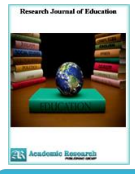

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Application of SOLO Taxonomy-Driven Question-Chain Teaching in High School Biology: A Survey-Based Study

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Abstract

The revised Chinese National Curriculum Standards for High School Biology (2017, 2020 revision) explicitly require that students actively engage in learning and develop scientific thinking habits. The Structure of the Observed Learning Outcome (SOLO) taxonomy provides a quantitative framework for evaluating students' cognitive levels, enabling both teachers and learners to identify the specific stage of thinking development that a student has attained. Question-chain teaching, which guides students through a logically sequenced series of questions, has been shown to promote the progressive development of higher-order thinking. Against this background, the present study adopts SOLO taxonomy as its theoretical lens and instructional design framework to guide the hierarchical organisation and progressive sequencing of question chains, to construct a question-chain teaching model, and to explore the design principles and implementation strategies associated with this model. A chapter on the fundamental procedures of genetic engineering serves as the illustrative case for classroom implementation. The study investigates the practical effectiveness and educational value of SOLO taxonomy-driven question-chain teaching in senior high school biology classrooms through a mixed-methods survey involving students and in-service teachers.

Keywords: SOLO taxonomy; question-chain teaching; cognitive hierarchy; high school biology; instructional design.

1. Introduction

In the context of ongoing curriculum reform in China, high school biology education has shifted its emphasis from rote memorisation and knowledge transmission toward the cultivation of disciplinary core competencies. The 'New Gaokao' reform has reoriented pedagogical goals: rather than training students to solve examination-type problems mechanically, the system now prioritises the elevation of cognitive hierarchy and the development of transferable scientific thinking skills. Correspondingly, teachers are expected to evolve from knowledge disseminators to competency cultivators, moving from didactic lecturing to diversified, student-centred interaction.

Despite these aspirations, conventional classroom practice in high school biology frequently features ineffective questioning or an absence of structured questioning altogether—a state of affairs that runs counter to the demands of the reformed curriculum and fails to support the development of students' core disciplinary competencies. Two theoretical resources are particularly well suited to addressing this gap.

The SOLO (Structure of the Observed Learning Outcome) taxonomy (Biggs & Collis, 1982) classifies students' cognitive responses into five progressively sophisticated levels: Prestructural, Unistructural, Multistructural, Relational, and Extended Abstract. By mapping observable learning outcomes to specific cognitive tiers, SOLO provides teachers with a principled means of diagnosing where students currently stand and designing instruction that moves them forward. Unlike outcome-focused evaluation frameworks that reduce learning to a single score, SOLO foregrounds the quality of thinking and the trajectory of cognitive growth.

Question-chain teaching organises instructional content as a coherent series of questions linked by logical and hierarchical relationships. Through this scaffold, learners are guided to complete complex reasoning tasks, thereby cultivating logical inference and inductive thinking as well as facilitating knowledge transfer. When SOLO taxonomy is used to drive the design of question chains, the five cognitive levels serve as blueprints for constructing low-, intermediate-, and high-order questions. Teachers then connect these questions into a pedagogical sequence that accompanies students step by step to the upper tiers of SOLO, fulfilling the curricular requirements of the new era.

The present study investigates the current landscape of SOLO taxonomy-driven question-chain teaching in Chinese high school biology classrooms by surveying students and interviewing in-service teachers. Drawing on the

empirical findings, the paper identifies existing challenges and offers evidence-based recommendations for classroom practice and school-level support.

The concept of a 'question chain' has been defined in several ways across the literature. Early formulations describe it as a thinking method that centres on a sequence of questions, suited to capturing the dynamic nature of the world and the rigorous logical structure of mathematics (Huang, 2003). More broadly, Wang (2010) defines a question chain as a systematically organised series of hierarchically distinct instructional questions that a teacher constructs by analysing students' existing knowledge and anticipating the difficulties they are likely to encounter during learning.

Despite variations in emphasis, these definitions converge on two core elements: 'question' and 'chain'. In educational terms, 'question' denotes a cognitive obstacle at the level of understanding, while 'chain' denotes a linear structure formed by multiple interconnected elements. A question chain may therefore be understood as a structure in which multiple questions are linked by their hierarchical and logical relationships—in essence, a systematically organised cluster of cognitive challenges.

Question-chain teaching is a dynamic instructional approach that takes the question chain as its organisational core, encompassing instructional design, student inquiry, and interactive feedback. It is distinct from the question chain itself: whereas the question chain is a tool focused solely on the design of the questions, question-chain teaching is a process oriented toward achieving instructional objectives through the deployment of that tool.

Early research characterises question-chain teaching as an instructional activity that uses the question chain as a thread to guide students' thinking and to promote cognitive development (Lü, 2014). A more process-focused account describes it as teaching in which the teacher organises students to work through a self-designed series of questions, thereby enabling students to construct knowledge, develop problem consciousness, and acquire pathways to new understanding (Yan & Li, 2011). Synthesising these perspectives, question-chain teaching may be defined as a pedagogical approach in which the teacher uses a purposefully designed question chain as the organising thread of instructional activity, guiding students to solve problems progressively while simultaneously constructing knowledge and developing higher-order thinking.

SOLO taxonomy (Biggs & Collis, 1982; Hook, 2016) classifies the quality of students' responses to a specific task into five hierarchical levels: (1) Prestructural—the student has virtually no understanding of the problem; (2) Unistructural—the student demonstrates a rudimentary, single-point grasp of the problem; (3) Multistructural—the student understands the problem in greater depth but still lacks integration; (4) Relational—the student achieves a holistic understanding and can solve the problem independently; (5) Extended Abstract—the student not only understands the problem as a whole but can also generalise and abstract it, applying the principle to novel situations (Pan, Wu, & Sun, 2020). By focusing on the structure of learners' thinking, SOLO taxonomy supports deep exploration across multiple domains of inquiry and provides a principled basis for designing differentiated instructional challenges.

2. Research Design and Survey Methods

2.1. Research Objectives

The present survey had three primary objectives. First, to document the current state of teacher questioning practices in senior high school biology classrooms and students' perceptions of those practices, thereby establishing a baseline understanding of question-chain teaching in situ and identifying existing pedagogical gaps. Second, to assess students' awareness of and expectations regarding question-chain teaching, and to evaluate the feasibility of implementing this approach in the local context. Third, to gather frontline teachers' views and recommendations on integrating SOLO taxonomy with question-chain teaching, so that the proposed model can be refined to better suit actual classroom conditions.

2.2. Participants

2.2.1. Student Sample

Student data were collected from Grade 11 students at X County No. 1 Senior High School using a random sampling procedure. A total of 330 students participated; the sample covered multiple class groups and diverse academic attainment levels, lending it a degree of representativeness. Of the 330 questionnaires distributed in paper form on an anonymous basis, 311 valid questionnaires were returned, yielding an effective response rate of 94.2%.

2.2.2. Teacher Sample

Six biology teachers from the same school's senior high biology teaching group were recruited for semi-structured interviews. As summarised in Table 1, the participants differed considerably in teaching experience, professional title, and academic qualifications, providing a diverse and representative perspective on current instructional practice.

Table-1. Profile of Interviewed Teachers

Teacher ID	Years of Experience	Professional Title	Education
Z	25	Senior Teacher	Bachelor's
F	9	Grade II Teacher	Bachelor's
W	11	Grade I Teacher	Bachelor's
D	2	Grade II Teacher	Master's
Y	8	Grade I Teacher	Bachelor's
G	15	Grade I Teacher	Master's

2.3. Instruments

2.3.1. Student Questionnaire

The student questionnaire comprised 16 items across four dimensions (Table 2): (1) Classroom Questioning Status (items 1–4), (2) Students' Classroom Perceptions (items 5–8), (3) Awareness and Experience of Question-Chain Teaching (items 9–12), and (4) Expectations Regarding Teaching Methods (items 13–16). The first 15 items were closed-ended (single or multiple choice); item 16 was an open-ended question. The instrument was reviewed and piloted with colleagues before formal administration to ensure clarity and appropriateness of item wording.

Table-2. Dimensions and Structure of the Student Questionnaire

Survey Dimension	Item Numbers
Classroom Questioning Status	1, 2, 3, 4
Students' Classroom Perceptions	5, 6, 7, 8
Awareness & Experience of Question-Chain Teaching	9, 10, 11, 12
Expectations Regarding Teaching Methods	13, 14, 15, 16

2.3.2. Teacher Interview Protocol

The semi-structured interview protocol contained eight questions organised around three themes (Table 3): (1) the current state of traditional teaching modes, (2) classroom questioning design and student responses, and (3) awareness and application of question-chain teaching and SOLO taxonomy. The three-part structure was designed to elicit teachers' understanding of both theoretical constructs and their practical implications, thereby informing subsequent instructional design.

Table-3. Dimensions and Structure of the Teacher Interview Protocol

Interview Dimension	Item Numbers
Status of Traditional Teaching Modes	1
Classroom Questioning Design & Student Responses	2, 3
Awareness & Application of Question-Chain Teaching and SOLO Theory	4, 5, 6, 7, 8

3. Results and Analysis

3.1. Student Questionnaire Findings

3.1.1. Classroom Questioning Status

Regarding the frequency of teacher questioning in new-content lessons, 60.5% of students reported that their teachers question occasionally, 28.9% reported frequent questioning, and only 10.6% indicated that their teachers rarely question (Figure 1A). These figures suggest that questioning is already a widely adopted instructional strategy, particularly for introducing new material and emphasising key knowledge, and that outright teacher-centred lecturing without any questioning is relatively rare.

With respect to whether teachers use questioning to introduce new content, 55.3% of students stated that this occurs occasionally, and 32.5% reported it happens frequently, while 12.2% were uncertain (Figure 1B). This finding indicates that question-driven lesson openings are common practice, supporting prior learning consolidation and directing students' thinking toward subsequent content.

When asked whether teacher questions helped them understand biological concepts, 81.0% of students answered affirmatively, 16.7% perceived only moderate benefit, and 2.3% found questioning unhelpful (Figure 1C). The strong endorsement suggests that students are broadly receptive to questioning as an instructional method.

The distribution of question types (multiple-choice item, Figure 1D) revealed that 77.8% of students identified recall of foundational knowledge as the dominant question type, 61.4% identified principle comprehension and application, 19.3% identified explanation of everyday phenomena, and 18.7% identified experimental analysis. Questions linking biological content to real-life contexts appeared relatively infrequent, suggesting room for greater contextualisation in classroom questioning.

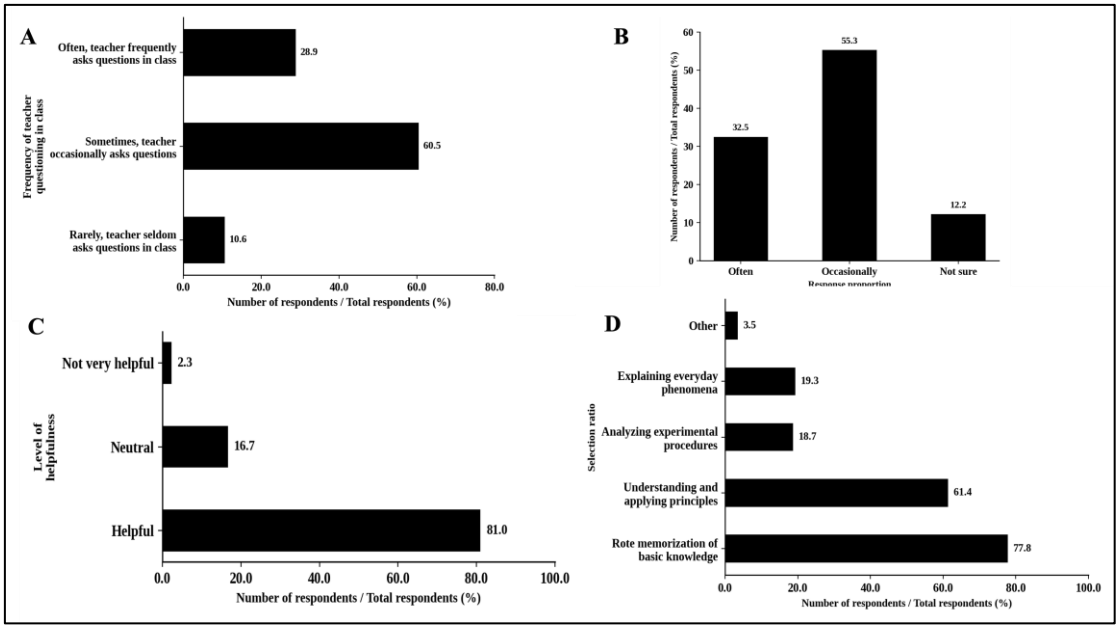

Figure-1. Survey Results on Teacher Questioning Behavior in the Classroom. A: Statistics on Classroom Questioning Frequency; B: Statistics on Methods of Introducing New Lessons; C: Statistics on the Benefits Gained from Questioning; D: Statistics on Types of Questions.

3.1.2. Students' Classroom Perceptions

On receptiveness to being questioned, 58.8% of students expressed neutral acceptance, 17.4% expressed a positive preference, and 23.8% reported disliking being questioned (Figure 2A). The predominant neutrality, combined with the relatively small proportion of students who actively dislike questioning, suggests a sufficiently favourable affective climate for implementing question-chain teaching.

Perceived difficulty of questions was rated as moderate by 87.8% of students, with only 10.0% finding them difficult and 2.3% finding them easy (Figure 2B). This clustering around 'moderate' points to an underrepresentation of both accessible questions (which might engage lower-attaining students) and more challenging questions (which might stretch higher-attaining students), highlighting the need for a more deliberate distribution of difficulty levels.

When a peer was being questioned, 84.2% of students reported actively thinking about the answer themselves, while only 3.9% felt the interaction was irrelevant to them (Figure 2C). This high rate of vicarious engagement is a favourable precondition for question-chain teaching, indicating that the class participates cognitively even when individual students are not directly addressed.

Regarding the perceived utility of teacher questions for knowledge comprehension, 73.0% of students found them helpful for clarifying the logical relationships within content, 25.7% found them only marginally helpful, and 1.3% found them unhelpful (Figure 2D). This pattern underscores the importance of designing question chains that make the internal logic of knowledge visible, rather than asking isolated or disconnected questions.

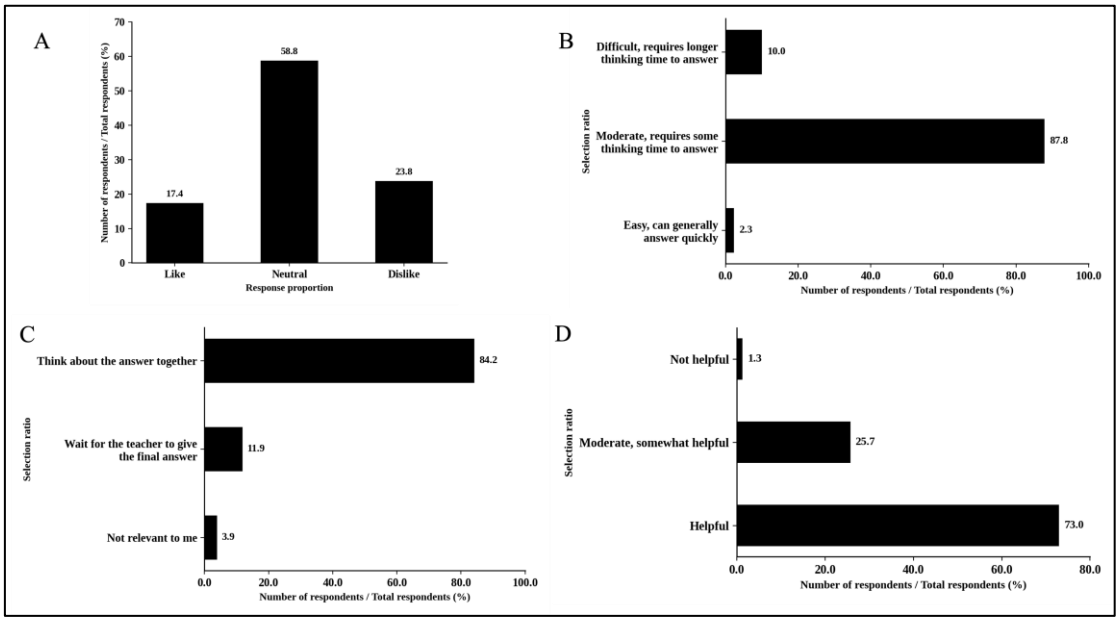

Figure-2. Survey Results on Students' Experiencein the Classroom.
A: Statistics on Acceptance of Being Questioned; B: Statistics on Perceived Difficulty of Questions; C: Statistics on Personal Performance; D: Statistics on Perceived Usefulness of Questions.

3.1.3. Awareness and Experience of Question-Chain Teaching

When asked whether they had encountered a hierarchically progressive question series (e.g., first asking about a phenomenon, then its cause, then its application), 77.5% of students reported having encountered such sequences occasionally, 12.2% frequently, and 10.3% almost never (Figure 3A). The prevalence of 'occasional' encounters suggests that while some teachers intuitively employ question sequences, systematic, theory-driven question-chain teaching has not yet been institutionalised.

Students' perceptions of the potential value of question-chain teaching (multiple-choice) were notably positive (Figure 3B): 76.2% believed it could help them organise the logical structure of knowledge, 64.3% believed it could stimulate deeper thinking, 51.8% believed it could enhance their capacity to solve complex problems, 28.0% believed it could clarify learning objectives, and only 3.2% anticipated no benefit. This favourable outlook provides strong motivational grounding for the introduction of question-chain teaching.

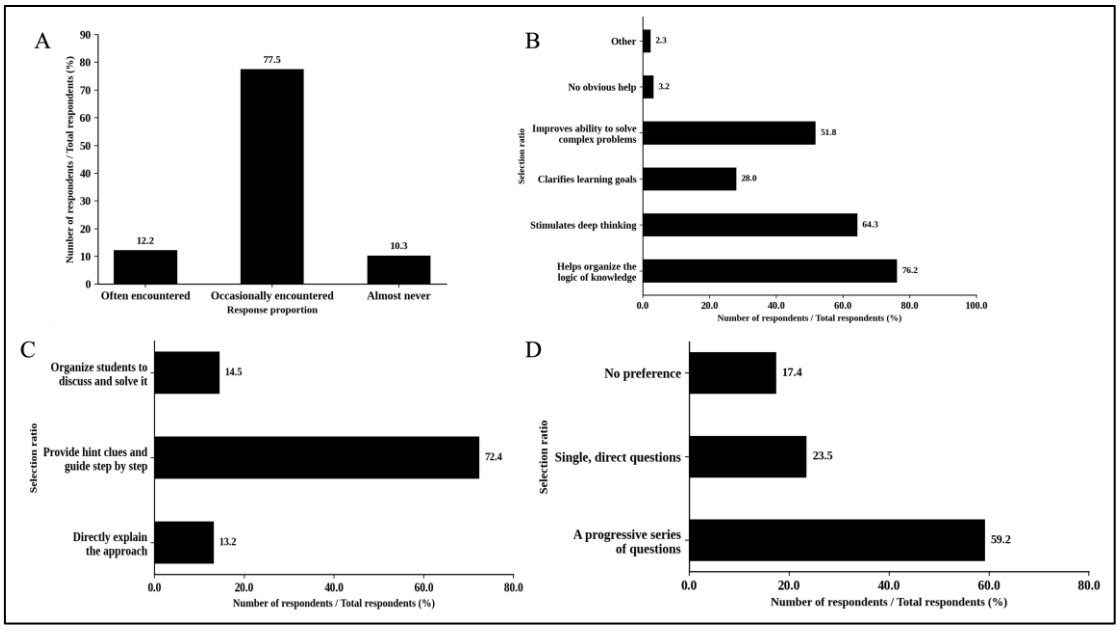

Figure-3. Survey Results on Awareness and Experience of Question-Chain Teaching. A: Statistics on Frequency of Exposure to Question Chains; B: Statistics on Perceived Value of Question Chains; C: Statistics on Strategies for Solving Difficult Problems; D: Statistics on Preference for Question Types.

Regarding preferred teacher strategies for difficult questions within a question chain, 72.4% of students preferred that teachers provide guided hints and lead them step by step toward a solution, 14.5% preferred small-group discussion, and 13.2% preferred direct explanation of the solution pathway (Figure 3C). The strong preference for scaffolded guidance is consistent with Vygotskian conceptions of the zone of proximal development and lends support to the incremental, hierarchical design central to SOLO-driven question chains.

When given a choice between single direct questions and progressive question series, 59.2% of students expressed a preference for the latter, 23.5% preferred single questions, and 17.4% were indifferent (Figure 3D). The majority preference reinforces the potential appeal of question-chain teaching, while the non-trivial minority who prefer direct questioning reminds practitioners to ensure that individual question chains are clearly worded and not unnecessarily complex.

3.1.4. Expectations Regarding Teaching Methods

Students' most preferred teaching method (multiple-choice) was detailed teacher explanation (64.3%), followed by experiment-integrated demonstration (22.5%), small-group discussion (20.9%), and autonomous inquiry (12.9%) (Figure 4A). A small number of students expressed a preference for combining all four approaches. These data suggest that students value clear conceptual guidance while also desiring practical, interactive, and inquiry-based components—an expectation well aligned with the differentiated question scaffolding inherent in question-chain teaching.

The overwhelming majority of students (86.5%) preferred a moderate instructional pace, with only 7.4% preferring a slow, in-depth pace and 6.1% a rapid pace (Figure 4B). This finding advises practitioners of SOLO-driven question-chain teaching to calibrate pacing carefully: allowing sufficient time for difficult higher-order questions while maintaining brisk momentum through straightforward content.

With regard to the types of help students hoped to derive from classroom questions (multiple-choice), 85.2% prioritised mastering problem-solving strategies, 62.7% wished to understand abstract concepts, 46.3% sought links to real-life phenomena, and 44.7% aimed to extend their depth of understanding (Figure 4C). These layered aspirations correspond naturally to the hierarchical levels of SOLO taxonomy and confirm that question chains designed to progress from recall to application to abstraction can address the full range of students' expressed learning needs.

Open-ended responses to the question asking how students most hoped their biology teacher would teach (item 16) were subjected to frequency analysis (Figure 4D). 'Explanation' emerged as the most frequently cited term, indicating students' desire for rich, multimodal explanation rather than passive information transfer. Recurring themes included connections to everyday life, classroom interaction, and an element of enjoyment—all of which are amenable to the question-chain approach.

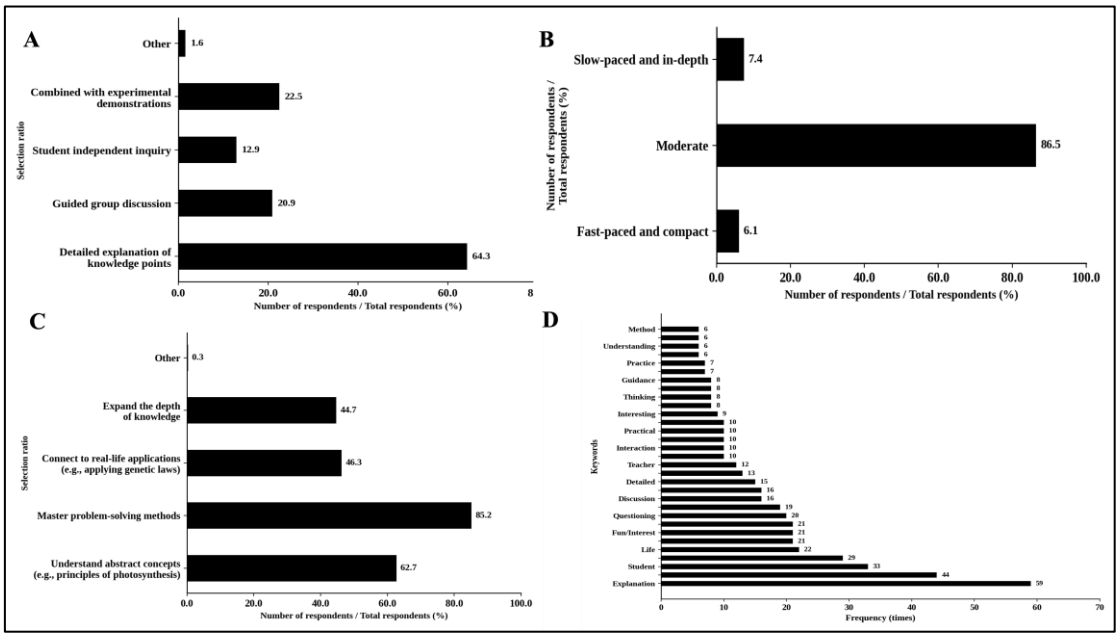

Figure-4. Survey Results on Expectations for Teaching Methods.
A: Statistics on Preferred Teaching Methods; B: Statistics on Preferred Classroom Pace. C: Statistics on Expected Gains from Questions. D: Detailed Word Frequency Analysis of Student Expectations.

3.2. Teacher Interview Findings

3.2.1. Status of Traditional Teaching Modes

All six teachers (Table 1), despite differences in experience and teaching style, identified a common limitation of traditional instruction (based on Table 2 and Table 3): its teacher-centredness, which marginalises students as active participants and stifles initiative and creativity. Teachers Z and W specifically noted that teacher-dominated classrooms prevent students from engaging in independent thinking. Teachers Y and G emphasised the logic-intensive character of biological knowledge and argued that transmission-oriented teaching neglects students' epistemic agency. Teacher F acknowledged that adopting new models increases planning workload, a concern that must be addressed in any reform initiative. The convergent critique of traditional modes confirms that a theory-guided alternative is both pedagogically desirable and practically necessary, provided that it is operationalised in a clear, normative, and workload-conscious manner.

3.2.2. Classroom Questioning Design and Student Responses

Teachers varied in their approach to question design. Teacher W aligned questions closely with Gaokao examination points; Teacher D used questions to scaffold a knowledge chain; Teacher Y calibrated question selection to exercise difficulty levels. Across classrooms, a consistent pattern of polarisation was observed in student engagement: high-attaining students participated actively, while lower-attaining students largely withdrew. This pattern highlights the urgent need for deliberate question design that broadens participation. Informed by constructivist and scaffolding frameworks, the analysis suggests that isolated or fragmented questions should be reorganised into coherent, logically connected series; SOLO taxonomy can then render these questions concrete by mapping them onto students' cognitive structures and thinking levels. Combining SOLO taxonomy with the zone of proximal development further enables teachers to calibrate the starting point and endpoint of each question chain, preventing sequences from being either excessively straightforward or prohibitively challenging.

3.2.3. Awareness and Application of SOLO Taxonomy and Question-Chain Teaching

On the topic of question-chain teaching, teachers Z and D valued it for its enhanced logical coherence. All six teachers agreed that question chains must be calibrated to students' cognitive levels and aligned with Gaokao requirements. Regarding SOLO taxonomy, Teachers D and G—drawing on their postgraduate academic backgrounds—demonstrated a deeper understanding of the framework and expressed strong support for its integration with question-chain teaching. The remaining four teachers had limited prior exposure to SOLO taxonomy but were generally open to the proposed combination. These responses confirm the theoretical and practical relevance of the proposed model while also identifying a clear need for systematic professional development before large-scale implementation: teachers who lack familiarity with SOLO taxonomy will require structured training to use it effectively as a design tool.

4. Discussion

4.1. Summary of Survey Conclusions

The combined survey and interview data support four conclusions. First, both students and teachers expressed dissatisfaction—to varying degrees—with certain aspects of current biology classroom practice, particularly the predominance of teacher-centred questioning and the relative neglect of question-based logic scaffolding. Second, both groups demonstrated a relatively high degree of acceptance of question-chain teaching. Third, both groups were broadly receptive to SOLO taxonomy as an organising framework for instruction. Fourth, implementing a SOLO taxonomy-driven question-chain teaching model represents a non-trivial challenge for students and teachers at this school, signalling the importance of phased introduction and ongoing support.

4.2. Implications for Theory and Practice

The findings have several implications. For instructional design, they affirm that a hierarchically organised, logically sequenced question structure has both theoretical legitimacy and practical appeal. For teacher professional development, they identify SOLO taxonomy fluency as a capacity that must be explicitly cultivated, not assumed. For assessment, they suggest that evaluating the quality of student responses—rather than merely their correctness—through a SOLO lens could yield richer diagnostic information and more responsive teaching.

5. Recommendations

5.1. Rethinking Pedagogical Beliefs: Constructing Cognitively Progressive Question-Chain Classrooms

Teachers need to reconceptualise question design beyond the simple serialisation of knowledge points. Drawing on SOLO taxonomy, questions should be classified into distinct tiers—Unistructural, Multistructural, Relational, and Extended Abstract—and sequenced from shallow to deep. During instruction, teachers should take students' current thinking as the starting point, design progressively challenging question sequences, and use follow-up questions to surface and diagnose students' cognitive processes. This diagnostic function allows teachers to adjust the difficulty and direction of the question chain in real time, enhancing students' understanding of the internal logic of biological knowledge and their capacity for knowledge transfer.

5.2. Selecting Question-Chain Materials Strategically: Building Contextualised, Logically Coherent Problem Environments

In selecting materials for question chains, teachers should adhere to the principles of gradation, appropriateness, contextualisation, and interactivity. Chosen questions should resonate with students' lived experience and cognitive level while remaining tightly aligned with instructional objectives and disciplinary core concepts. Crucially, question chains should be embedded in authentic contexts that integrate abstract biological principles into concrete everyday phenomena and scientific case studies. This contextualisation activates students' intrinsic motivation for inquiry and deep reasoning, guiding them through the logical structure of a question chain to construct coherent knowledge systems and achieve the transition from lower-order to higher-order thinking.

5.3. Institutional Support: Developing Teachers' Capacity for Question-Chain Design and SOLO Application

Schools should provide systematic professional learning platforms, including specialised training workshops on SOLO taxonomy and question-chain teaching, expert lectures, curated research literature, and the gradual development of school-based repositories of question-chain materials and exemplary lesson plans. Collaborative lesson planning and reflective teaching practices within subject teaching-research groups should be strengthened, encouraging teachers to co-design question chains aligned with SOLO levels and to observe each other's classrooms. Peer learning and teaching competitions can serve as additional levers for professional growth. On the material side, schools should update multimedia teaching equipment and ensure reliable access to digital tools, providing the technical infrastructure necessary for effective question-chain instruction. In summary, schools should invest in building multi-faceted platforms for teacher learning and development, continuously enhancing teachers' capacity to design and implement SOLO taxonomy-driven question-chain teaching.

6. Conclusion

The SOLO taxonomy-driven question-chain teaching model breaks with the transmission-dominated paradigm of conventional instruction by foregrounding the progressive development of students' cognitive hierarchy and positioning students as the central agents of the classroom. Based on a systematic survey of student and teacher perceptions at a Chinese senior high school, this study demonstrates that both groups are broadly receptive to SOLO taxonomy and question-chain teaching, while also acknowledging the challenges inherent in scaling up a theory-grounded innovation. The findings call for teacher re-orientation of pedagogical beliefs, strategic selection and contextualisation of question-chain materials, and robust school-level institutional support. Together, these conditions are necessary for SOLO taxonomy-driven question-chain teaching to fulfil its potential as a vehicle for realising the high-order thinking aspirations of China's reformed biology curriculum—and, more broadly, for any educational system that seeks to move students from surface to deep learning through principled, progressive questioning.

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