discussed in section 7.2.5, Wynne firstly used the wings of dead chickens to teach how bones, joints and muscles produced movement. Students were confused because they could not understand why muscles could not push a bone back to the original position. Wynne then used a frog hind leg with a preserved nerve and asked a sequence of questions: for example, "Look at the experimental result; is it the same with your hypothesis you made just now?", "Can you describe what you observed?", and "I am giving the nerve a stimulus now. Could this bone be pushed back?" she was unable to ask these questions when she used the chicken wings to help students engage in scientific practices, such as making a hypothesis, analysing experimental results, and drawing conclusions based on evidence.

As discussed in section 7.2.8, when Sue asked questions about ecological balance (e.g., “If there is less grass, how will the number of sheep change?” and “The number of sheep has decrease; so, what about the amount of grass?”), she was using seesaw gestures to reduce the difficulty of her questions, rather than using a graph that showed the population dynamics between sheep and grass. Her deictic and iconic gestures could attract attention and a lower cognitive load because students might use them as additional resources for understanding teacher questions. Moreover, her seesaw gestures, coupled with questions (e.g., “Do the number of sheep and the amount of grass remain constant? What’s it like?”), related a familiar object to the abstract concept of ‘ecological balance’.

To offer another example that shows the role of drawings in teacher questioning, Wynne used three student drawings to introduce a lesson. Initially, her questions were to review the characteristics of amphibians, but she developed a sequence of new questions according to the drawings (e.g., “Can frogs live in this environment?” and “Why can frogs not survive in the water-scarce terrestrial environment?”). These drawings helped the teacher develop questions that aimed to draw out students’ ideas rather than have them recall knowledge, setting the context of her questions and conveying the theory of evolution, which was the focus of the lesson.

In discussing the importance to teacher questioning of materials, gestures, and drawings, I suggest viewing them as an integral part of questioning practices, which is consistent with the findings of Roth (1999), who argues the language itself is insufficient as a means to understand classroom discourse. Teacher questioning happens in a shared physical world. What students notice includes spoken and unspoken context. If any non-verbal element is removed, students may have different meaning-making processes. Embracing a multimodal perspective can help teachers in three ways: (1) promoting awareness of the role of unspoken aspects of communication (e.g., bodies and gestures) in questioning; (2) discussing and improving teacher questions from diverse modalities, not limited to the wording of questions; and (3) considering creating an appropriate questioning setting and environment.

9.2.3.2 Use of student drawings and teaching episodes to interview students

It was a difficult task to collect students' perceptions of teacher questions because (1) it was challenging to interview students who were not talkative and provided shorter and less elaborate answers to most of interview questions; and (2) compared with a broad topic (e.g., teaching and learning), it was hard for students to comment on the specific topic of teacher questions because they might have neglected, forgotten or not had time to reflect on the questions, even though they heard plenty of teacher questions as a matter of routine. Thus, I used teaching episodes to talk with students and asked them to draw a diagram that represented how their biology teachers worked with them when they were learning science knowledge. This was trialled a little in my design and produced some interesting insights, which suggests this could be a methodology used more extensively in future studies involving using in-depth student interviews.

I selected three or four episodes that were taken from classes students were in and had been used to interview their teachers before. Episodes were used successfully because they could evoke memories and support students in identifying and evaluating teacher questions within a particular context and did not depend on students recalling teacher questions.

I trialled pre-interview and post-interview drawings. Both methods invited students to relate their experiences, supported reflection, and enabled to make their own ideas clear (Kearney and Hyle, 2004). In addition, student drawings provided a larger complete picture of how teachers typically teach science knowledge (e.g., the teacher's position in the classroom and teacher-student interactions). The whole was useful when looking to understand the part (Ellis et al., 2013) – students' views about teacher questions – in terms of the hermeneutic circle (Smith et al., 2009). This circle means one can only understand the part by understanding the whole: for example, one can only understand students' views about teacher questioning by understanding students' views about teaching. However, pre-interview drawings offered the following benefits when compared to post-interview drawings: (1) establishing successful rapport and building an interactional relationship that refers to both the student and I being engaged in meaning making of the drawing (Brenner, 2012) at the beginning of the interview; and (2) sparking reflective insights, identifying students' noticing, and providing important information for the rest of the interview: for example, S1_Simon mentioned Simon in his drawing like he was a friend rather than a traditional teacher.

The combination of using episodes and student drawings was used to trigger memories and enhance students' engagement in the interviews through visual and textual elicitation. Importantly, it helped students comment on teacher questions without separating them from the question context because a single teacher question was meaningless unless it was linked to the context.

9.3 Implications for policy and practice

The research contributions of this study have several important implications for teaching and learning, teacher professional development, and policy making.

9.3.1 Implications for teaching and learning

I highlighted the complexity of teacher questions as a key research contribution with important implications for teaching and learning. The complexity of teacher questions refers to (1) teacher questions being affected by personal, internal, and external factors; (2) questioning practices being influenced from different angles, which was not limited to the types of questions; and (3) teachers experiencing tensions when they asked questions within the context of scientific practices. It reveals that there were no simple generalizations or recipe approaches in terms of how to ask good questions that engage students in scientific practices. Even the same teacher might ask questions quite differently in different classes because students are different. However, the core of teacher questions was concerned with drawing students' ideas out rather than judging students and checking their understanding (Roth, 1996).

Drawing things out relies on multimodal resources rather than the language used on its own (Mortimer and Scott, 2003; Prain and Tytler, 2022; Tang, 2022; Wilmes and Siry, 2021). As described in section 9.2.3.1, the role of multimodal resources when positioning questions in the classroom was another research contribution that suggested that teachers can draw on gestures and resources (e.g., physical models and student pictures) in order to support questioning: for instance, attracting students' attention, interesting students, lowering their cognitive load, and developing a sequence of questions based on teaching materials to help students make hypotheses, and explain and draw conclusions. When preparing for lessons, teachers may consider supporting their questions from other aspects besides language to engage students in learning. For example, a teacher may ask a student to gently touch the back of a frog and ask about how it feels, to which the answers may be that it feels cool or smooth. The teacher then challenges the students by asking them why. This kind of questioning draws on real objects and students' tactile experiences more effectively than presenting a picture and asking what covers the body of a frog, what the function of the mucus is, and whether frogs are warm- or cold-blooded.

Another very important factor was that teachers need to value spontaneous questions, which represented one of this study's research contributions. Some teachers might be uncomfortable and lose control when they asked open questions because sometimes students give unexpected answers or go off-course (Nilssen et al., 1995). They might not know how to introduce questions in the moment in response to student answers. In that case, teachers need to recognize the importance of spontaneous questions, use spontaneous questions as an important mode of communication in the classroom, and learn the related pedagogic knowledge from their own experience. As suggested by Roth (1996), beginner teachers can improve their questioning skills by observing the questioning practices of expert teachers. So, they may learn expert teachers' knowledge from lesson observations, classroom video analysis and discussions. They may discuss spontaneous questions with their mentor teachers when they reflect on their own lessons or comment on mentor teachers' lessons. They need to recognize the importance of spontaneous questions and plan for them.

Scenario-based questions represent another important research contribution. Teachers can use scenario-based questions to help students think and make decisions from the scientist's perspective. This type of question can also be used in other occasions. For example, if a teacher asks a question in the textbook, "If your finger is suddenly pricked by a sharp object or burned, do you withdraw your hand first or feel the pain first and why?" (Zhu and Zhao, 2012, p.91), students will consider that (1) hand withdrawal involves the receptor detecting the stimulus, the sensory neurone sending impulses to the spinal cord, and the motor neurone sending impulses to the effector, before the finger is moved away; (2) feeling pain involves the receptor that feels the stimulation, the sensory neurone, and the spinal cord sending the information to the brain; and (3) which is faster. This question might be complex, boring, and not easy to understand. If the teacher asks a scenario-based question – "Imagine you are a spinal cord; if your finger is pricked, which one do you do first – withdraw the hand or tell the brain?" – things would be different. It makes a difficult question simple. Moreover, students can think from the perspective of the spinal cord: "I should withdraw the hand first, because if I tell the brain first, the hand has already been pierced by the time the brain makes a response".

I have been a teacher for several years in a secondary school in China, but I have never thought about scenario-based questions as a focus. Teachers I worked with, especially on teacher development courses I took, did not mention anything about different types of questions. Therefore, this focus on a particular type of question would be very helpful for developing my teaching based on my experience. I hope it will be helpful for other teachers. The challenges for teachers in using such scenario-based questions might be they have never thought about it before, and that they are so busy. The study shows evidence that students valued scenario-based questions, as described in section 8.2.3, and this finding can be used to encourage busy teachers to think about scenario-based questions.

One research contribution was that the study illustrates that students showed complex thinking and sophisticated judgements when they commented on teacher questioning. As described in section 8.2.2, one student valued opportunities to identify an inquiry question and engaging in an open inquiry project in the society class. The teacher used questions to help students think about possibilities and alternatives and then make decisions on their own in an open inquiry activity, which was different from the use of questions in normal classes. Thus, for those students who have interests in science and motivation in their learning, open inquiry was a good opportunity to work with peers, learn deeply without the limitation of textbooks and tests, and enjoy the pleasure of identifying an inquiry question, arguing, and reasoning (Berg, et al., 2003; Sadeh and Zion, 2009; Zion and Mendelovici, 2012).

Students noticing different levels of teacher authority in teacher questioning (e.g., S3_Ziv drew an analogy of teacher questions in the normal class, saying that in those classes teacher questions made students go along a one-way path) suggested teachers should open up students' discursive spaces and accommodate different views, rather than focusing entirely on the textbook-based knowledge or predetermined answers. From the students' perspectives, if the teacher conveys to them that knowledge is authoritative and they do not need to contribute to knowledge co-construction, they engage with it differently (Russ, 2018). As discussed in section 7.2.5, a student's question helped the teacher Wynne develop her teaching materials and her teaching. Students should have the courage to ask questions when they feel confused. This might not be encouraged by teachers due to time constraints and exam stress. Students might not want to speak aloud for fear of making mistakes or losing face in front of the teacher and classmates. Teachers should emphasize students' contributions and encourage them to discuss science in class, rather than simply judging their responses as right or wrong (Oliveira, 2010).

9.3.2 Implications for teacher professional development

Teachers used different words (e.g., broad and divergent) to express the idea of open questions. One possible reason is that they were familiar with related pedagogic knowledge but did not know the concept of *open questions*. Related training about closed and open questions should be made available to teachers, and I provide an example of resources that could be used in teacher professional development in Appendix 17. The table shows the different types of teacher questions and some of the examples identified in the study. Teacher trainers might ask, for example, "Can you give us an example of this type from your own teaching?" They could also use teaching episodes and ask teachers to discuss in small groups, for example, the role of different types of questions in the episodes and how the teacher used open questions to engage students in scientific practices. Additionally, evidence shows that students' views about teaching and learning can act as a catalyst for change in teacher practices and beliefs (Messiou and Ainscow, 2015). In this study, students stated the benefits of a range of question types in interviews, which provides not only a research contribution but also powerful data. Therefore, teacher educators may also present what students said about different types of teacher questions and help teachers to recognize the need for open questions and thereby avoid using too many closed memory questions.

As explained earlier, understanding the complexity of teacher questioning is a key research contribution. I therefore suggest that educators in teacher training programmes should recognize the complexity of how teacher questioning is affected by personal, internal, and external factors, understand teachers' difficulties and struggles, and help teachers negotiate tensions. I provide in Appendix 18 a case study of how Ziv, an expert teacher, has negotiated these challenges positively. He 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 (e.g., are your water bottles clean?). His experience of facilitating students in open inquiry affected his understanding of scientific practices and teaching in normal classes. During teacher training sessions, the teacher trainer 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.

The contributions of this study show that polishing lessons is a powerful way of delivering what the curriculum standards aim to implement in the classroom. It not only gives beginner teachers access to expert teachers but also gives expert teachers opportunities to develop teaching. During my study, I have seen the evidence that expert teachers tried to develop lessons and engage students in scientific practices, and that they used more open questions in polished lessons. Therefore, how should polished lessons be employed in teacher professional development programmes? If there are many teachers in the audience (e.g., two hundred), how should post-observation discussions be collected and the opinions of the audience collected? How should the process of how the lesson was polished be shown to the audience, as opposed to only showing a finished product? Possible solutions include (1) providing different ways of collecting feedback – for instance, emails and online discussion; and (2) the expert teachers talking, after the polished lesson, about how the lesson was developed, including the initial lesson plan, changes, difficulties, and frustrations. In addition to focusing on teacher performance and pedagogical skills, lesson observations and discussions should centre on student learning, for example, how to help students overcome their learning difficulties (Cajkler et al., 2014). I also considered how such a scheme might transfer to other country contexts. For example, there are a few empirical studies on lesson study in the UK (e.g., Dudley, 2013; Ylonen and Norwich, 2012) because it can be challenging to implement polished lessons in busy schools. Also, it may be quite difficult for beginner teachers in the UK to watch expert teachers teach because some teachers might not like to be watched. This suggests the need for culture-based teacher training sessions that highlight the advantages of polished lessons and have respect for cultural differences. For example, watching expert teachers' lessons could be open to a small audience.

It is important to note the teachers were interviewed in a friendly and reflective atmosphere. They were encouraged to share good teaching practices and expertise and give their own accounts of lessons that were observed. They stated that interviews were helpful for improving their teaching. These expert teachers could clearly articulate what they did in the classroom and why they asked a particular question or sequence of questions. Such articulation represented a reconstruction of their thinking and a way of using language to develop thinking and then to develop teaching (Brown and McIntyre, 1993). This might make ambiguous purposes clearer and make good practices stronger. An implication of this is the possibility that teacher educators use teaching episodes or videos to encourage teachers to talk about what they did and why they did it in an environment that emphasizes respect and expertise sharing (Zhu and Qin, 2008), rather than criticism.

9.3.3 Implications for policy makers

Policy makers refer to editors of curriculum standards and decision makers who are responsible for teaching, learning and assessment in secondary schools (e.g., the high school entrance examination) across the different levels of educational administration departments in China.

There is a definite need for editors of curriculum standards to clearly explain, for example, how scientific practices are a pedagogic approach or a learning goal, and that they focus on what scientists do or include everything. As described in the literature review and in the findings, teachers and researchers had different understandings of the definition of scientific inquiry (Crawford, 2014; Lederman et al., 2019; Pei and Liu, 2018) or scientific practices that were poorly defined in the national curriculum standards. For example, as described in section 7.2.7, Simon focused on how scientists worked and the nature of science while Sue employed a broad usage of the term.

Making biology an exam subject in the high-school entrance exam, which is a significant external factor, changed teachers' classroom enactment of scientific practices significantly. For example, after the shift of biology into an entrance exam subject, 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 was making biology an exam subject while the curriculum policy was around scientific practices, with the two policies pushing in different directions. An implication is that policy makers need to consider how policies might interact as well as thinking about their advantages and disadvantages. For example, on the one hand the policies on examination and accountability can improve students' academic performance, but on the other hand, it might form a barrier to scientific practices and teachers and students may pay too much attention to scores. Currently, traditional paper-and-pencil tests are still employed to evaluate students' certain aspects of inquiry abilities, for instance, asking students to make hypotheses or design experimental plans. Secondary school teachers can prepare students for these tests using traditional lectures and exercises (Luo, 2013). Policy makers should consider diversifying the methods used to assess scientific practices, as suggested by evidence in the literature. This could include informal formative assessments (Ruiz-Primo and Furtak, 2007), scales for assessing scientific inquiry abilities (Zachos et al., 2000), and a combination of paper-and-pencil tests and performance assessments (Kruit et al., 2018).

As explained earlier, one methodological contribution of this study is the use of multiple data sets and teaching episodes to look at teacher questions holistically. This method enabled me to position teacher questions within a broad context in which personal, internal, and external factors interacted. As described in section 7.3, the urbanization policy led to a rapid increase in the numbers of primary and junior secondary students in the city over the last few years, but the number of senior secondary schools had not increased accordingly. Therefore, students who wanted to pass the senior high school examination faced fierce competition and teachers felt assessment-related stress and tension; for example, teachers' personal goals of fostering inquiry skills and asking open questions to improve divergent thinking conflicted with their internal challenges (e.g., accountability) and external stresses (e.g., exam assessment). There is therefore a need for policy makers to balance multiple factors, such as the enactment of scientific practices, the assessment of students' academic performance, the intense competition in the academic pathway, and the long-term development of the students and society. The educational administration departments need to reduce the academic pressures the teachers and students felt by expanding the number of senior secondary schools in order to match the rapid growth in junior secondary student numbers. In addition, school policies should avoid the frequent use of each class's average score in the monthly school exam to judge teachers (Li et al., 2011) so that teachers have time to think about more and better implementation of scientific practices, rather than spending too much time struggling to improve their students' academic performance.

Another important research contribution is that a student noticed the use of teacher questions was different in two different types of classes: the normal class and the society class. Also, as discussed in the previous section, the experience of facilitating students in open inquiry in the society class improved Ziv's understanding of scientific practices over time. These findings suggest even in schools where teachers were busy, focused on exams, and had high pressure, there was flexibility for some classes and students appreciated that. One possible implication is that policies need to encourage schools and teachers to organize various types of classrooms (Zhou and Li, 2020). If there are classes (e.g., society classes) that are set aside and have a slightly different status, they could provide an opportunity for teachers to try out new things (e.g., carrying out open inquiry) and be more flexible.

9.4 Thesis limitations

Reflecting on the thesis limitations that involve weaknesses related to sampling, data collection and data analysis help to lay the foundations for future research study (Creswell and Creswell, 2018). Several important limitations need to be considered. First, in this study, teachers were purposefully selected based on those who won a prize in the national teaching competition or was awarded the title of expert teacher. This sampling did not include teachers who did not receive any awards but employed diversified questioning strategies. Also, focusing on this special group of teachers limits the broader applicability of the findings. For example, the purposes and strategies used by expert teachers in polished lessons may not be feasible for other teachers in their day-to-day teaching. Six participant teachers lacked variety in terms of school locations across the province. Six participant teachers worked in different districts in the capital city of Shaanxi Province. Two teachers working outside the city were withdrawn from the study because they did not respond to attempts to contact them. I did not include any rural schools in the province. Second, although I distributed student information sheets, made a video, and clarified anonymity to recruit students, I only interviewed eight of three of the teachers' students and did not interview any students of the other three teachers. I was therefore only able to explore the relationship between what students and their three teachers (Ziv, Helen, and Simon) said about teacher questioning. Considering the small sample size in this study, students might not show any significant differences in terms of academic performance or interest in biology. A larger sample would likely show up different voices about teacher questioning and new features of student attention to teacher questioning.

In terms of limitations related to my design for data collection, the study involved school policies (e.g., the school policy on teachers' involvement in open inquiry) and a broad context in which teacher questioning happened; however, I did not interview any school leaders. Thus, I could not hear the voices of school authorities nor explore in depth how teaching and teacher questioning were influenced by school leaders. Furthermore, due to time constraints, I was unable to collect data over a longer period. The study involved teacher reflections on changes or development in classroom teaching over time; therefore, it might be more convincing if I did three years of data collection to capture these changes.

9.5 Future research study

What the study shows is that teaching can be seen in holistic terms and as something that has been done within a context. It is therefore important not to see teacher questions and teaching as separate things. When I started the programme, I wanted only to focus on teacher questions: for instance, counting them, analysing them, and comparing different teachers. However, as I looked at the literature, I came to realize I needed to see teaching within context and more holistically. Therefore, future studies need to take it further. Teacher questioning is not just something happening in the classroom but is affected by other things happening in the school: for instance, teacher professional development programmes, school policies, and cultural perspectives. Therefore, if I want to consider teaching holistically, I need to obtain multiple data sets and use teaching episodes. Moreover, I need to visit schools to get a sense of the school leaders and talk to them. I could not do this because of COVID-19. I also wanted to see how things changed over time. Teachers might change their views and classroom behaviours significantly over only a few years; therefore, a longitudinal study is needed. Overall, seeing teaching holistically needs to be considered in future research studies.

As discussed above, a three-year longitudinal study is needed that can capture the interactions between external, internal, and personal factors and associated teacher development: for example, how teachers' use of questions and understanding of scientific practices change over time within the interacting contexts. The potential design might involve interviewing a sample of about 10 teachers from different schools across a variety of locations, school types, school age ranges, and level of students' academic performance. I would carry out one lesson observation, and one face-to-face, one-to-one interview for each teacher in the first, second and third year of the project. I would use teaching episodes to interview teachers and each interview would last about one hour. I would also interview one or two school leaders in each school. Interview questions would involve school responses to the curriculum reform, the challenges of implementing scientific practices, any support the school provided for teachers, school policies, teacher professional development, and views about polished lessons.

Further research should be done to investigate students' views regarding teacher questions. As described in the literature review chapter, I was not able to find any literature specially focusing on students' views of teacher questions and a possible explanation for this may be it is difficult to get detailed comments on teacher questions from students. Face-to-face interviews with more students are needed that would use two different approaches. The first way would be to use episodes and pre-interview drawings to elicit lengthy and in-depth responses in a one-hour, one-to-one interview. The other would be to interview students about their feelings and for their responses to teacher questions within a few minutes after a lesson. In addition, as described in section 9.2.2.1, future studies need to collect more data on students' views about differences in teacher questioning between the society class and normal class.

There is also abundant room for further progress using a multimodal perspective to study teacher questions. When a teacher asks questions, students not only hear the language but also see the teacher's gestures, facial expressions, and teaching materials. They might be even smelling something different or touching the skin of an animal. It would be interesting to use video recordings to explore how teachers use multimodal resources (e.g., gestures, drawings, experimental materials, space, eye contact and the sense of smell and touch) to support their questioning. A mass of literature has been produced on how teaching and learning happen in a multimodal context. For example, Moro et al. (2020) used social semiotic multimodality (Jewitt, 2008; Kress, 2010) and joint action theory to analyse the video data and demonstrated how teachers used gestures, gaze, speech, and proxemics to help students make meaning in science classrooms. They found too that teachers used gestures to help students understand abstract scientific concepts; for example, when the teacher uttered a word scatter, he opened out his arms or hands, which was related to light scattering. Siry and Gorges (2020) used frame-by-frame video analysis to show how a multilingual student used a range of resources (e.g., semiotic resources, objects, linguistic resources, and spaces for interaction) to express her understanding of a sound investigation. These analysis frameworks, methodological perspectives and distinctive findings could be used more reflectively to look at teacher questions.

9.6 Personal reflections

Qualitative data analysis is not an easy process for a novice researcher, because it demands creativity and intellectual endeavour to deal with complex and chaotic human experiences, and there are no precise steps or recipe-book approaches. I have learned to compare, pick, and find my own analytical procedures by reading textbooks, discussing with supervisors, and attending relevant courses. To some extent, the process was like learning to swim. The beginners can never improve their swimming skills if they only watch videos and listen to swimming teachers' instructions, without being immersed in water. The important thing in qualitative data analysis is to be immersed in data. I learn as I experience. The whole data analysis journey is time consuming, challenging, but fascinating, as new skills make me look at the world in a different way.

I have learned to be more systematic and have started to justify the rationale for my selections when I analyse and present my data, rather than fishing for something interesting. In my PhD journey, I also learnt to think critically. For example, when I was a teacher in a secondary school, polished lessons had become part of my routine, whether I was willing to polish my own lessons or not. When I became a researcher, I started to think about the reasons behind the increasing popularity of polished lessons, the advantages and disadvantages, and how teachers work in other countries. These are valuable skills in my research career and my life.

A few years ago, I thought I would teach and retire in that secondary school, and never thought I would study for a PhD abroad. However, life is like a box of chocolates, and I never know what I am going to get. When I sat quietly and wrote my thesis in my office at Hilary Place or when I looked at squirrels, rabbits, and birds outside the window, I still had vivid memories of my teaching. I remember the happiest moment was when my teaching provided some inspiration for the students. For example, I remember when a student was making a presentation in the front of the classroom and I was sitting and listening at the back; the whole class was amused by the student's humorous talk. Sometimes, I had terrifying nightmares; for example, I once had a high fever but had to stand on the platform and teach for several hours. However, eight years of teaching has been a treasure in my lifetime. When I became a researcher, I could better understand the busy schedules and difficulties that teachers face, rather than criticising them.

Teacher questioning is not a new research topic. Two thousand years ago, the Greek philosopher Socrates introduced Socratic Method, which was based on teacher questioning. In its basic form, it is a teacher helping students shape and develop their ideas through continual probing questions. In my study, I have seen some similarities; for example, teachers ask questions to draw out ideas. However, the question purposes may vary as time goes on. Currently, teacher questioning is undergoing significant changes because it happens in a competitive education system and in a globalized world. I hope the findings of this study (e.g., the purposes of teacher questions, the reasons behind questioning practices, and students' voices regarding teacher questioning) offer fresh insights and have implications for teaching and learning.

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Appendices

Appendix 1: A Sample Lesson Plan from Biology Curriculum Standards for Compulsory Education (2022 Edition)

I translated a scientific inquiry lesson plan taken from *Biology Curriculum Standards for Compulsory Education (2022 Edition)* (MOE, 2022, pp.53-54):

An investigation into environment factors influencing the distribution of woodlice

Length of lesson: one class period

Objectives: make an inquiry about environmental factors influencing the distribution of woodlice

Equipment and materials: woodlice, choice chambers, filter papers, cardboards, etc.

Methods and procedures

(1) Students are divided into several groups. Each group investigates the habitats of woodlice and collects some of them before class. (Be careful not to damage lawns or gardens in the school or community.) Students raise their questions on the habitats of woodlice.

(2) Students communicate the habitats in which woodlice were found and make hypotheses about environmental factors influencing the distribution of woodlice.

(3) Students design experiments using equipment and materials provided by teachers and other laboratory resources to test hypotheses.

(4) Students conduct experiments based on the experimental designs, then monitor and record the movement of woodlice within a limited time.

(5) Students work in groups to communicate results. They analyze their own data and the whole class data and discuss if the data support the hypotheses.

(6) Students discuss how sunlight, temperature, water and other environmental factors affect the distribution of woodlice, communicate, and write lab reports.

Do not forget to release the woodlice back into their natural habitats after class.

Comments

The goal of this activity is directly related to the core literacies of inquiry practices. Students can understand scientific ideas and research methods and develop scientific inquiry abilities through the process of scientific inquiry itself. Through this learning process, it is necessary for students to understand that scientific research begins with questions and addressing scientific questions usually requires hypothesis-making that is often required to explain the causal relationship between related things. For example, woodlice are found in dark places, and it is difficult to find woodlice within a bright environment; therefore, we can make a hypothesis that light affects the distribution of woodlice. The purposes of the design of a scientifically feasible experimental plan based on questions and hypotheses are to collect data and evidence through carrying out this plan and to reach correct research conclusions based on the analysis results.

Appendix 2: Pilot Study: Focus Group Student Interview Guide

(1) What do you get from your biology teacher or biology lessons?

(2) What do you think of your teacher's questioning?

(3) Tell me about the sort of teacher questioning you like. Tell me about the sort of teacher questioning you don't like.

(4) How have teacher questions affected you personally?

Prompts:

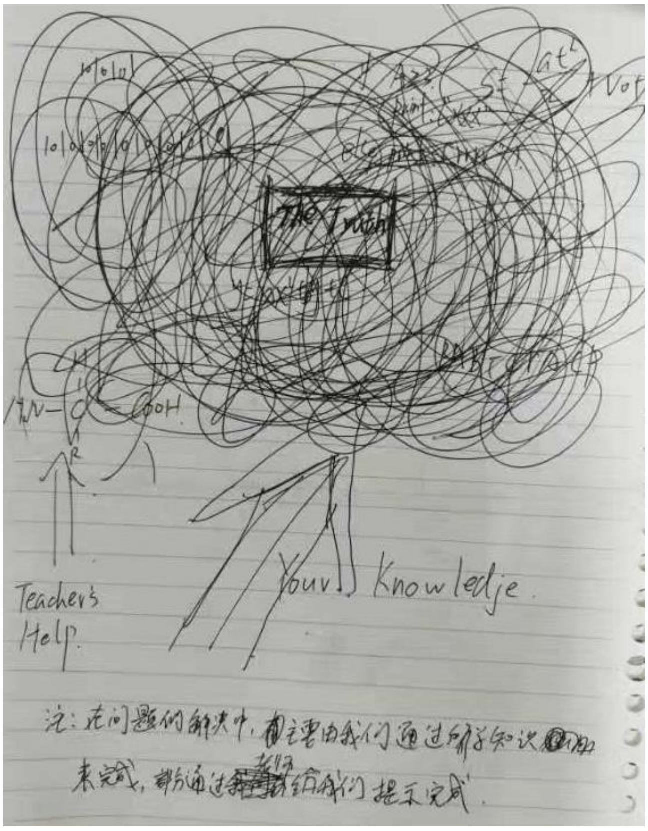
a. To what extent do these questions help you learn to argue?

(5) Do you have any challenges when you do scientific practices?

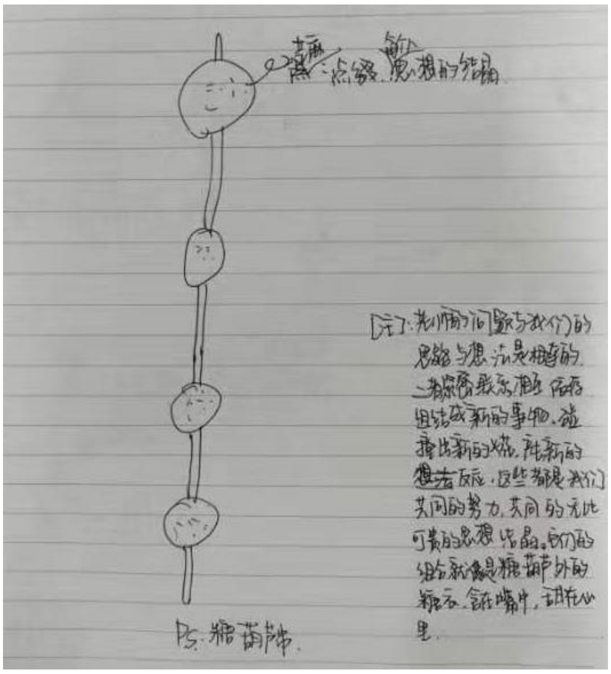
(6) Draw a picture that shows your understanding about your biology teacher's questions and write down your explanation in two or three sentences.

Appendix 3: Pilot Study: Student Drawings

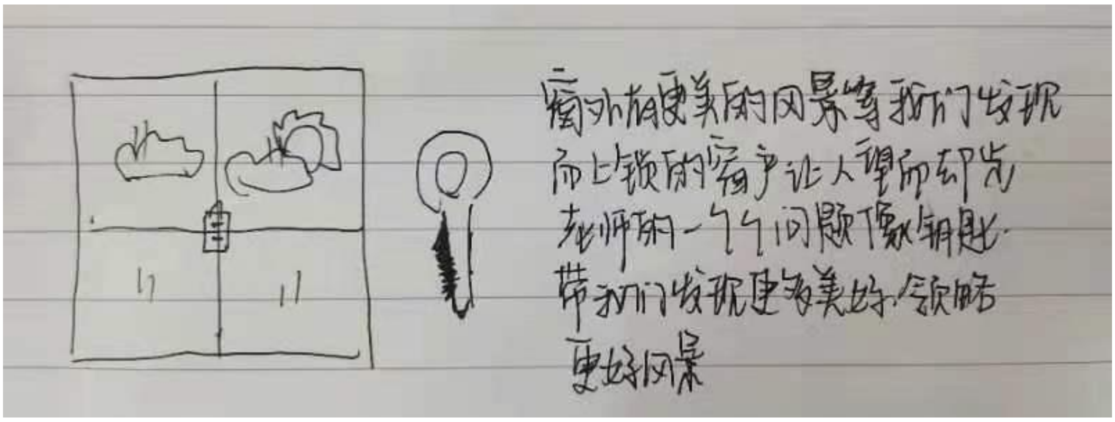
Four students' drawings in the pilot study are listed as follows. I translated what they wrote down on paper.



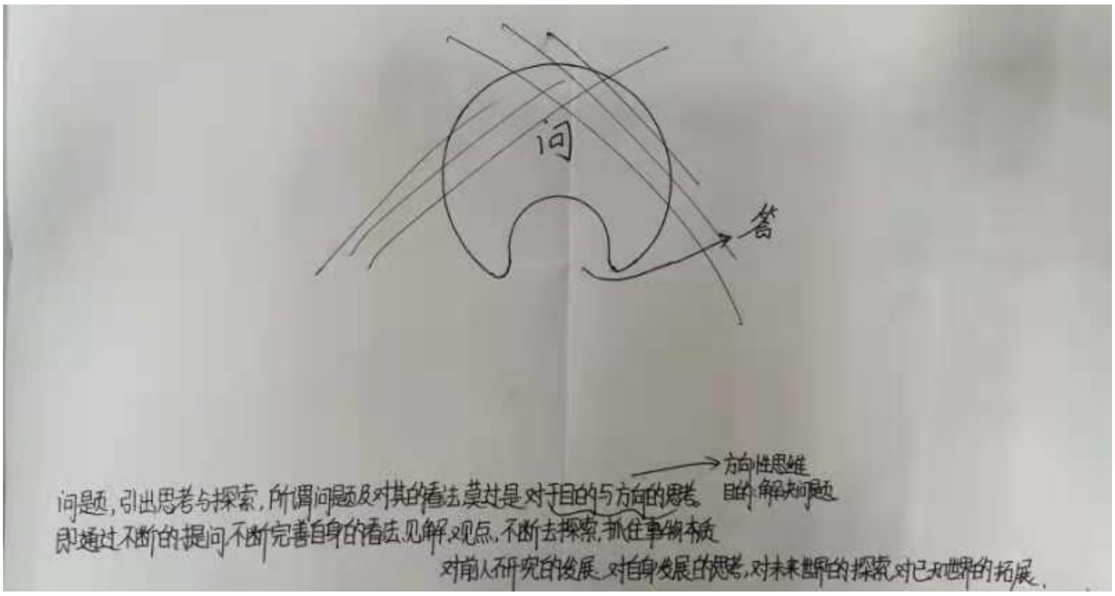
Translation: The question is addressed mainly through the knowledge we have learnt, and partly through the teacher's help.



Translation: Our thoughts and ideas are like Chinese candied hawthorn. Teacher questions are like the sugar coating. They are closely related. The combination produces new things.



Translation: The scenery outside the window is beautiful. We cannot explore it because of the locked window. The teacher’s questions are like keys, which lead us to discover more things and admire more beautiful scenery.



Translation: Questions lead to our thinking and exploration. Through continuous questioning, we improve our insights and viewpoints, grasp the essence of things, and develop previous research. Questions lead to the exploration of the future world, and the expansion of the known world.

Appendix 4: Teacher Interview Schedule

The first interview (before the first lesson)

(1) Could you please tell me about your background and the context of the school?

Prompts:

a. Be sure to ask about teachers' previous employment (including any before teaching); school assessment policies; and current school priorities from the perspective of the teacher.

b. The process of polished lessons in the school.

(2) What do you think is good teaching? What do think is good teaching in science?

(3) What are your views about the part of the biology curriculum that highlights scientific inquiry?

Prompts:

a. The teacher's understanding of the curriculum element, the extent to which they think it is important, and why they think it is (un)important.

(4) How do you prepare an inquiry lesson?

Prompts:

a. Biology curriculum standards? Textbooks? Teacher's guidebooks? Journal papers? Teaching videos? Website resources? Lesson plans?

b. Tell me how you reflect on and improve your lessons.

(5) Tell me your experience of implementing scientific inquiry.

Prompts:

a. What has helped you implement this part of the curriculum?

b. What challenges/problems have you experienced in implementing this part of the curriculum?

The second interview (after the second lesson)

(1) How do you think the two recorded lessons went?

Prompts:

a. Strengths? Weaknesses?

b. What do you think about your questioning practices?

(2) Describe your *favourite* episodes related to the two lessons. What do you value most about these episodes?

Prompts:

a. You mentioned… Can you give me an example from other lessons?

(3) Talk about the episodes that April selected from the two lessons.

Prompts:

a. Any comments? What was happening there? Why did you ask this question?

(4) Can you tell me more about… in other lessons?

The third interview (after the third lesson)

(1) How do you think the third recorded lesson went?

Prompts:

a. Strengths? Weaknesses?

b. What do you think about your questioning practice?

(2) Describe one or two *favourite* episodes related to the third lesson. What do you value most about this episode?

(3) Talk about the episodes that April selected from the third lesson.

Prompts:

a. Any comments? What was happening there? Why did you ask this question?

b. Can you tell me more about… in other lessons?

(4) How do you develop questions or teaching in scientific practices?

Prompts:

a. Tell me about things that help or not help you develop questioning or teaching.

b. The impact of high school entry examination or national college entrance examination

c. The role of students

(5) How do you think your purposes for teacher questioning will be different by 2030?

Prompts:

a. Dilemma? Confusion?

b. Anything at all you would like to add? You know about my project. Please feel free to tell me anything else that you think is important but that I did not ask about during the interviews.

Appendix 5: April Post Interview Review

Interviewee：

Interview date：

Today's date:

1. What were the main issues or themes that struck you in this interview?

2. Summarize the information you got about each of the research questions you had for this interview.

Q1

Q2

Q3

Q4

3. Anything you would like to improve for this interview? What interview questions do you have when considering the next contact with this teacher?

Appendix 6: Student Interview Schedule

Before the interview, draw a diagram that represents how your biology teacher works with you when you are learning science knowledge.

(1) Talk about your picture.

(2) What do you think about your teacher?

(3) What do you think of the lesson April listened to?

Prompts:

a. What do you think of this episode? (Episodes were selected by April and the Word document sent to students.)

b. What do you think about the questions the teacher asked in this episode?

c. Which question do you like best from this episode?

d. Do you find the teacher questions challenging or easy?

(4) What do you think about the questions your teacher used in other lessons?

(5) Tell me about a memorable or enjoyable time when you engaged in scientific practices, including teacher questions.

(6) What do you think about how this teacher works for you overall? What are the good points of your teacher's questioning?

Appendix 7: Headteacher Letter (English Version)

FACAULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

Dear headteacher

I am a PhD student under the supervision of Professor Jim Ryder (email: j.ryder@education.leeds.ac.uk) and Dr Michael Inglis (email: m.inglis@leeds.ac.uk) at the University of Leeds. I am writing to you because I am leading a project titled *Teacher Questions in Secondary Biology Classrooms: Making Scientific Practices Meaningful for Students*. It is about how teachers use questions to engage students in the practices that scientists employ as they investigate and build models and theories about the world in secondary biology classrooms in mainland China.

This is a small-scale project. A small number of biology teachers will be invited to take part in the study, and only two biology teachers in your school will participate. I am not able to conduct lesson observation or school visits due to the pandemic. So, I will request the teacher to audio record three lessons. I will interview each teacher three times and each online interview will last for about one hour. I will also recruit volunteer students from the class in which lessons will be recorded. I will conduct one-to-one and online student interviews about students' perceptions of the teacher questions. Each student interview will last for about 40 minutes.

Before studying for a PhD at the University of Leeds in October 2019, I taught biology in Qujiang No.1 Middle School for eight years. I know that Sue and Ziv are very famous biology teachers. It would be exciting and beneficial if I could interview such exemplary teachers to generate new insights that can inform the design of teacher professional development activities and if I could introduce the Chinese classroom enactment of scientific practices to the world.

Also, it is hoped that you would enjoy reviewing the interesting findings and sharing them with your school community.

Please be assured that all research data will be processed lawfully. Data will be held securely in accordance with the Data Protection Act and university data policy. General findings may be published, but any data revealing student identities or your school will be given pseudonyms.

Providing you are supportive of this project, teacher and student information sheets are enclosed for your approval.

If you require additional information, please feel free to contact me (Email: edzz@leeds.ac.uk).

Best wishes,

Zhongyan Zhang

Appendix 8: Teacher Information Sheet (English Version)

FACULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

★The title of the research project

Teacher questions in secondary biology classrooms: making scientific practices meaningful for students.

★Invitation

You are being invited to take part in a research project. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others, if you wish. Please tell me if there is anything that is not clear or if you would like more information. After you have finished, you can decide if you want to take part.

★What is the project about?

I am doing this project because I am a research student at the University of Leeds. Research means finding out about things and why they happen. I want to find out how teachers use questions to engage students in the practices that scientists employ as they investigate and build models and theories about the world in secondary biology classrooms in mainland China.

★Why do I want you to take part?

I need six expert teachers who may use a relatively large number of rich and interactive questions in classrooms. The participant teacher should meet these criteria: (1) many years (e.g., at least five years) of classroom experience in secondary biology teaching; (2) a good reputation for excellence in teaching: for instance, the honorary title of provincial expert teacher; and (3) a real willingness to collaborate in this study.

★Do you have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep (and be asked to sign a consent form), and you can still withdraw at any time before September 2022 without affecting any benefits that you are entitled to in any way. You do not have to give a reason.

★What will happen to you if you take part?

You need to audio record three lessons. Lesson plans and handouts will be collected. You will be interviewed three times about teacher questions and scientific practices. Each interview would take about one hour.

★Will you be recorded?

You will audio record three lessons. I will use a digital voice recorder to record interviews. The audio recordings of your lessons and interviews made during this research will be used only for transcription and analysis. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.

★What will happen to the results of the research project?

All the contact information that I collect about you during the research will be kept strictly confidential. I will take steps wherever possible to anonymize the research data so that you will not be identified in any reports or publications. Research findings will be published in the doctoral thesis and research journals and presented in research meetings and at conferences.

★Who is organizing the research?

The research project is organized by Zhongyan Zhang of the University of Leeds, who is a PhD student under the supervision of Professor Jim Ryder (email: j.ryder@education.leeds.ac.uk) and Dr Michael Inglis (email: m.inglis@leeds.ac.uk).

★Contact for further information

Name: Zhongyan Zhang

Email: edzz@leeds.ac.uk

WeChat: zhangzhongyan2018

Please feel free to contact me if you have any questions about the project.

Thank you for taking the time to read through the information.

Appendix 9: Student Information Sheet (English Version)

FACULTY OF EDUCATION, SOCIAL SCIENCES AND LAW
SCHOOL OF EDUCATION
HILLARY PLACE, UNIVERSITY OF LEEDS
LS2 9JT

UNIVERSITY OF LEEDS

★The title of the research project

Teacher questions in secondary biology classrooms: making scientific practices meaningful for students

★Invitation

You are being invited to take part in a research project. Please take time to read the following information carefully and tell me if you have any questions. After you have finished, you can decide if you want to take part.

★What is the project about?

I am doing this project because I am a research student at the University of Leeds. Research means finding out about things and why they happen. I want to find out how teachers use questions to engage students in scientific practices (e.g., planning and carrying out investigations) in secondary biology classrooms in mainland China.

★Why do you want me to take part?

I need to speak to students who are happy to talk to me about teacher questions.

★Do I have to take part?

It is up to you to decide if you want to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. You can withdraw at any time before September 2022 without a reason.

★What will happen to me if I take part?

You will be interviewed online about what you think about teacher questions. This will take about 40 minutes.

★Will I be recorded?

I will use a digital voice recorder to record the one-to-one interview. All the information that I collect about you during the research will be treated as confidential and used only for this PhD research.

★What will happen to the results of the research project?

I will anonymize the research data (e.g., use a pseudonym) so that you will not be identified in any reports or publications. Research findings will be published in the doctoral thesis and journals and presented in research conferences.

★Who is organizing the research?

The research project is organized by Zhongyan Zhang of the University of Leeds, who is a graduate student under the supervision of Professor Jim Ryder (email: j.ryder@education.leeds.ac.uk) and Dr Michael Inglis (email: m.inglis@leeds.ac.uk).

★Contact for further information

Name: Zhongyan Zhang

Email: edzz@leeds.ac.uk

WeChat: zhangzhongyan2018

Please feel free to contact me if you have any questions about the project.

Thank you for taking the time to read through the information.

Appendix 10: Teacher Consent Form (English Version)

FACULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

I confirm that I have read and understand the information letter and I have had the opportunity to ask questions about the project *Teacher Questions in Secondary Biology Classrooms: Making Scientific Practices Meaningful for Students*.

Also, I understand that

(1) I will be interviewed three times to help the researcher delve deeply into the context and focus on understanding the experience from the perspective of the participant.

(2) My participation is voluntary, and I am free to withdraw at any time without giving any reason until September 2022 and without being any negative consequences. In addition, should I not wish to answer any questions, I am free to decline.

(3) My name will not be linked with the research materials, and I will not be identified or identifiable in the thesis, reports, presentations, and papers.

(4) The data collected from me may be stored and used in relevant future research. Interviews and lessons will be audio recorded with my permission for the purpose of transcription. Lesson plans, lesson handouts and photographic materials will be collected with my consent for the purpose of the doctoral thesis, reports, papers, and presentations.

I **agree** to take part in the above research project.

Name: Date: Signature:

Appendix 11: Parent Consent Form (English Version)

FACULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

If you are happy for your child to participate, please complete the form below, and return it to the biology teacher as soon as possible. To find out more about the project, please read the attached information sheet. If you have any questions, please feel free to contact the researcher Zhongyan Zhang (edzz@leeds.ac.uk).

I confirm that I have read and understand the information letter. Also, I understand that

(1) Participation is voluntary, and both my child and I are free to withdraw at any time without giving any reason until September 2022 and without having any negative consequences.

(2) My child's name will not be linked with the research materials, and my child will not be identified or identifiable in the thesis, reports, presentations, and papers.

(3) The data collected from my child can be stored and used in relevant future research. Interviews will be audio recorded with my permission for the purpose of transcription. The photograph of my child's drawing will be collected with my consent for the purpose of the doctoral thesis, reports, papers, and presentations.

I give **permission** for my child (name of child: ________) to participate in the above research project.

Name of parent: Date: Signature:

Appendix 12: Child Consent Form (English Version)

FACULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

To find out more about the project *Teacher Questions in Secondary Biology Classrooms: Making Scientific Practices Meaningful for Students,* please review the enclosed information sheet with your parent to check that you agree with everything. Please discuss your participation in this project with your family. If you are happy to take part, please fill in the form below and return it to your biology teacher as soon as possible.

I understand that

(1) My participation is voluntary, and I am free to withdraw at any time without giving any reason until September 2022 and without having any negative consequences. In addition, should I not wish to answer any questions, I am free to decline.

(2) My name will not be linked with the research materials, and I will not be identified or identifiable in the thesis, reports, presentations, and papers.

(3) The data collected from me can be stored and used in relevant future research. Interviews will be audio recorded with my permission for the purpose of transcription. The photograph of my drawing will be collected with my consent for the purpose of the doctoral thesis, reports, papers, and presentations.

I **agree** to take part in the above research project.

Name: Date: Signature:

Appendix 13: Child and Parent Content Form (English Version)

FACAULTY OF EDUCATION, SOCIAL SCIENCES AND LAW

SCHOOL OF EDUCATION

HILLARY PLACE, UNIVERSITY OF LEEDS

LS2 9JT

UNIVERSITY OF LEEDS

If you agree to take a photo of the written work or artefact, please complete the form below, and return it to the biology teacher as soon as possible. To find out more about the project or you have any questions, please feel free to contact the researcher Zhongyan Zhang (edzz@leeds.ac.uk).

Name of child: ________

I confirm that I have agreed to allow the researcher Zhongyan Zhang take a photo of my written work or artefact. This photo may be used for her doctoral thesis, reports, papers, and presentations. I understand who will have access to the photo and how it will be stored. I understand that I am free to withdraw my permission at any time without giving any reason until September 2022 and without there being any negative consequences.

Name: Date: Signature:

Name of parent: ________

I confirm that I have agreed the researcher Zhongyan Zhang may take a photo of my child's written work or artefact. This photo may be used for her doctoral thesis, reports, papers, and presentations. I understand who will have access to the photo and how it will be stored. I understand that my child and I are free to withdraw permission at any time without giving any reason until September 2022 and without there being any negative consequences.

Name: Date: Signature:

Appendix 14: Numbers of Different Types of Questions in Three Lessons for Each Teacher

1. Numbers of different types of questions in three lessons (Ziv):

Question type	Lesson 1 (40 min)	Lesson 2 (30 min)	Lesson 3 (40 min)	Lessons 1, 2 and 3
All closed questions	35	35	55	125
Closed memory	16	10	23	49
Closed other	19	25	32	76
All open questions	1	2	13	16
Open divergent	1	2	11	14
Open evaluative	0	0	2	2
Open scenario-based	0	0	0	0
Rhetorical questions	5	20	42	67
Managing discussion	2	9	8	19
Totals	43	66	118	227

2. Numbers of different types of questions in three lessons (Sue):

Question type	Lesson 1 (45 min)	Lesson 2 (40 min)	Lesson 3 (30 min)	Lessons 1, 2 and 3
All closed questions	121	127	80	328
Closed memory	57	79	43	179
Closed other	64	48	37	149
All open questions	15	1	0	16
Open divergent	12	1	0	13
Open evaluative	3	0	0	3
Open scenario-based	0	0	0	0
Rhetorical questions	30	23	16	69
Managing discussion	20	3	3	26
Totals	186	154	99	439

3. Numbers of different types of questions in three lessons (Zachary):

Question type	**Lesson 1 (45 min)**	**Lesson 2 (49 min)**	**Lesson 3 (45 min)**	**Lessons 1, 2 and 3**
All closed questions	81	102	67	250
Closed memory	38	52	29	119
Closed other	43	50	38	131
All open questions	1	10	6	17
Open divergent	1	5	5	11
Open evaluative	0	5	1	6
Open scenario-based	0	0	0	0
Rhetorical questions	30	33	47	110
Managing discussion	2	1	9	12
Totals	114	146	129	389

4. Numbers of different types of questions in three lessons (Wynne):

Question type	**Lesson 1 (41 min)**	**Lesson 2 (47 min)**	**Lesson 3 (43 min)**	**Lessons 1, 2 and 3**
All closed questions	51	77	34	162
Closed memory	25	39	26	90
Closed other	26	38	8	72
All open questions	8	6	9	23
Open divergent	5	3	4	12
Open evaluative	3	3	5	11
Open scenario-based	0	0	0	0
Rhetorical questions	11	22	11	44
Managing discussion	5	13	6	24
Totals	75	118	60	253

5. Numbers of different types of questions in three lessons (Helen):

Question type	**Lesson 1 (40 min)**	**Lesson 2 (38 min)**	**Lesson 3 (40 min)**	**Lessons 1, 2 and 3**
All closed questions	146	63	123	332
Closed memory	58	24	62	144
Closed other	88	39	61	188
All open questions	2	1	0	3
Open divergent	1	1	0	2
Open evaluative	1	0	0	1
Open scenario-based	0	0	0	0
Rhetorical questions	48	19	54	121
Managing discussion	6	5	0	11
Totals	202	88	177	467

6. Numbers of different types of questions in three lessons (Simon):

Question type	**Lesson 1 (40 min)**	**Lesson 2 (40 min)**	**Lesson 3 (40 min)**	**Lessons 1, 2 and 3**
All closed questions	59	33	86	178
Closed memory	34	3	24	61
Closed other	25	30	62	117
All open questions	1	0	1	2
Open divergent	0	0	0	0
Open evaluative	0	0	0	0
Open scenario-based	1	0	1	2
Rhetorical questions	30	17	41	88
Managing discussion	2	4	1	7
Totals	92	54	129	275

Appendix 15: Two Examples of Episodes (English Version)

Episode 1. What does the finding tell us? What made steamed buns taste sweet? (Ziv_L1)

1 Ziv: In which test tube was the starch broken down?

2 Student 1: No.1.

3 Ziv: No.1, the starch was broken down. Why was it broken down?

4 Student 1: Because...

5 Ziv: Because steamed buns were small pieces in test tube 1.

6 Student 1: And saliva.

7 Ziv: There was also saliva, and there was also shaking and mixing, right? Where else was the starch broken down? Was the starch broken down in No.2?

8 Student 1: No.

9 Ziv: It is still there in No.2, isn't it? Was the starch broken down in No.3?

10 Student 1: Yes.

11 Ziv: The starch was broken down in test tube 3 but part of it was broken down, and it was light blue, right? Does anyone agree with their analysis?

12 Students: Yes [students answered in unison as a group].

13 Ziv: The starch was broken down in test tube 1, it was not broken down in test tube 2, and it was partially broken down in test tube 3. So, what conclusions can we draw from this? What made steamed buns taste sweet?

14 Students: Starch/saliva [one student answered starch, but more students answered saliva].

15 Ziv: Saliva. Because we see saliva in No.1 [inaudible]. Do the teeth and tongue work?

16 Students: Yes.

17 Ziv: Can the teeth and tongue work alone yet?

18 Student: No.

19 Ziv: Doesn't the No.2 test tube tell us that teeth and tongue alone cannot work? What do they have to work with?

20 Student: Saliva.

21 Ziv: Saliva. OK, let's see – what conclusions can we draw? Please turn to page 28 in the textbook…

Episode 2. A typical controlled experiment (Ziv_L2)

1 Ziv: Look, what kind of experiment is this?

2 Students: Controlled experiment.

3 Ziv: A controlled experiment. And for these three test tubes, how many pairs do they have? [Here one pair refers to a control group and an experimental group and there is only one dependent variable between them]

4 Student: Three.

5 Ziv: How many?

6 Students: Two.

7 Ziv: Put your hand up. How many pairs are there for these three test tubes? Note that the controlled experiments should be in pairs, right? Come on, you can tell me.

8 Student 5: Two pairs.

9 Ziv: Which two pairs do you mean?

10 Student 5: One pair is about saliva.

11 Ziv: Is there saliva or not, right? The independent variable is saliva.

12 Student 5: The other is about if they imitate the chewing of teeth and the mixing of tongue.

13 Ziv: Do they have the chewing of teeth and the mixing of tongue, right? Please sit down. No.1 and No.2 are a pair, No.1 and No.3 are a pair, aren't they? Does anyone think that No.2 and No.3 can also be a pair?

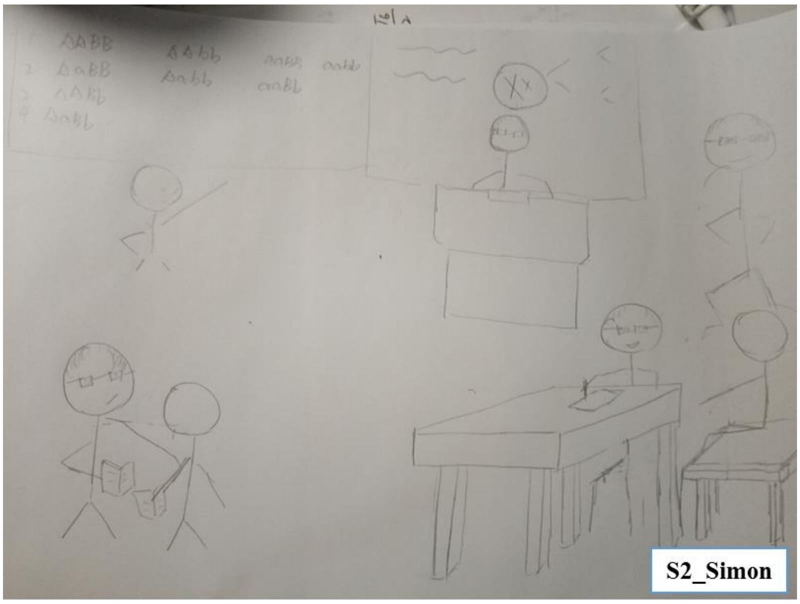
14 Students: No.

15 Ziv: Why? Why can't No.2 and No.3 be treated as a pair? They are also two test tubes.

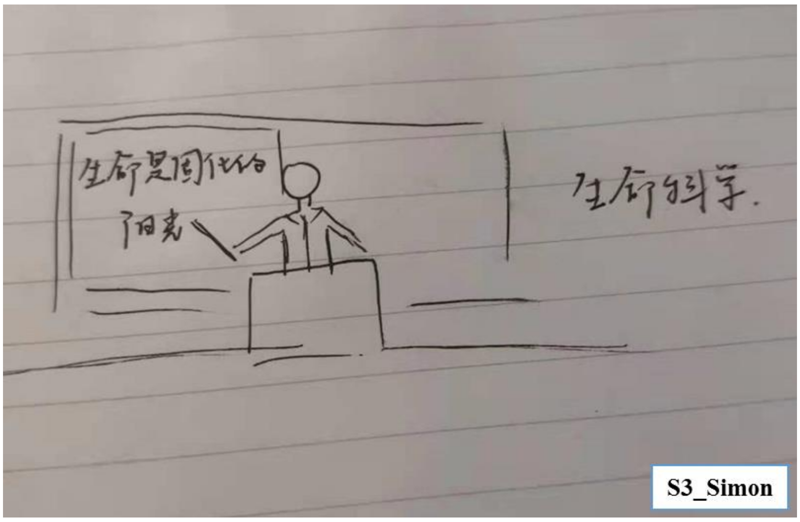
16 Student 6: Firstly, one has steamed bun crumbs and one has steamed bun chunks. Secondly, one has water, and one has saliva. In addition, one was mixed, and one was not mixed.

Appendix 16: Five Students' Drawings in the Formal Data Collection

1. S2_Simon's and S3_Simon's drawings:

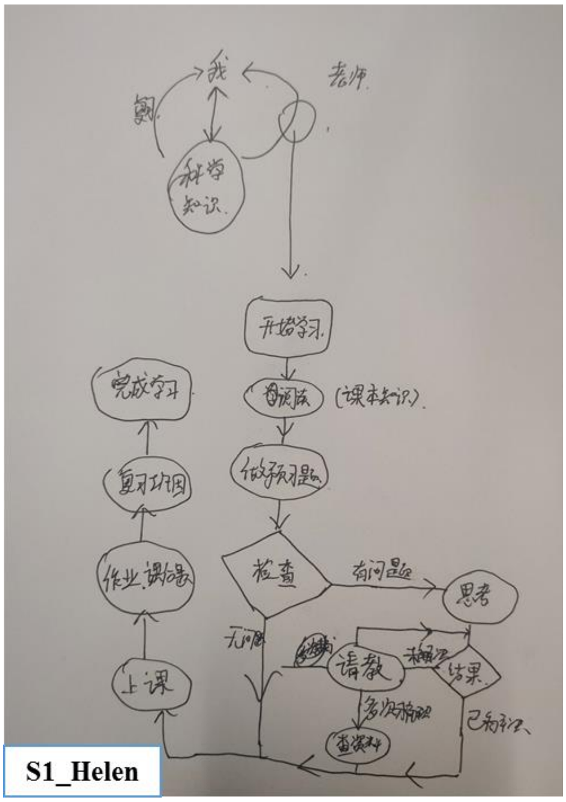


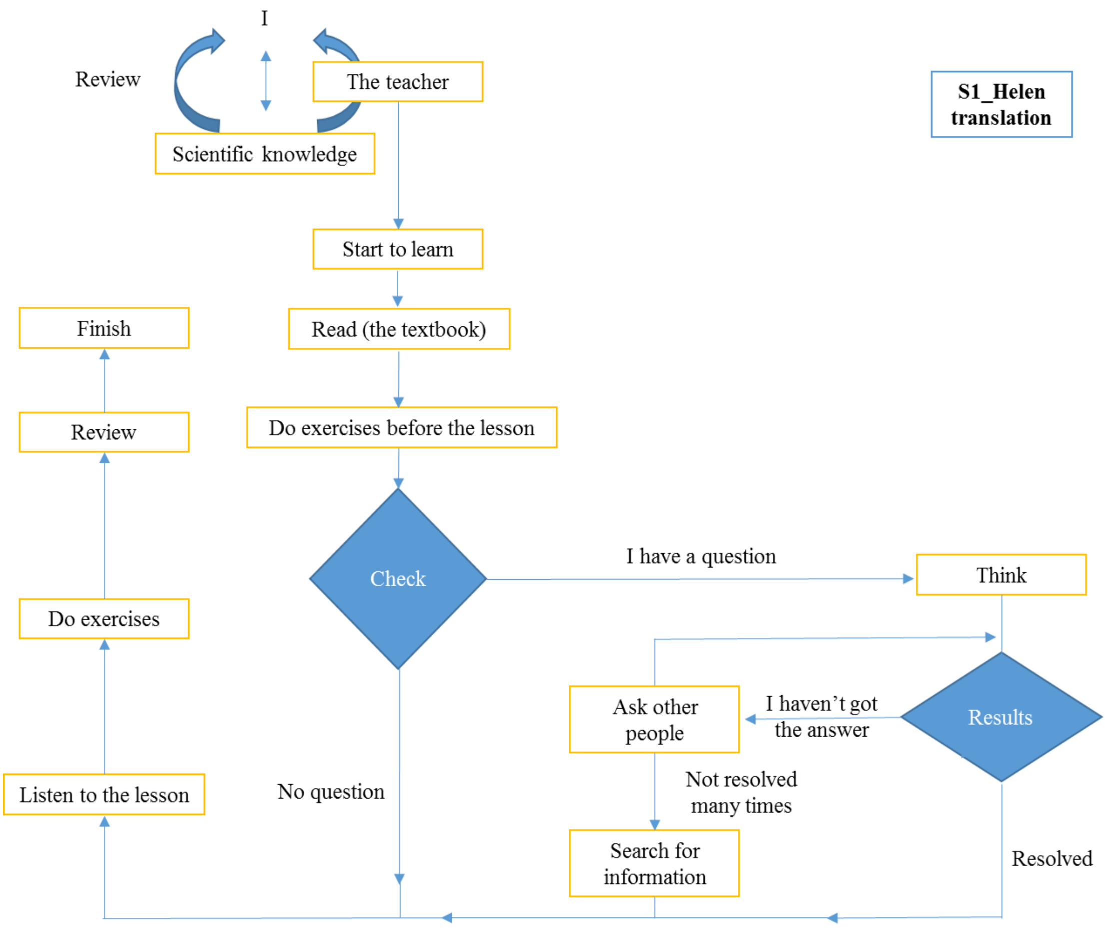
S2_Simon



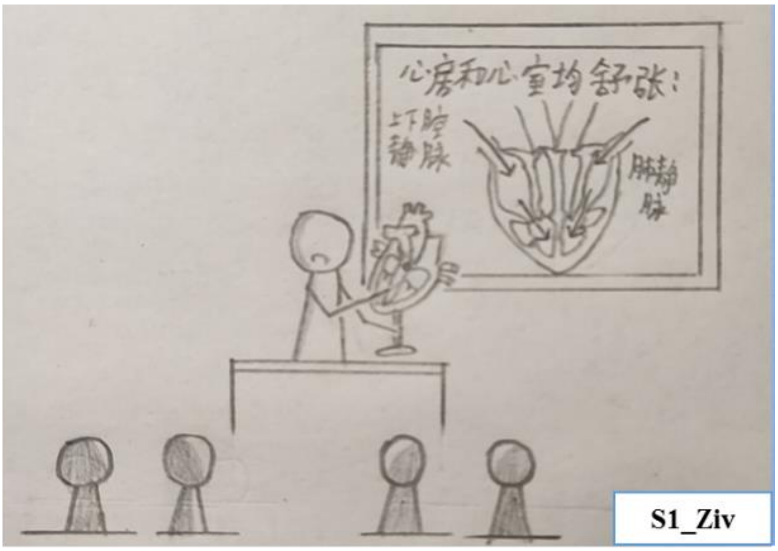
S3_Simon

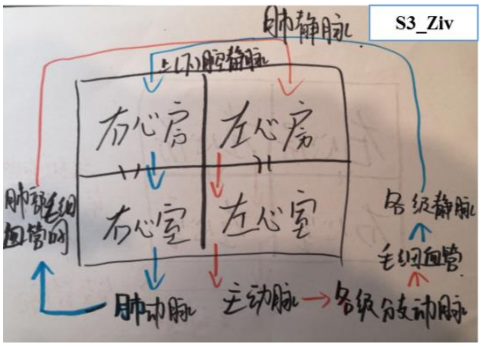
2. S1_Helen's drawing and its translation:

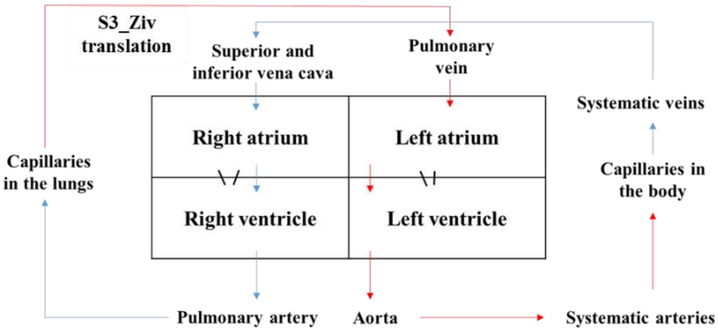




3. S1_Ziv's and S3_Ziv's drawings and translation of S3_Ziv's drawing:







Appendix 17: Teacher Professional Development on Teacher Questions

1. The table below shows different types of teacher questions. Can you take an example from you for each type?

Question type		Description	Example
Closed questions	Closed memory	Closed, to recall knowledge	1. Does it have ribosomes? 2. How many pairs of chromosomes does a somatic cell have?
	Closed other	Closed, to elicit higher cognitive thinking	1. How do you know it is starch? 2. Why was an equal mass of steamed buns added to each test tube?
Open questions	Open divergent	Open, a wide range of possible answers	1. Which activities can destroy the balance of an ecosystem? 2. Why cannot frogs survive in water-scarce terrestrial environments?
	Open evaluative	Open, to encourage students to elaborate from their own perspectives	1. Why do you think its skin has this function? 2. Have you ever felt…when did you use simple reflexes?
	Open scenario-based	Open, to think from another angle	1. Imagine you are the scientist Sutton or Morgan, what conclusions can you make from data? 2. Imagine you are the spinal cord, what should you do if your finger is pricked, and neurons send this message to you?
Rhetorical questions		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		To check consensus, to probe	1. Anything to add? 2. Does everyone agree with his idea?

2. Please use the questions classification system to label each teacher question in the following two teaching episodes. For example, if a question is a closed memory question, you will label

it *Closed memory*. After you finish, please discuss these questions in small groups: (1) what do you think about the role of different types of questions this teacher used? (2) how did the teacher use open questions to engage students in scientific practices? (3) could you please select one question the teacher asked and change it into a scenario-based question? Note that [in unison] below means students answered in unison as a group.

Episode 1 What will occur if I place a phospholipid monolayer at the air-water interface?

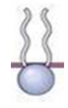
The teacher Joan invited the students to look closely at the structure of a phospholipid and she emphasized that the *head* was water loving and the *tails* were water hating. The students were then asked to draw a phospholipid at the air-water interface.

1 Teacher: What will occur if I place a phospholipid monolayer at the air-water interface?
2 Students: [in unison] Head is down.
3 Teacher: Could you please draw it in your notebook with a pen? A few students will be asked to draw on the blackboard.

Three students drew on the blackboard. After they finished, Joan continued:

4 Teacher: Look at the three pictures on the blackboard. All heads are down, right? There are still some slight differences. What are the differences? This one?
5 Students: [in unison] Water loving.
6 Teacher: Water loving. All the hydrophilic head is under water. This one?
7 Students: [in unison] Next to…
8 Teacher: Part of the hydrophilic head is under water. This?
9 Students: All…down…
10 Teacher: Part of the hydrophobic tail is under water, right? Which one do you think is more accurate?
11 Some students say the first one and some students say the second one.
12 Teacher: The hydrophilic head, the entire head is water loving. So, which one is correct?
13 Students: [in unison] The first one.
14 Teacher: This one, what should not be under water?
15 Students: [in unison] Tails.

The expected result is shown below.



Episode 2 Phospholipids form a double layer in the red blood cell membrane

In this episode, Joan confronted the class with a question about how phospholipids arranged themselves in the red blood cell membrane. Next, she invited students to analyze a scientific experiment to test their hypotheses.

1 Teacher: According to the surrounding in which the red blood cell lives, do you think phospholipid molecules form a single layer or a double layer in the red blood cell membrane? Why?
2 Student 1: A single layer.
3 Teacher: Tell me the reason.
4 Student 1: Red blood cells need to carry oxygen.
5 Teacher: Do you mean that red blood cells carry oxygen that can cross the cell membrane, and if the cell membrane is a single layer, materials can go into and out of the cell easily? Is there a different view?
6 Student 2: The intracellular fluid is on the inside of a cell, and the interior is hydrophilic. The external environment may have water.
7 Teacher: Red blood cells...
8 Student 2: Red blood cells are in the blood vessels that carry blood. So, the outside should be hydrophilic. So, phospholipids should form a double layer in the red blood cell membrane.
9 Teacher: He said red blood cells lived in the environment where there was the extracellular fluid and the intracellular fluid dissolved in water, and therefore he supported a double layer. What do you think, a single layer or a double layer?
10 Students: Single… double…
11 Teacher: Is there any problem with his analysis?
12 Students: No. [applause]

13 Teacher: Right, his analysis is good. So, how do we speculate that phospholipids arrange themselves in red blood cells?

14 Students: [in unison] A double layer.

15 Teacher: Now, do we have any supportive experimental evidence?

16 Students: [in unison] No.

17 Teacher: Now let's see if scientists can provide experimental evidence for it. In 1925, Dutch scientists did this experiment. Then, what can we learn from this experiment?

18 Student 3: Phospholipids are two layers in the cell membrane of red blood cells.

3. Please read the following paragraphs. What do think about students' views on different types of teacher questions?

I like that (question) better (…) he (Simon) asked if genes must be on chromosomes and if there is only one conclusion. So, there are some possibilities. I like it because I don't need to give a fixed answer and therefore have a feeling of divergence. (S3_Simon)

It's just that I personally prefer this kind of open-ended questions we can discuss because I like to argue with people (…) it's like a debate. I think perhaps there may be some people who agree on this issue and some people who disagree, and then we can discuss these ideas. (S3_Ziv)

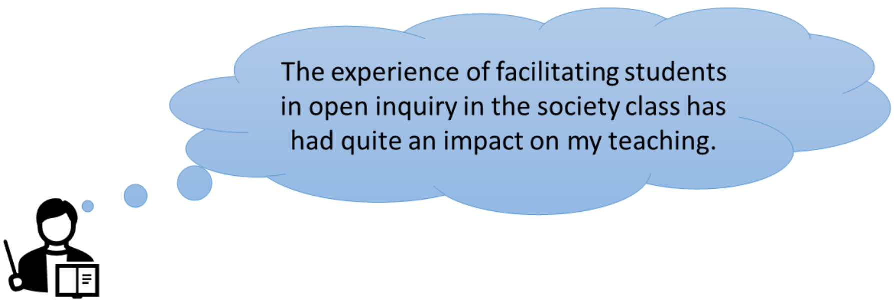
I think one of the most memorable things for me is that the teacher often asks us that imagine you are that cell or organelle, imagine you are a kind of creature, and you can imagine what you are going to do when faced with some of the work they do. In fact, when he teaches the knowledge in anthropomorphic ways in class, I think it's easier for us to accept these things and memorize them. (S1_Simon)

Appendix 18: Case Study Training Resource

Ziv had twenty-one years teaching experience and he was a municipal teaching expert. He enjoyed engaging with students, but he was really struggling to use a variety of teacher questions in the classroom. For example, his desire to use more open questions conflicted with his task of supporting 56 students in acquiring prescribed subject knowledge.

However, he taught the Science Micro Video Society that was about 100 minutes every week in the school. In the society class, there were 36 students, no learning objectives about subject matter knowledge and no teaching schedule requirements. Students did open inquiry in small groups. He often told students no conclusion was always correct, and science was getting closer and closer to the truth but would never reach the truth. Ziv used more open questions. Also, he encouraged students to pose inquiry questions they were interested in (e.g., are your water bottles clean?) and make decisions on their own.

His experience of facilitating students in open inquiry affected his understanding of scientific practices and teaching in the normal class. For example, in the past, when students investigated natural selection in peanuts, Ziv just asked students to measure the size of peanuts and gave students two conclusions: some variation was heritable, and some variation was the result of differences in the surroundings. His experience of engaging students in open inquiry in the society class made him reflect on the importance of using mathematical thinking and data to support a claim. So, he realised he should emphasize data collection and analysis, rather than focusing mainly on drawing conclusions.



Ziv