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An analysis of students' perceptions of teachers' questioning in secondary biology classrooms

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Abstract
Secondary students' perceptions of teachers' questioning have not been clarified in the literature, but these perspectives are invaluable as they help to make sense of what students notice about teachers' questioning and enhance teachers' questioning skills. In this study, eight students from three schools in Xi'an City, aged 12 to 16, were interviewed individually with teaching episodes and student drawings used to elicit in-depth perspectives during those interviews. The findings indicated that students demonstrated sophisticated and thoughtful reflections on open and closed questions, on how teachers used questions differently in two types of classes, on scenario-based questions that asked them to think from the perspective of a scientist, and on other aspects of teacher questioning. The students expressed a preference for scenario-based questions and valued questioning that demonstrated teacher power and authority less and supported student engagement in knowledge construction. These findings have several important implications for teaching and learning and teachers' professional development: for example, using students' views to encourage teachers to think about scenario-based questions.

Keywords Student drawings, Student voice, Teacher questioning, Teaching

Introduction

Teachers' questioning practices are an important consideration when implementing curriculum standards and scientific practices (McNeill & Pimentel, 2010) and represent the key indices of teaching quality (Chen et al., 2017; Kruse et al., 2022). Chin (2007) argues that the types of questions teachers ask and their approach in doing so enable students to engage in high levels of cognitive thinking and knowledge construction. Teachers' questioning is also crucial for engaging students in productive classroom dialogues (Vrikki & Evagorou, 2023). For example, key teachers' questions (e.g., "Why can't they both be correct?") play a role in transitioning the classroom dialogue from an authoritative orientation to a dialogic one by opening up classroom talk and giving space to student voices (Lehesvuori et al., 2019, p.2564; Mortimer & Scott, 2003).

Although teachers' questioning is widely understood as an essential component of classroom discourse (Chen et al., 2017; Chin, 2007; de Boer et al., 2021; Khoza & Msimanga, 2021), the literature lacks clarity on how students perceive these questions. Previous studies have primarily focused on teachers' perspectives, including typologies of teachers' questions (e.g., Oliveira, 2010; Roychoudhury & Roth, 1996), teacher training related to questioning techniques (e.g., Joglar & Rojas, 2019) and the

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relationship between teachers' questioning and student responses (e.g., Chen et al., 2017; Lee & Kinzie, 2012). However, these studies often did not utilize qualitative data in order to delve more deeply into students' perceptions of teachers' questions, perhaps because it is difficult to encourage students to focus on teachers' questions and articulate their feelings. Compared with talking about a broad topic (e.g., homework), commenting on teachers' questions is challenging for students because they might have neglected, forgotten or not had time to reflect on the issue, despite having heard plenty of questions from teachers as a matter of routine. This study aims to characterize students' attention to teachers' questioning and explores the question: How do students perceive their teachers' questioning in class? In this context, *teachers' questioning* refers to strategies that not only encompass teachers' questions but also consider their context and progression over time. The research question seeks to provide insights into how students' learning, motivation, and engagement are affected by this important element of classroom practice, with the goal of contributing to improved guidance in teachers' training and development.

Literature review

Due to the elevated status of students (e.g., Convention on the Rights of the Child) and student-centred curriculum initiatives over the last three decades, there has been growing interest in examining the student voice. However, the term *student voice* lacks a consistent definition (Cook-Sather, 2006; Jenkins, 2006). It can broadly refer to "the ideas, perceptions, opinions, or perspectives of students within specific schooling contexts and for particular purposes" (Gonzalez et al., 2017, p.3), encompassing issues primarily concerning students: for instance, their views on effective teaching, the role of the science curriculum, their understanding of the nature of science, and their attitudes towards learning science. Additionally, it involves students' reflections on the school system as a whole (e.g., school policies). The focus of this paper is more on the implications for teaching, learning, and teachers' professional development. Therefore, *student voice* refers to students' views about the form, content and experiences of teaching and learning (Jenkins, 2006).

Students often hold complex and thoughtful views, along with sensible strategies, when expressing their opinions about school matters (Lie et al., 2021; Pietarinen, 2000). The student voice is not static; it evolves and changes, necessitating continual re-evaluation (Cook-Sather, 2006). Previous studies have tended to use it as a tool to benefit teachers' professional development and improvements in schools (Flutter, 2007; McIntyre et al., 2005). Also, investigating how consulting students' perspectives on science and their school science education programmes can enhance their motivation, foster a sense of active community participation, cultivate diverse teaching strategies and thereby improve student attainment in science (Flutter & Rudduck, 2004; Rudduck & McIntyre, 2007). It is building "communication as dialogue" that paves the way for transformation (Robinson & Taylor, 2007, p.8).

Students' concerns and teaching and learning preferences as identified in the literature tend to focus on: (1) the conceptual dimension; for example, students preferred practical activities because scientific concepts were easier to understand and remember (Osborne & Collins, 2001); (2) the social dimension; 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"– and Hume and Coll's (2008) research supports this finding, demonstrating that students valued the opportunities to work with group members because they could easily share knowledge and expertise to solve a problem and felt safe clarifying any misconceptions in a small group; (3) the affective dimension; for example, regarding science curriculum, students felt that dissection (e.g., a pig's heart and kidney) was fun and expressed a desire for a humorous, happy, and relaxed learning environment (Osborne & Collins, 2001); (4) the autonomy dimension; for example, students showed their fondness for practical work because they were able to select appropriate equipment and had a sense of autonomy when planning and carrying out investigations (Osborne & Collins, 2001; Toplis, 2012); and (5) the pedagogical dimension; for example, students focused on teaching approaches and highlighted the role of storytelling and visual stimuli in their learning (Cooper & McIntyre, 1996). Each of the five dimensions is significant. Understanding what students notice and value across various dimensions is crucial for comprehending their needs and could serve as a catalyst for teacher professional development (Messiou & Ainscow, 2015).

However, there is a lack of empirical studies that specifically focus on students' views about teachers' questions. Much of the qualitative research on teachers' questioning has relied on teachers' perceptions and classroom observations (e.g., Joglar & Rojas, 2019; Soysal, 2022), while students' perceptions of different types of questions– for instance, their experiences, needs, what they value and what aspects they find interesting– are unknown. However, van Zee et al.'s (2001, p.180) study does present students' comments regarding their teacher's questioning approach, which involved the teacher adopting an innovative 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 several possible answers, rather than simply providing a correct response. On the one hand, a student commented that the teacher made them evaluate what they were asking, while on the other, the student who asked the question stated that the responses were irritating and ambiguous. Such comments are important because they not only reveal what students perceive as teachers' questioning and why that is but also prompt deeper reflections for teachers.

This study is a rare example, however, and a much more systematic investigation of students' views on teachers' questioning is needed to ensure that current advice to teachers, as offered in training courses and textbooks, is valid. Closed and structured questionnaires are often used to study student voice (Bakx et al., 2015; Jenkins, 2006; Osborne & Collins, 2001; Wall et al., 2005), and this indicates a need to qualitatively explore students' perceptions.

Regarding the collection of qualitative data on student voice, students' drawings offer an alternative method of presenting their perspectives. However, this technique is not commonly employed with adolescents about their "understanding of classrooms and schooling" (Haney et al., 2004, p.247). Additionally, there is a tension between the interviewer and student (Wall et al., 2005) and commenting on teaching and learning deviates from students' traditional role (Rudduck & McIntyre, 2007). To address these issues, certain studies employ stimulated recall interviews that use cues (e.g., videos and photographs) to aid participants to recall their thoughts and feelings when they produce the action (Dempsey, 2010) and "interviews about instances" using specially selected cards to elicit students' views about science concepts (Osborne & Gilbert, 1980, p.311). The existing literature highlights a notable absence of stimulated recall interviews in researching student perspectives on teacher questioning. This gap offers insights into the structuring of student interviews, as will be elaborated in the following section.

Methods

This study was part of a larger project examining how teachers use questions in secondary biology classrooms to engage students in scientific practices and how students in Xi'an City in mainland China perceive these questions, drawing on data generated in audio-recorded lessons and student interviews. It was conducted from March to August 2021 and originally aimed at collecting data in a naturalistic setting and focusing in depth on cultural context. However, due to the global pandemic, the planned school visitations and lesson observations could not be implemented. It was therefore difficult to observe students' responses to teachers' questions in the classroom and establish trust and rapport with the students.

Purposive sampling was undertaken to gain access to teachers who had a good reputation for excellence in teaching (e.g., being awarded the honorary title of expert teachers) and might therefore use a relatively large number of dialogic and interactive questioning sequences (Mortimer & Scott, 2003). Three secondary biology teachers (Helen, Simon and Ziv) were involved in this paper and their informed consent was obtained. The teachers were then asked to disseminate information sheets and consent materials to recruit students in the classes whose lessons were audio-recorded. Eight students expressed interest in this study and were happy to take part: two of Helen's 15- to 16-year-old students (S1_Helen and S2_Helen), three of Simon's 15- to 16-year-old students (S1_Simon, S2_Simon and S3_Simon) and three of Ziv's 12- to 13-year-old students (S1_Ziv, S2_Ziv and S3_Ziv) (see Table 1). Digital student and parent consent forms were collected via their biology teachers.

All participants were allocated pseudonyms. Helen, Ziv and Simon worked in a public school, private school and university-affiliated school, respectively. The public school was funded by the government, and the private school, which was owned and managed by a private company, was mainly funded by student tuition fees. The university-affiliated school was run by a university and recruited many students whose parents were working at the university or whose grandparents had retired from working there. All eight students had learned integrated

Table 1 Details of the eight students involved in the study

Student	Gender	Age	Grade	School level	School type	Description of the teacher
S1_Helen	M	15–16	10	Senior secondary	Public school	Helen: 12 years in teaching; awarded the title of *Expert Teacher*
S2_Helen	M					
S1_Simon	M	15–16	10	Senior secondary	University-affiliated school	Simon: 23 years in teaching; awarded the title of *Expert Teacher*
S2_Simon	M					
S3_Simon	F					
S1_Ziv	F	12–13	7	Junior secondary	Private school	Ziv: 21 years in teaching; taught a society class where students engaged in scientific practices once a week for approximately 100 min
S2_Ziv	M					
S3_Ziv	F					

science as a subject in primary school, covering biology, chemistry, geology, and physics. The three students in the junior secondary school learnt three separate science subjects– physics, chemistry and biology. Although the biology score was not included in the total score for the high school entrance examination at the time, they were still required to pass this exam to obtain a junior secondary school diploma. For the five students in the senior secondary school, biology, physics, and chemistry were assessed as one subject in the national college entrance examination, accounting for 300 points of the total score of 750.

Each teacher was asked to record three lessons using audio-recording devices, and lessons were selected by teachers based on the requirement of students' participation in scientific practices (e.g., engaging in arguments based on evidence). The topics included the role of saliva, teeth, and tongue in digesting starch; healthy diet and food safety; the process of meiosis; the location of genes on chromosomes; and DNA as the main genetic material. Individual semi-structured student interviews (see Appendix) were conducted online, and each lasted approximately 40 min, beginning with a discussion about the teacher and his/her teaching. It then delved deeper to gather students' perceptions regarding the questions posed in the recorded lessons. Finally, the topic was expanded, with inquiries, for example, about the students' views on the teacher's questions in other lessons. To draw out the students' experiences of their teachers' teaching and questioning, teaching episodes from the recorded lessons were used with each episode consisting of a roughly three-minute teaching extract from the lesson transcription. Three or four episodes that showed the students' engagement in scientific practices were selected and sent to the students to review approximately two days before their interviews. This approach not only enabled the students to talk about the lessons with which both the interviewer and interviewee were familiar but also helped students to focus on specific situations or questions from teachers: for example, "Now we turn to episode one, what do you think about the questions the teacher asked in this episode?" and "Which question do you like best from this episode?" Importantly, the episodes helped the students comment on teachers' questions without separating them from the context because a single question from a teacher was meaningless unless it was linked to the context.

The students were also asked to draw a diagram that represented how their biology teachers worked with them when they were learning science knowledge in class at the beginning of the interview. Drawings were used as a tool to start interviews and elicit the students' perspectives (Brenner, 2012; Kearney & Hyle, 2004). For example, at the beginning of S2_Ziv's interview, a series of questions were used, such as "Could you please talk about your drawing?", "What was in the teacher's hand?", "What was he doing?" and "Why did you select these three scenes?" (see Fig. 1).

All lessons and interviews were conducted in Mandarin, audio-recorded and transcribed for analysis with six phases of thematic analysis employed to make the inductive analysis as systemic and critical as possible (Braun & Clarke, 2006). The students' stimulated recall of what they were thinking during classroom activities and their comments on their teachers' questioning were analysed. The interview data was therefore paired with the lesson episodes to develop familiarity with the teaching and to understand the students' perceptions, and during the data

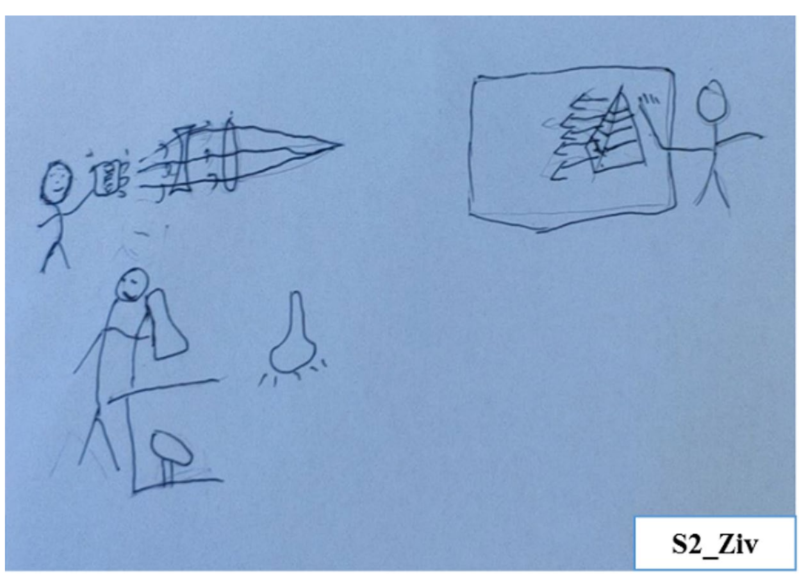

Fig. 1 S2_Ziv's drawing

immersion process, a variety of terms used by students to describe their views regarding teachers' questions were observed, such as "challenging" and "interactive". The unit of analysis for coding was the entire segment of the interview transcript in which a student describes his/her feelings about a teacher's question, a sequence of their teacher questioning, or a teaching episode, and all codes were data-driven. To enhance credibility, an initial coding manual containing descriptions and examples was also developed. This manual was then discussed and refined in collaboration with two experienced tutors, which helped in resolving any ambiguous definitions. Once an agreement was reached, the first author independently coded all the data. NVivo 12 was used to collate extracts for each code. Coding entailed a continuous comparative analysis, involving reviewing iteratively and gaining new insights, selecting codes, merging similar ones and discarding others. For example, a student used a few words to express his views about questions that were not included on the scripted slides but instead were asked based on student responses, and this code was discarded because of insufficient data. Mind maps were utilized to organize the codes and to facilitate the discovery of themes, then all the transcriptions were examined again to check if there was anything missing in the initial coding and whether there was anything that did not fit the codes or themes.

Results

This study concentrates on four broad themes that emerged from the student interviews: views about open and closed questions; views about questions asked in the society class and normal class; views about scenario-based questions; and students' attention to other aspects of teachers' questioning. These have been notably underrepresented in the existing literature. Some conventions were used in the extracts from the transcriptions in the following subsections. "Simon_L3" means Simon's third lesson, while "…" means that a student did not finish the sentence they were speaking. "[]" means an insertion was added to clarify meaning and "(…)" refers to the deletion of a brief segment of text from the transcript.

Views about open and closed questions

Overall, the students made only few comments that explicitly addressed closed questions. Considering a closed question used to recall factual knowledge– "Is pneumococcus prokaryotic or eukaryotic?" (Simon_L3)– S1_Simon remarked, "In fact, this question is mainly used to review prior knowledge. It's not interesting." S1_Helen had a similar response, keeping silent despite knowing the answers:

> *For a simple recall question, my thinking… 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 I have enough time, I will think about its related knowledge. Yet I don't want to say the answer. (S1_Helen)*

Elsewhere in his interview, when asked which questions he liked in an episode, S1_Helen indicated those that had a limited number of right answers but required higher cognitive levels (e.g., inferring and comparing): for example, "If I 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?" (Helen_L3). He explained, "these questions require me to consider many things" and "involve some new knowledge, like the knowledge of isotopes, and test and improve my ability".

Open questions do not have fixed answers and can elicit two or more different responses. S3_Simon stated that she liked the following open question: "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 other conclusion can you draw?" (Simon_L1). Sutton proposed the chromosome theory of inheritance, which states that the behaviour of genes is parallel to the behaviour of chromosomes. Students normally inferred that genes were located on chromosomes, as shown in the title of the lesson in the textbook, but Simon challenged students to think about alternative hypotheses that the scientist might make based on the evidence at that time.

> *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)*

In a lesson investigating the role of the mouth (saliva, teeth, and tongue) in digesting Chinese steamed buns, S1_Ziv remarked she liked the question of "What is the difference and connection between the roles of the teeth, the tongue and the saliva?" when compared with closed questions, such as "Which two tubes in test tubes 1, 2 and 3 can be a fair test?" She remarked:

> *I prefer questions that don't have very fixed answers, similar to this one, which explores the differences and connections between the roles of the teeth, the tongue, and 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)*

Both students noted that since open questions do not have fixed answers, they could use their imagination, think from multiple perspectives and experience a feeling 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 question 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)*

In this excerpt from the interview with S3_Ziv, as the conversation developed, the following point was highlighted:

> *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)*

Her fondness for the approach of asking questions in her friend's classroom suggests a preference for open questions and a value for a social learning process where students feel safe to make mistakes and learn from their peers' errors. This supported the finding of Oliveira (2010), who proposed tentative questioning should be employed that encourages students to give uncertain or even incorrect answers and engage in discussions in scientific practices. S3_Ziv also highlighted the pedagogical domain, that is, how questions were asked and discussed in her friend's classroom: (1) regarding the presence of a question– for example, is it raised verbally, presented in the slides or sent to an iPad?– and (2) regarding social function and the setting– for example, is the question for the whole class or small groups, and do students sit in their seats or in a circle on the floor when they discuss the question? She did not simply consider teachers' questioning as teacher–student interaction as it might involve multimodal interactions between a teacher and students, between an iPad and students, and between students and students.

Views about questions in the society class and normal class

This section presents a student's perspectives on the differences in teachers' questioning across two types of classes. The insights are thought-provoking and have the potential to inform school policy. S3_Ziv joined the Science Micro Video Society, which took place for approximately 100 min every week at school, with 36 students working in small groups and engaging in their own open inquiry projects. For example, her group in the society class was sceptical of the advertisements claiming that air-fried food is healthier than traditionally fried food and explored the differences in calorie content. She was the only student who experienced two different class types and mentioned the differences in terms of teachers' questioning:

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

The teacher–student ratio was 1:3 in her society class and 1:56 in her normal class; therefore, Ziv's questions in the society class were only for a few group members. S3_Ziv also stated that the purposes of the teachers' questions were different: teachers used questions to help students learn science knowledge in the normal class, but to solve students' practical problems in the society class.

> *In the classroom, we mainly (…) learn the biology textbook. The teacher's questions are to get the knowledge, that is, to ask us to think about his questions and better understand that knowledge. However, in scientific inquiry, (…) we assert that in scientific experiments, there is no such thing as success or failure; rather, we may conclude that we haven't achieved our experimental objectives. This's 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 class were about practical problems we were facing. So, they are different in essence… (S3_Ziv)*

She also addressed whether the teacher's questions were flexible:

> *In the classroom, questions make us just go straight along a road and we can't go back. So, this kind of thinking is very fixed. In the society class, (…) even if our method is not good, (…) the teacher will help us investigate it step by step and explore which method is the best. Then, he'll suggest using this improved method. He provides both support and advice. In*

> *our society class, all activities are optional. Our teacher describes himself as a facilitator, allowing us to make our own decisions. This means we have the freedom to either follow his suggestions or reject them. I believe this approach enables us to form our own opinions. (S3_Ziv)*

S3_Ziv emphasized the significance of student autonomy. She stated that there were no right or wrong answers, and students were given opportunities to try and modify their methods and make their own decisions in the society class. Therefore, in this example the teacher's power and authority shifted to teacher–student dialogue and negotiation. S3_Ziv also described her feeling of responding to these questions in the normal class as like she was travelling along a one-way road and it was impossible to return. Three of Ziv's students were interviewed, and while S1_Ziv did not make an analogy, S2_Ziv used a similar analogy regarding teachers' questions, that of staircases (see Fig. 2). These two analogies showed some similarities: (1) a teacher's question or a sequence of teachers' questions had a single direction, rather than various directions, which suggested that teachers' questions tended not to be divergent; and (2) the teacher seemed to control his questions and students were not given opportunities to alter the direction.

Views about scenario-based questions

Scenario-based questions asked students to pretend to be a person, plant, animal or object and to think about an imagined scenario. Simon, specifically, used this kind of question to encourage students to understand a living animal or a scientist: for example, "Imagine you are a mouse. What do you think?" All three of Simon's students were impressed by this type of question. For example, S3_Simon commented, "I think it's more immersive. I can think from another angle…", while S1_Simon remarked:

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

S2_Simon explained his appreciation of the question "Imagine you are the scientist Sutton. Why did you rule out the other two hypotheses?" (Simon_L1), which was asked after students suggested three hypotheses regarding the relationship between genes and chromosomes: genes are located on chromosomes; chromosomes are located on genes; and genes are chromosomes. Simon

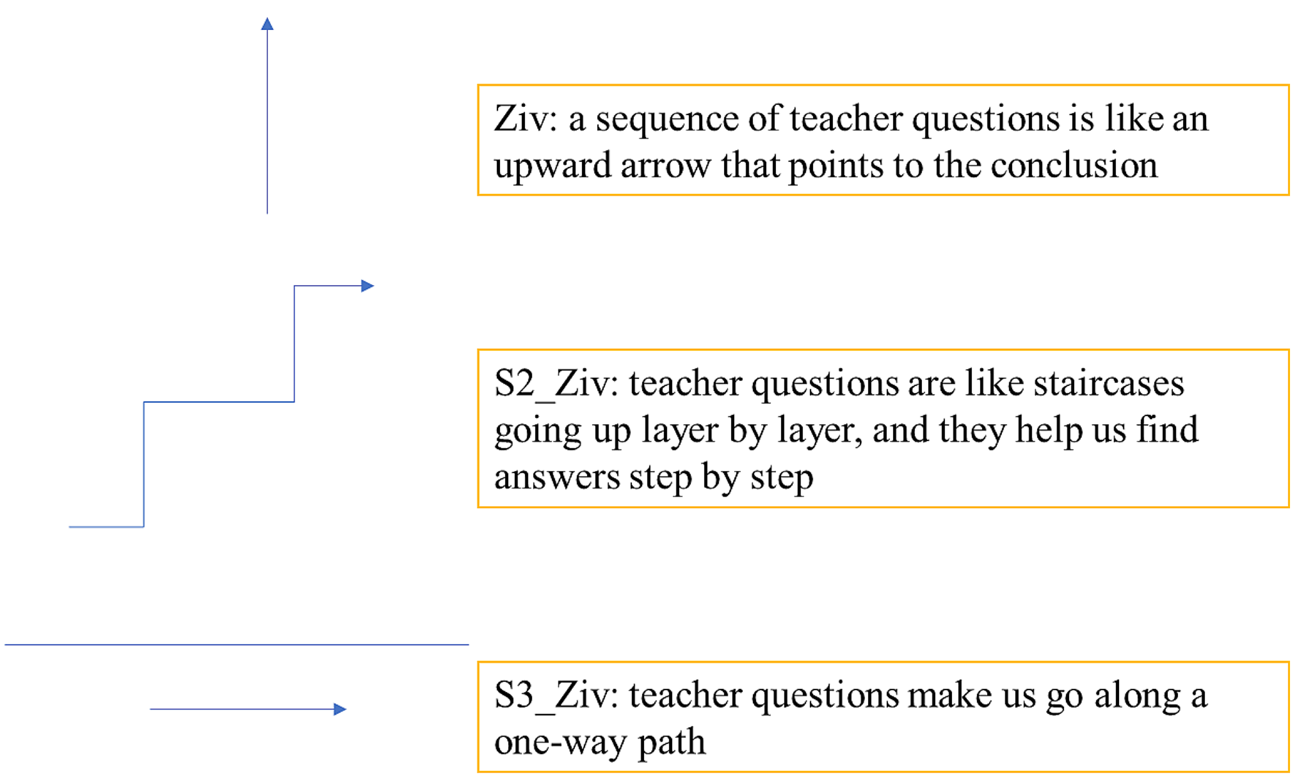

Fig. 2 Analogies of teacher questions

then asked students to rule out the incorrect hypotheses, about which S2_Simon remarked:

> *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. (S2_Simon)*

As the conversation went on, he added the following observations:

> *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.' (...) When the scientist selected male fruit flies for his experiment, the teacher posed a question, for example, 'If you were this scientific researcher, why would you want to select these [male fruit flies] that were so rare in nature?' (S2_Simon).*

Overall, in terms of the pedagogical domain, the students stated that scenario-based questions pushed them to imagine they were scientists and to try to think and make decisions from the scientist's perspective. Moreover, in terms of the epistemic domain, this type of question, such as "If you were Mendel..." and "If you were Sutton...", supported scientific practices that aimed to develop students' creative thinking and help students not only understand what scientists did but also know why they did it. 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 together and help students think actively about the question and data.

Table 2 Types of students' attention to teacher questioning

Categories of student attention	Focus of student attention	Domains of student attention	Potential messages sent by attention
Attention to the content of teacher questions	• Linked to examination	• Conceptual domain: learning science content knowledge	• Teacher questions should involve exam knowledge
Attention to the pedagogic aspects of teacher questions	• Gradually increasing difficulty • Using materials to support questioning	• Pedagogical domain: using questions in a way that relates to teaching methods and theories	• Teacher questions should align with the way in which students construct knowledge
Attention to the effect of teacher questions	• Improving concentration • Increasing learning motivation • Improving critical thinking	• Affective domain: attitudes; motivation • Epistemic domain: learning the nature of science	• Teacher questions should interest students • Teacher questions should develop the understanding of how science knowledge develops

Students' attention to other aspects of teachers' questioning

Students' attention to teachers' questioning refers to what they told me they noticed. This includes three categories (see Table 2): (1) the content of teachers' questions; (2) the pedagogic aspects of teachers' questions; and (3) the effect of teachers' questions.

The content of teachers' questions

Students tended to notice if teachers' questions involved knowledge that was more likely to be tested in exams, such as:

> *In terms of these two big questions, they are not written in the textbook. So, they are easily ignored by many people. However, examiners especially like to test this particular knowledge in exams. For example, this question was tested in the final exam of this semester. (S2_Helen)*

There were two questions that Helen asked after teaching the Hershey-Chase's method of experimentation: "How are T2 bacteriophages labelled with phosphorus-32 or sulfur-35?" (Helen_L3) 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?" (Helen_L3) Theoretically, there should be 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's attention may suggest to teachers that the content of teachers' questions should be focused more on preparing students for exams.

The pedagogic issues of teachers' questions

This section includes gradually increasing difficulty and using materials to support questioning. Four students noticed that their teachers gradually increased the difficulty level of their questions. 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 that increased in difficulty. Furthermore, as shown in Fig. 2, S2_Ziv commented that "teachers' questions are like staircases going up layer by layer, and they help us find answers step by step". This corresponds with Chin's (2007) view that a series of teachers' questions should be like a cognitive ladder that helps students to reach a high level of knowledge and understanding progressively.

Two students paid attention not only to the teachers' questions per se but also to the materials used. As S1_Ziv explained, "In terms of teachers' questions, what impressed me most was that the teacher brought a real heart for dissection. He took some parts of the real heart out and then asked questions." Teachers using real objects to support their questions impressed students more than a scenario in which Ziv might point at a ventricle in a picture of a heart and ask which blood vessel was directly linked to it. This may serve as a message to teachers about the value of utilizing resources to support effective questioning.

The effect of teachers' questions

Comments on the effect of teachers' questions included improved concentration and critical thinking and increased learning motivation, as explained in the following sections. Simon featured very prominently in this category because he used a wider range of forms of questioning and stressed the importance of critical thinking.

First, four of the students from senior secondary schools, S1_Helen, S2_Helen, S1_Simon and S2_Simon, focused on improving concentration. Subject knowledge in textbooks at this stage is more difficult to understand than that in junior secondary school, and therefore it is challenging for students to maintain their focus. The four students commented that teachers' 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, they 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."

Second, four students, S1_Simon, S2_Simon, S3_Simon and S1_Helen, remarked that teachers' questions increased their learning motivation, as shown in the following examples:

> *Why can bacteria cause sepsis when they have capsules? It, it needs expanded 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 the lesson, I just wouldn't know such knowledge. So, it sounded very novel at the time. (S1_Simon)*

Students used words such as "self-exploration", "interesting" and "novel" to describe their affective experiences when they were talking about two questions: "Why can bacteria cause sepsis when they have capsules?" (Simon_L3) and "What is the site of injection [of a mouse]?" (Simon_L3). Both of these questions from Simon involved subject matter knowledge that was not required in the textbook. However, in students' views, both questions not only broadened their minds but also maintained their interest. In the recording when Simon explained this question "What is the site of injection [of a mouse]?", he made this exchange funny and interesting and thereby created a relaxed and enjoyable atmosphere.

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 difficult and challenging, but it motivated S2_Simon to learn, which they explained as follows:

> *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)*

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

> *Interviewer: 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 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.*
> *Interviewer: Were you dazed?*
> *S2_Simon: That is, he suddenly… I felt that he suddenly demolished a building that had just been com-*

pleted. I just couldn't jump to conclusions. He often does this kind of thing. (S2_Simon)

Elsewhere in his interview, S2_Simon noted that Simon's questions helped him develop his critical thinking, and he started to critique: "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 my critical thinking." (S2_Simon). The comments indicated that the approach of suddenly asking students to critique a theory they had previously accepted helped them realize that scientific knowledge is not fixed and infallible. This approach helped students gain an epistemic understanding of how scientific knowledge develops, fostering a critical outlook and enabling them to examine scientific theories more critically. Attention to this epistemic function may indicate to teachers that they should use questions to help students develop an understanding of the nature of science, and this message is in line with curriculum standards, which emphasize that students should recognize that scientific knowledge evolves as research progresses (Ministry of Education, 2017).

Discussion

This study is a detailed account of students' perceptions of a specific question from teachers, a sequence of questions or teachers' questioning in general. As mentioned above, prior research on students' views (e.g., the nature of science) has tended to rely on questionnaires, and more importantly, few studies specifically address students' comments about teachers' questioning. A qualitative investigation is therefore distinctive and significant, extending our knowledge of student perceptions of teachers' questioning.

Students used a range of terms, such as "immersive", "fixed", "expanding thinking", "review prior knowledge", "from the perspective of this scientist", "a feeling of divergence", "debate" and "a task-driven feeling", to describe their views regarding teachers' questions. These examples showed students' sophisticated and thoughtful reflections on the role of teachers' questions, supporting Batten's (1989) demonstration that students were able to identify some aspects of teaching crucial to a lesson's success (e.g., clear instructions) and that listening to students' voices was important to researchers, teachers and teacher educators. Students pay attention to various elements of teachers' questioning, including the conceptual, pedagogical, social, affective and epistemic domains. Teacher educators can present students' views to teachers as a powerful tool for raising awareness, thereby assisting teachers in comprehending the different types of attention students exhibit and the messages they convey. It further motivates teachers to develop a diverse set of purposes for questions. This approach stands apart from previous studies that have concentrated on contrasting expert and novice teachers in professional development programmes (e.g., Carter et al., 1988; Jacobs et al., 2010).

In this current study, students liked being challenged and preferred it when teachers used materials (e.g., a real heart) to support questioning and when they created a fun, engaging atmosphere, which accords with Osborne and Collins's (2001) study examining students' views about the role and value of the science curriculum, as described in the literature review. Students stated that scenario-based questions (e.g., "Imagine you are the scientist Walter Sutton…") helped them think about the reasons behind a scientist's actions, encouraging students to make decisions from the scientist's perspective, and this finding provides powerful data that can be presented to teachers in teacher-training programmes and encourages the teachers to ask questions that fully engage students with issues and enable them to think from different perspectives.

Teachers' questions can serve as indicators of the extent of teachers' authority in shaping classroom discourse: for instance, the amount of verbal space allocated for student participation (Osborne & Reigh, 2020). This study has shown that students valued questions that were asked in a way that demonstrated teachers' power and authority less and supported student engagement in knowledge construction: a conclusion based on the following three findings. First, students preferred open questions over closed; for example, S1_Helen kept silent in response to closed questions used to recall factual knowledge. Several students commented that open questions with no fixed answers encouraged them to think from different perspectives, inspired their imagination and creativity, and helped them find a personal interest in the argumentation of theories. Second, S3_Ziv highlighted the importance of a safe and relaxed questioning environment in which teachers' questions were not used as tools to judge students' prior knowledge and 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 regarding group work (e.g., Hume & Coll, 2008; Roychoudhury & Roth, 1996).

The third finding, an original and important perspective, was offered by a student who noticed significant differences in the teachers' questions in the society class and the normal class. According to S3_Ziv, teachers' questions appeared to be rigid and fixed during normal sessions but more flexible in the society class. She also stated that teachers' questions were used to teach specific scientific knowledge in the normal class, while in the society class they were asked in response to students' confusions and difficulties and to help students think about different possibilities and options. As a result, teachers' questions in the society class were less concerned with transmitting their authority as teachers, and it seems possible that teachers could ask more open questions when they have different goals compared with when they are under assessment pressure to teach prescribed subject content knowledge. This finding not only contributes to the literature by providing the student's observation that the teacher used questions very differently in different class types but also presents implications for policy and practice. Schools and teachers are encouraged to organize various types of classrooms. If there are optional classes (e.g., society classes) that are set aside and have a slightly different status, this can provide an opportunity for teachers to try new things (e.g., carrying out open inquiry) and be more flexible.

This study serves as a base for related future studies involving in-depth student interviews (e.g., students' views about teachers' feedback). The combination of episodes and student drawings successfully triggered memories and enhanced students' engagement in the interviews through visual and textual elicitation. This suggests that the technique methodology could be used more extensively in future studies.

Several important limitations need to be considered. Data collection during the pandemic prevented classroom observations and face-to-face interactions with students, potentially impacting rapport-building and student recruitment for the study. Moreover, students showed no significant differences in academic performance or interest in biology, while primarily highlighting the advantages of teachers' questioning without offering any negative feedback. This suggests that a further study, focusing on diversified student views regarding teachers' questioning, is needed.

Conclusions

Students can show their sophisticated and thoughtful reflections on the role of teachers' questions, focusing not only on the conceptual aspects of teachers' questions but also addressing a variety of domains, including pedagogical, social, affective and epistemic. The students also preferred teachers' questioning that demonstrated the teacher's power and authority less and supported student engagement in knowledge construction. This discussion would extend our understanding of how students perceive teachers' questioning and provide resources for teachers' professional development by using student data to enhance teachers' awareness.

Appendix 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 audio-recorded lesson?

Prompts:

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

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Author contributions

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Data availability

The datasets generated by the research during and/or analyzed during the current study are available in the University of Leeds research data repository, https://doi.org/10.5518/1392. Access to the data is subject to approval and a data access agreement.

Declarations

Ethics approval and consent to participate

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

Consent for publication

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

Competing interests

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

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