

Research paper

High School Biology Teachers' Perspectives on Future-Oriented Pedagogy through Inquiry-Based Laboratory Practices

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ABSTRACT

As education systems increasingly seek to prepare students for an uncertain and rapidly changing future, inquiry-based biology instruction offers meaningful opportunities to develop critical thinking, collaboration, adaptability, and real-world problem-solving skills. These competencies closely align with the principles of Future-Oriented Pedagogy (FOP). This study explored how high school biology teachers perceive integrating Future-Oriented Pedagogy into their inquiry-based laboratory instruction. Twelve biology teachers from a high school in Kazakhstan participated in structured interviews, and the data were analyzed using thematic content analysis guided by the six dimensions of FOP: personalization, collaboration, globalism, change, integration, and informality. The findings revealed that inquiry-based laboratory teaching naturally supports personalization, as students make choices and take ownership of their learning; collaboration, through group work and peer support; and change, by helping students develop resilience when facing unexpected outcomes. Inquiry activities also promoted integration by helping students connect scientific learning with real-world environmental and health issues and encouraging informal learning beyond the classroom. However, the globalism dimension, particularly ethical and cultural awareness, was less consistently expressed. Challenges included limited resources, time constraints, and insufficient collaborative structures for teachers. The study indicates the need for professional development, institutional support, and curriculum alignment to strengthen inquiry-based biology education as a future-oriented instructional approach.

Keywords: biology education, future-oriented pedagogy, inquiry-based learning, laboratory instruction

In an era marked by constant scientific, social, and technological transformation, biology education must equip students with critical competencies for the future (Adkins et al., 2023). Inquiry-based science instruction, especially in laboratory contexts, offers students authentic experiences with problem-solving, collaboration, and scientific thinking (Goldberg & Dawin, 2025). The Future-Oriented Pedagogy (FOP) model emphasizes six key principles: personalization, collaboration, globalism, adaptability to change, integration, and informality. These principles align closely with the goals of inquiry-based instruction. Building on the study by Sachyani et al. (2024), this project

seeks to explore how biology teachers perceive the alignment between their lab-based inquiry teaching practices and the FOP framework.

The significance of this study lies in its contribution to enhancing biology teaching and learning through the implementation of inquiry-based pedagogy. In traditional classrooms, biology is often taught through rote memorization, which limits students' ability to think critically, explore scientific phenomena, and apply knowledge to real-world problems. Inquiry-Based Biology Education (IBBE) offers a transformative approach that increases active learning, curiosity, and problem-solving skills by positioning students as investigators in the learning process (Beck et al., 2014; Spence et al., 2020). Previous studies have demonstrated that IBBE both improves conceptual understanding and develops higher-order thinking and scientific reasoning. For instance, Manishimwe et al. (2018) and Chikaluma et al. (2022) found that inquiry-based approaches significantly enhance students' motivation, engagement, and laboratory competence in African secondary schools, suggesting that such methods are effective across diverse educational contexts.

Furthermore, this study is significant for teachers and curriculum developers seeking to reform biology education through innovative, evidence-based methods. Silm (2017) emphasized that teacher readiness and professional development (Wekullo, 2026) are critical for the successful adoption of inquiry-based strategies, as educators serve as facilitators who guide students' investigations and scaffold their learning experiences. Likewise, Chengere et al. (2025) provided empirical evidence that guided inquiry-based laboratory (IBL) instruction enhances students' science process skills, skills essential for developing scientific literacy and pursuing careers in STEM fields. By integrating these findings, the present study contributes to ongoing efforts to modernize biology education, aligning it with 21st-century competencies and national curriculum reforms that prioritize inquiry, critical thinking, and creativity. Ultimately, the study shows the pedagogical and societal importance of empowering learners to think scientifically, make informed decisions, and contribute innovatively to sustainable development.

Research Questions

1. How do biology teachers perceive the integration of FOP in their current inquiry-based laboratory instruction?
2. Which FOP principles are perceived to be naturally aligned with their teaching practices?
3. What challenges or support systems do teachers report when implementing inquiry-based biology instruction with a future-oriented focus?

LITERATURE REVIEW

Inquiry-based education

Inquiry-Based Education (IBE) represents a student-centered approach that positions learners as active constructors of knowledge through questioning, investigation, and reflection. It encourages curiosity, critical thinking, and problem-solving by engaging students in authentic learning experiences that mirror scientific and real-world inquiry processes (Bonney et al., 2024; Dobber et al., 2017; Tekin & Eryılmaz Muştu, 2021). Numerous studies have demonstrated the effectiveness of IBE in enhancing learning outcomes and motivation. Öztürk et al. (2022), through a second-order meta-analysis, confirmed that inquiry-based learning exerts a medium positive effect on student achievement across disciplines. Similarly, Attard et al. (2021) showed that professional learning programs centered on IBE, particularly when combined with industry partnerships, significantly improve student engagement in STEM fields (Yaki, 2022). Rubio and García Conesa (2022) found that applying IBE in primary classrooms nurtures curiosity and retention, supporting the development of foundational scientific reasoning from an early age. However, effective implementation of IBE requires teachers to skillfully balance student autonomy with structured guidance, acting as facilitators who scaffold inquiry processes and model reflective thinking (Dobber et al., 2017; Schmidthaler et al., 2023). For teacher preparation, Strat et al. (2024) pointed out that embedding inquiry-based science education in teacher training increases pedagogical confidence and a deeper understanding of scientific inquiry.

Inquiry-based biology education

IBBE increases active participation in the learning process by engaging students in scientific questioning, experimentation, and reflection to construct biological knowledge rather than passively receiving it. Numerous studies confirm that IBBE enhances conceptual understanding, motivation, and attitudes toward learning biology. For example, Manishimwe, et al. (2018) demonstrated that implementing inquiry-based strategies significantly improved Rwandan secondary students' attitudes and enthusiasm for biology. Similarly, Chikaluma et al. (2022) found that inquiry-based learning in Malawian secondary schools enhanced learners' analytical and practical laboratory skills, indicating its potential to improve biology teaching quality in resource-limited contexts. Beck et

al. (2014) argued that incorporating more open forms of inquiry in biology laboratories encourages students to think and act like scientists, increasing ownership of learning. Spence et al. (2020) also showed that inquiry-driven lab curricula improve students' critical thinking and engagement by allowing them to design and test their own hypotheses. Research shows that IBBE both promotes deeper understanding of biological concepts and cultivates scientific literacy, creativity, and lifelong inquiry skills vital for modern science education (Chengere et al., 2025; Silm, 2017; Spence et al., 2020; Stylianidou et al., 2018).

Future-oriented pedagogy

FOP represents an educational paradigm designed to equip learners with the competencies, dispositions, and values needed to thrive in an unpredictable and rapidly changing world. Rooted in the principles of 21st-century education, FOP emphasizes adaptability, creativity, and systemic thinking as responses to global challenges (Abbiss, 2015). It calls for a reorientation of education toward innovation and complexity, showing the importance of learning environments that promote collaboration, autonomy, and authentic engagement with real-world problems. The OECD's Future of Education and Skills 2030/2040 initiative supports this direction, indicating the need for students to develop transformative competencies that enable them to create better futures for themselves and for society (OECD, n.d.).

Empirical research has expanded our understanding of how educators conceptualize and apply FOP in diverse contexts. Sachyani et al. (2024) examined high school biology teachers' views on integrating FOP within inquiry-based molecular biology laboratories and found that such approaches help students embrace uncertainty, experimentation, and creative problem-solving. Similarly, Bound et al. (2024) emphasized that FOP extends beyond traditional classrooms to adult and lifelong learning, where pedagogy must address emergent, unstructured, and continuously evolving futures. Chen and Hsu (2020) further demonstrated that futures-oriented education enhances students' anticipatory and visioning skills, helping them to imagine multiple possible futures and act purposefully. FOP integrates forward-looking thinking with pedagogical innovation to increase resilience, agency, and reflective learning (Abbiss, 2015; Bound et al., 2024).

Beyond classroom implementation, researchers and policymakers recognize the broader systemic role of FOP. Ioannidou and Erduran (2022) showed that policymakers across several European contexts regard future-oriented skills, such as critical thinking, ethical reasoning, and global citizenship, as essential for the sustainability of science education. In parallel, Chan and Erduran (2025) found that future-oriented science learning both enhances students' futures literacy and strengthens their emotional engagement and agency in addressing complex global challenges in the Anthropocene. FOP is more than a pedagogical innovation; it represents a transformative educational framework that bridges research, policy, and practice to empower learners as proactive agents of change in a complex and evolving world (Chen & Hsu, 2020; Ioannidou & Erduran, 2022; Mutseekwa, 2024).

According to Sachyani et al. (2024), FOP consists of six interconnected dimensions: Personalization, which emphasizes learner agency and individual pathways; Collaboration, which promotes cooperation among learners and educational stakeholders; Globalism, which develops awareness of global challenges and citizenship; Change, which prepares learners to adapt to uncertainty and complexity; Integration, which supports meaning-making and holistic thinking; and Informality, which recognizes learning beyond formal educational settings.

METHODS

Implementation of IBBE in Kazakhstan

The implementation of IBL instruction in Kazakhstan's high schools aligns closely with the goals and principles outlined in the State Compulsory Educational Standard (SCES), which defines the framework for quality education across the country (Minister of Education and Science, 2018). The SCES establishes core learning outcomes, curriculum structure, and assessment requirements to ensure the development of key competencies such as scientific literacy, communication, critical thinking, digital competence, and civic responsibility.

In line with the educational reforms introduced in 2016 and 2018, Kazakhstan transitioned from a knowledge-based to a competence-based curriculum, harmonizing national educational objectives with international benchmarks such as the OECD Learning Framework 2030 and the Cambridge curriculum standards (Lim, 2012; OECD, n.d.). Within this reformed framework, science education, including biology, emphasizes student-centered, active, and inquiry-oriented learning. Teachers are encouraged to guide students through authentic research experiences that integrate theoretical knowledge with hands-on experimentation, project work, and collaborative problem-solving.

The subject-specific standard for Biology, as outlined in the SCES, specifies grade-level learning outcomes that foreground inquiry, experimentation, and the application of biological knowledge to real-life contexts. Laboratory and project-based learning have become essential elements for increasing students' curiosity and enabling them to engage with the scientific process as young researchers (Robinson, 2013). This pedagogical shift requires teachers

to create conditions that encourage questioning, hypothesis formulation, data collection, and evidence-based reasoning, the same processes that underpin authentic scientific inquiry.

Furthermore, the SCES promotes multilingual education through the national Trilingual Policy (Kazakh, Russian, and English), expanding students' access to global scientific discourse and resources (Karimsakova et al., 2022). This policy supports the integration of internationally recognized inquiry-based programs and increases intercultural communication in science education. Through these approaches, Kazakhstani schools are nurturing a generation of learners who can critically analyze information, participate in global scientific communities, and contribute to sustainable national development.

The integration of inquiry-based learning under the SCES thus represents a strategic national initiative to modernize science education, cultivate future-oriented competencies, and align teaching practices with global educational trends while maintaining local relevance. By connecting the national curriculum vision with classroom-level experimentation and reflection, teachers serve as agents of innovation, implementing IBL activities.

Participants

The population of this study consisted of biology teachers working in various high schools across the country, representing public, private, and specialized institutions. These schools followed the same curricula, including national and international programs, providing diverse educational contexts. While the exact number of biology teachers in Kazakhstan is not publicly available, national statistics indicate that approximately 399,000 teachers were employed in Kazakhstan's schools in 2024 (Koniukhova, M., 2024, October 4). From this population, twelve teachers (five female and seven male) were selected based on their relevance to the research topic. All participants were practicing biology teachers with two to 15 years of teaching experience, regularly engaged in conducting laboratory sessions (See [Table 1](#)).

Table 1

Characteristics of the Participating high school biology teachers

Teacher ID	Gender	Years of Experience	School Type
T1	Female	3	Public
T2	Male	8	Private
T3	Female	12	Specialized
T4	Male	5	Public
T5	Female	10	Private
T6	Male	7	Specialized
T7	Male	15	Public
T8	Female	4	Specialized
T9	Male	9	Private
T10	Male	2	Public
T11	Female	13	Specialized
T12	Male	6	Public

A non-probability purposive sampling technique was used to select participants who met specific inclusion criteria: being currently employed as a biology teacher, having at least two years of teaching experience, conducting inquiry-based laboratory work, and providing informed consent for participation and recording. All twelve participants were from high schools, which may limit the representativeness of the findings for rural or under-resourced settings. Nonetheless, the sample reflected a range of gender, experience, and institutional backgrounds among high school teachers. Most schools were relatively well-equipped with laboratory facilities, access to the internet, and basic technology for teaching.

Instrument

To explore high school biology teachers' perspectives on FOP as reflected in their IBL practices, a structured interview protocol was developed. The instrument was informed by the six dimensions of FOP as operationalized in more recent literature on future-focused science education (Sachyani et al., 2024). The interview protocol consisted of 10 open-ended questions; each aligned with one or more of the FOP principles. Questions were designed to elicit detailed narratives and reflections from teachers about their instructional approaches, the role of student agency, inclusiveness, resilience, global-local connections, collaboration, and informal learning opportunities in their biology classes. The interview protocol was reviewed by two experts in science education. The first expert was a professor of science education with extensive experience in inquiry-based learning and science teacher education, while the second expert specialized in curriculum development and qualitative research in secondary science education. Both experts evaluated the interview questions for clarity, relevance, and alignment with the six dimensions of Future-Oriented Pedagogy. Following their feedback, several questions were revised to

improve wording precision and reduce potential ambiguity. The protocol was then piloted with two experienced high school biology teachers. Based on their feedback, minor adjustments were made to simplify question wording, improve the sequence of questions, and add clarifying prompts to encourage more detailed responses.

Data collection and ethics

During the first academic semester of 2025-2026, individual interviews were conducted with 12 biology teachers. Each teacher participated voluntarily and was informed about the purpose of the study, which focused on inquiry-based learning practices in biology education. The researcher met online with the teachers to discuss their experiences, challenges, and reflections regarding the implementation of inquiry-based approaches.

Among the participants, 10 teachers provided their responses in audio form by recording voice messages via the WhatsApp platform, while two teachers submitted written responses. All collected materials were compiled into a unified database, and the audio recordings were transcribed verbatim to ensure accuracy and reliability. These transcriptions formed the primary dataset for subsequent qualitative analysis of teachers' perspectives on inquiry-based biology instruction. To maintain confidentiality, all participants were assigned coded identifiers (T1–T12), and any identifying details were removed from the transcripts.

The interviews were conducted primarily in Kazakh and Russian, depending on participants' preferences. Audio recordings were first transcribed verbatim in the original language and subsequently translated into English by the researchers, who were fluent in both the source languages and English. To minimize semantic loss and linguistic bias, the translated transcripts were compared with the original recordings and transcripts, and ambiguous expressions were discussed among the research team until consensus was reached. Particular attention was given to preserving the intended meaning of participants' statements rather than producing literal word-for-word translations.

Ethical procedures were strictly followed throughout the data collection process. Participation was entirely voluntary, and participants were informed about the purpose of the study, the confidentiality of their responses, and their right to withdraw at any time without penalty. An ethical review report was obtained for this study from Abai Kazakh National Pedagogical University.

Data analysis

The data collected through structured interviews were analyzed using a thematic content analysis approach, guided by the conceptual framework of FOP. The six dimensions of FOP- Personalization, Collaboration, Globalism, Change, Integration, and Informality- served as the analytical categories guiding the coding process. All interview recordings were transcribed verbatim in English. Each transcript was reviewed multiple times to ensure accuracy and to preserve participants' intended meanings. The researchers read through the transcripts iteratively to gain an overall sense of the data, identify emerging patterns, and make preliminary notes related to the six FOP dimensions.

Using a deductive–inductive hybrid approach, initial codes were generated both from the theoretical FOP framework (deductive) and from recurring ideas emerging directly from the data (inductive). Each transcript was manually coded line by line. Codes reflecting teachers' views, experiences, and perceived challenges in implementing inquiry-based pedagogy were organized within the six FOP categories. When new concepts appeared beyond the framework (e.g., emotional regulation, ethical awareness), they were integrated into subthemes under the most relevant dimension. Within each FOP dimension, thematically related codes were clustered to form principles (e.g., “resilience and recovery from crisis” under Change and “peer and team learning” under Collaboration). This process allowed a clear linkage between teacher quotations, conceptual principles, and the theoretical constructs of FOP. Discrepancies in coding were discussed among the research team until full agreement was reached. For each dimension, a summary table was developed, containing three columns: The principle's definition based on the FOP framework, Illustrative interview quotations representing that principle, and the essence of the quotation explained, summarizing the underlying meaning.

AI usage statement

Artificial intelligence tools were used only for language refinement and the transcription of interview audio files. All AI-generated transcriptions were checked manually for accuracy, and AI-assisted language corrections did not alter the meaning of participants' responses. Human researchers made all analytical and interpretive decisions.

RESULTS

This section is organized according to the six dimensions of FOP: Personalization, Collaboration, Globalism, Change, Integration, and Informality. Each dimension is presented separately to maintain conceptual clarity and

to reflect the structure of the analytical framework used in this study. For each dimension, a concise interpretive synthesis is provided then a table is designed that includes three elements; the principle's definition, illustrative interview quotations, and an explanation of the quotations' essence.

Personalization

The first principle of FOP, personalization, emphasizes allowing learners to choose and promote their learning according to their individual interests, ambitions, abilities, and personal traits. This principle was clearly reflected in the teachers' interviews, as most of them reported giving students opportunities to select topics, materials, and experimental approaches that align with their curiosity and motivation. Teachers indicated that offering freedom of choice increases students' sense of ownership and engagement, as they feel responsible for their projects. Teachers also encouraged flexible task designs, allowing students to decide how to represent or modify their findings. However, a few participants admitted that students' voices were limited due to their own inexperience or institutional constraints, which reduced the degree of personalization possible in practice.

Across interviews, teachers observed that this learner-driven approach increased stronger intrinsic motivation and active participation, particularly among students who were already curious or self-directed. Teachers noted that when students could select inquiry questions or research topics, they became more engaged and demonstrated greater perseverance in problem-solving. Yet, the findings also reveal tensions between the ideal of personalization and classroom realities. Some teachers pointed out difficulties balancing curricular requirements with open-ended inquiry, while others noticed that students with lower confidence or fewer prior skills struggled with decision-making and self-regulation. **Table 2** presents teachers' views regarding the Personality dimension of the FOP.

Table 2

Views of teachers for the personality dimension of FOP

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
Learners choose and promote their learning characteristics in accordance with their interests, ambitions, abilities, and personal traits	"I give them opportunity to choose any plant seeds that they would like to grow." (T2) "I encourage them to choose research topics that interest them." T5 "Students do their lab in their own pace and in their own way." (T10) "Students did not have much voice... it was not as interesting for them." (T11) "In project work... students can change their research question and project things." (T12).	Most teachers' value student agency by allowing learners to choose topics, questions, materials, or methods aligned with their interests, though a few note that limited student voice reduces engagement.
The learners will be required to manage their learning independently	"They could develop critical thinking... work or explore things on their own." (T2) "They have to brainstorm, discuss... and decide why they were adding solution." (T3) "They take ownership of the questions and methods." (T5) "They form hypotheses, collect data, and present their findings." (T7) "Students do certain things on their own, learn new concepts and do lab work independently." (T11).	Teachers consistently promote autonomous and self-regulated learning, enabling students to manage tasks, organize collaboration, and engage in independent inquiry both inside and beyond class.
Resilience and the ability to recover from crisis	"If they have unexpected results... I explain any result is a result of your work." (T1) "They get frustrated... I explain it's okay and they must write exact results and find reasons." (T2) "Unexpected results are learning opportunities... flexibility is important." (T5) "Mistakes are also learning moments." (T7) "When projects don't go as expected, students become unsatisfied." (T10) "Some students panic, some try to fix issues, some seek help." (T11).	Across teachers, resilience emerges as a key theme: students are guided to handle failure, reflect on errors, and persist through challenges, though some still struggle emotionally when outcomes differ from expectations.
Enhancing personal abilities	"They build critical skills, teamwork, communication, and analytical skills." (T1) "They develop critical thinking skills and explore on their own." (T2) "They become more independent and confident." (T6) "They learn to ask questions, find solutions, and make evidence-based decisions." (T7) "They gain practical skills and learn emotional control through mistakes." (T8) "They learn to think critically, ask meaningful questions, and design answers." (T9).	Inquiry-based teaching increases personal growth, enhancing analytical thinking, communication, problem-solving, self-confidence, and emotional regulation.

Collaboration

The second principle, collaboration, shows the importance of cooperative learning and multi-level partnerships between students, teachers, schools, and the wider community. Across the interviews, teachers emphasized that effective collaboration increases essential future skills such as communication, teamwork, and social responsibility. At the classroom level, collaboration manifested through peer learning and team work, where students divided responsibilities, exchanged ideas, and supported one another during inquiry-based lab activities. Teachers commonly formed mixed-ability groups to promote mutual learning, with many noting that these partnerships often extended beyond class time; students met after school, collaborated online, or created small science clubs to continue their discussions.

Beyond the classroom, collaboration expanded to include interdisciplinary and institutional cooperation. Several teachers described joint initiatives between biology and chemistry departments, where cross-subject projects such as water-quality testing or environmental studies allowed students to connect scientific inquiry to real-world problems. Others pointed to cooperation with lab assistants, access to local laboratories, and partnerships across schools as key supports for implementing inquiry-based approaches. Teachers also emphasized the value of professional collaboration; participation in workshops, co-teaching opportunities, and support from senior leadership teams; as critical to aligning teaching practices with future-oriented goals. [Table 3](#) presents the teachers' views regarding the Collaboration Dimension of the FOP.

Table 3

Views of teachers for the collaboration dimension of FOP

Principle's Definition	Interviewee Quotations (verbatim)	Essence of Quotation Explained
Individuals and education institutions must join together to cooperate with various shareholders in the world of education and the society	"I think it would be better to have some kind of cooperation with other teachers to create some inter disciplinary lessons." (T1) "... some workshops, collaborations with other professionals, co-teaching..." (T2) "... and opportunities to collaborate with other teachers would be very helpful." (T5) "...sharing ideas with other teachers would be great." (T6).	Teachers showed the need for institutional and professional collaboration, including co-teaching, shared lab resources, interdisciplinary projects, and administrative or leadership support.
Peer learning, team learning	"This lab work was done like by the groups" (T1) "Students self-divide into groups of friends ... collaboration extends beyond the classroom ... they study together." (T3) "Students work in small groups where they share tasks and discuss results." (T5) "They work in teams, share ideas, and help each other." (T6) "Lab work is done in pairs or in groups ... students help one another ... some unusual friendships may start by these group works." (T11).	Across all teachers, teamwork and peer interaction formed the foundation of inquiry learning. Students divided roles, shared tasks, and helped one another. Collaboration frequently continued beyond class through online discussions or science clubs, increasing both academic growth and social connection.
Collaborative learning projects will enable communication between distant sites and will communicate through collective discussions between many participants.	"They usually work in small groups ... share responsibilities ... teamwork often continues outside the class." (T7) "Some have even started small science clubs where they discuss new experiments or environmental topics." (T9)	Only limited evidence of inter-school or distant collaboration emerged.

Globalism

The Globalism dimension shows how teachers increase students' awareness of both global and local issues through inquiry-based learning. Across the interviews, nearly all participants incorporated learning experiences that connected classroom investigations to real-world contexts. Many teachers designed projects that addressed environmental sustainability, such as local water-quality testing or greenhouse effect experiments. These activities encouraged students to explore global concerns; pollution, conservation, and climate change; through local observations and data collection, nurturing an understanding of how global phenomena manifest in their immediate environments. Others linked inquiry to social and health-related global challenges, including cosmetics

safety, paper conservation, and heart-attack prevention for elderly people. Such examples reveal how inquiry tasks enabled students to connect scientific learning with global citizenship and sustainability awareness.

Teachers also described how students developed a systematic understanding of the environment, progressing from local, tangible experiences to abstract, global-level thinking. By comparing their results with international data or examining similarities between global and national issues like the Flint River crisis and Kazakh village pollution, learners began to view science as a system of interconnections that transcends classroom boundaries. Several teachers emphasized that these experiences made learning more meaningful and future-oriented, as students were encouraged to analyze real societal problems, discuss ethical implications, and reflect on their role as responsible citizens in a global community. Table 4 presents the teachers' views regarding the Globalism Dimension of the FOP.

Table 4

Views of teachers for the globalism dimension of FOP

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
Experiencing concerns of global and local significance	"We tried to solve some community issue... (T1) "Yes, I had that experience in the lab where we were exploring the greenhouse effect." (T2) "When we did the workshop, it helped me to see worldwide topic and actual problems of the world." (T4) "Students related their findings to environmental problems in our community, such as pollution and water conservation." (T5) "... collected the water of Irtysh River and then... compared to international data." (T7). "We did a lab on water purification and pollution... connected this to real world issues such as access to clean drinking water." (T9). "..., project is directly connected to the issue of cell phones effect to surroundings." (T10). "In our project the topic was about global problem, saving trees." (T11).	Teachers and students engaged with global; local issues such as sustainability, pollution, conservation, and health; showing awareness of worldwide problems through locally meaningful inquiry.
Exposes the learner to fields of knowledge relating to culture, language, broad sustainability, and global citizenship	"We choose very relevant topic for the women world it is cosmetics." (T4). "They research it compared to international data, what quality should be, what elements should be or should not be in water." (T7). "We had the Flint River Crisis... then the students start to find out some similarities between some Kazakhstan villages... one student whose relatives were living in that village." (T8). "The topic was about global problem, saving trees." (T11).	Only a few teachers directly linked inquiry to cultural, ethical, or global citizenship contexts.
Engaging with ethical literacy concepts and critical thinking	"..., the critical thinking is needed... in all fields of life." (T1). "They could develop critical thinking skills and work or explore some things on their own." (T2). "They help them to develop their critical thinking skills." (T3). "These activities help students develop critical thinking, problem-solving, and teamwork skills." (T5). "Students learn how to ask questions, how to find solutions and make their own evidence-based decisions." (T7). "They learn how to say critically ask me for questions and design ways to find answers." (T9).	Most teachers emphasized critical thinking, however none demonstrated ethical awareness through inquiry topics that carried moral or social significance.

Change

The fourth characteristic, change, focuses on learners' ability to adapt, thrive, and function in a complex, uncertain world. Across the interviews, teachers recognized that inquiry-based learning naturally places students in situations where outcomes are unpredictable, requiring flexibility, resilience, and analytical thinking. Teachers observed that students often became frustrated when experiments did not produce expected results, yet they emphasized that these moments were among the most valuable learning experiences. Several participants noted that they encouraged students to record and analyze their actual findings rather than conceal or disregard them. This process taught learners that science is not about obtaining perfect results, but about understanding why things happen differently than expected. Teachers also viewed such experiences as opportunities for students to develop emotional control and persistence when facing ambiguity or failure.

Some teachers reflected on the varied reactions of students to unexpected results. While some learners panicked, tried to mask their mistakes, or sought immediate help, others took initiative to identify the causes and redesign their procedures. These differences revealed how inquiry-based settings can expose students' individual capacities for adaptation and problem-solving. Teachers found that helping students accept the uncertainty of experimentation, normalizing mistakes and guiding reflection, was key to increasing growth. In some cases,

teachers themselves also had to confront unpredictability in the classroom, learning to manage time constraints, limited resources, or unplanned technical issues while maintaining students' engagement and motivation. **Table 5** presents the teachers' views regarding the Change Dimension of the FOP

Table 5

Views of teachers for the change dimension of FOP

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
The learner's ability to adapt, thrive, and function in a complex, changing, and highly uncertain reality.	"Usually, I say that all results are results. Even if students fail something... as long as they can analyze and justify, they are fine." (T3). "..., students can be frustrated, but I encourage them to see unexpected results as learning opportunities. We discuss possible sources of error and the importance of flexibility...." (T5). "We talk about why it happened and what they learned from it." (T6). "... unexpected results are quite real part of the science... we don't need to redesign the experiment, the mistakes are also the learning moment of our lessons." (T7). "When things go wrong and they often do, I treat it as one of the best learning opportunities... they stop seeing mistakes as failures and start viewing them as steps in the scientific process." (T9). "..., some students start to panic, some students try to hide and mask unplanned process, some students come and ask from lab assistant or teacher what was wrong and what can be done more to fix the issue." (T11).	Across teachers, the shared essence reflects how inquiry-based learning exposes students to uncertainty and failure, teaching them to interpret unexpected outcomes as part of authentic science. Teachers reported that while students initially experience frustration, confusion, or anxiety, these moments become opportunities for reflection, problem-solving, and growth.

Integration

The Integration dimension of FOP emerged as a vital aspect of teachers' instructional practice, reflecting how inquiry-based learning encourages students to construct personal meaning and self-realization. Across the 12 teachers, integration was strongly linked to connecting classroom inquiry with real-world issues such as environmental sustainability, community health, and technology's impact. Teachers described how these activities motivated learners to see science as relevant to their lives, helping them develop agency, responsibility, and purpose in navigating a changing world. Students' ability to draw parallels between global and local issues (e.g., pollution, heart disease, digital effects) illustrated the emergence of personally meaningful learning narratives.

Teachers also identified reflective literacy as central to developing holistic thinking. Through guided discussions, post-lab reflections, and accepting experimental uncertainty, students learned to analyze results, question causes, and see "mistakes" as opportunities for growth. Reflection was frequently integrated into lab procedures (e.g., reflective questions, real-life connections, or post-activity journals), allowing students to extend their understanding beyond the immediate experiment toward ethical and social implications.

However, teachers across contexts pointed out arguments for improvement that constrain the full realization of integration. The main barriers included insufficient resources, time, and institutional support for interdisciplinary collaboration and reflection. Several emphasized the need for teacher professional development, workload reduction, and structured collaboration between science and other subjects to enable sustained reflection and cross-curricular integration. Despite these challenges, teachers' collective voices indicate a shared commitment to increasing learners who can link knowledge with meaning, bridging personal, scientific, and societal dimensions in a rapidly evolving world. **Table 6** presents the teachers' views regarding the Integration Dimension of the FOP

Table 6

Views of teachers for the integration dimension of FOP

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
The learners' ability to formulate personal meaning in a world of change, build their own narratives, and achieve self-realization in the changing reality.	"Through labs they can look forward with their professional skills to choose future occupation." (T4) "Students related their findings to environmental problems in our community." (T5) "They often discuss what did in real life, like how temperature affects food or health." (T6) "Students began to see how scientific understanding can be applied to social and environmental solutions." (T9) "Project is directly connected to the issue of cell phones' effect to surroundings." (T10) "We made a project to prevent heart attack for elder peoples." (T12)	Teachers consistently emphasized the value of connecting inquiry tasks to real-life issues; environmental, health-related, and technological, allowing students to construct meaning and develop self-realization through relevant, socially grounded investigations.

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
Developing holistic thinking, developing reflective literacy	"Every lesson we plan reflective questions to deep understand." (T4) "Students write reflections about what they learned and how it connects to real-life issues." (T5) "We talk about why it happened and what they learned from it." (T6) "I include reflection questions... students connect their results to environmental and medical issues." (T7) "Students try to extend their knowledge in the same field they were studying." (T10)	Teachers described reflection as a key process in increasing holistic understanding. Across classrooms, reflective literacy developed through discussing errors, rethinking procedures, and linking science to social, and environmental dimensions.
Points for improvement	"It will be good if we get a lab assistant." (T3) "Universities are not good on school curriculum... need better teacher preparation." (T4) "It would help to have more lab materials and training for teachers." (T6) "Inquiry-based labs need a lot of preparation and time." (T7)	All teachers noted systemic barriers such as time, resources, and institutional support. They called for professional development, collaboration, and reflective time to sustain integrated, future-oriented teaching practices.

Informality

The Informality dimension of FOP captures how learning transcends traditional boundaries of space, time, and institutional control. Across the 12 teacher interviews, informal learning appeared as a vital channel through which students internalize curiosity, independence, and self-regulation. Teachers described multiple forms of informal engagement; peer collaboration outside class, home-based explorations, online resource use, and project-driven discussions; that together form a living "ecosystem of learning streams." These informal pathways enable learners to connect formal science content to their lived realities and to sustain inquiry as a habit of mind rather than a task bound to the classroom.

All 12 teachers observed that students frequently continue their learning activities outside of class, often driven by genuine curiosity. For example, several teachers mentioned students meeting after school or online to continue experiments, prepare digital reports, or discuss findings. Teachers also described informal learning as a space for independent exploration. Students often took initiative by watching educational videos, searching scientific information on YouTube or Khan Academy, or investigating real-life cases within their families and communities. For instance, teachers reported that students engaged voluntarily with documentaries, science competitions, and online research platforms. Within this dynamic, teachers consistently described their evolving role from authoritative knowledge providers to pedagogical mentors and learning counsellors. They support students by providing credible resources, suggesting exploration directions, and helping them interpret unexpected results. [Table 7](#) presents the teachers' views regarding the Informality Dimension of the FOP.

Table 7

Views of teachers for the informality dimension of FOP

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
An ecosystem of learning streams available anytime and anywhere facilitates connecting and learning independently without being dependent on the formal education system	"They work with their groups ... not only during the class time ... out-of-class teamwork ... sometimes they are gathered together at some place to finish that work." (T1) "Students work together in lab and study for exams and quizzes together ... discuss what we covered last week." (T4) "Collaboration continues outside class ... share resources and prepare presentations." (T5) "They even continue talking about their results after class or online." (T6) "Students continued discussions after lessons in group chats and started small science clubs." (T9) "They came in groups to observe plants during their free time." (T10) "By every lab work students form new groups ... some unusual friendships start." (T11)	Across teachers, learners were frequently observed extending collaboration beyond scheduled lessons; meeting at home, online, or in workshops; forming flexible learning ecosystems sustained by peer initiative and digital communication.

Principle's Definition	Interviewee Quotations	Essence of Quotation Explained
Informal independent learning that takes place anywhere and at any time	"Go and search for an answer at home and share it next lesson." (T2) "Certain students passionate about biology ... I give resources to explore new things." (T3) "Some conduct extra experiments or read articles ... I guide them to science fairs." (T5) "Students read or watch videos about biology ... I give extra materials." (T6) "Some research topics for fun ... share findings with the class." (T7) "Students ask their relatives about diabetes and come back with questions." (T8) "They watch YouTube and documentaries and share ideas with peers." (T11).	Informal, curiosity-driven learning is widespread: students watch educational media, discuss real-life contexts, and pursue home-based inquiries that bridge school science and personal experience.
The teacher as a pedagogical mentor and expert learning counsellor	"I set the direction and leave some unanswered questions for students to search." (T4) "I guide them by providing structure and checkpoints, but they take ownership." (T5) "I tell them that in science it's normal ... we talk about why it happened." (T6) "I show real-life videos that affect them emotionally and connect to topics." (T8) "I shared videos, books, and projects related to their interests." (T11) "I give links to websites and prepare them for deeper learning." (T12)	Teachers consistently act as guides rather than directors, encouraging autonomy, modelling reflection, and scaffolding inquiry through real-world connections and resource guidance.
Points for improvement	"Inquiry-based lessons need more time and cooperation with other teachers." (T1) "Need more resources and updated materials." (T2) "Need more digital tools and training on inquiry-based learning." (T7) "Professional development, time, and cross-curricular resources." (T9) "Time to develop activities and link to curriculum better." (T10) "Teachers should do lab works and small research themselves to learn the process." (T11) "Prepared materials and tips for encouraging further exploration would help." (T12)	Teachers unanimously identify structural constraints; insufficient time, materials, collaboration, and professional training; as obstacles to fostering sustainable informal learning and mentorship.

DISCUSSION

The goal of the study was to explore how high school biology teachers perceive the integration of FOP within their IBL instruction, identify which dimensions of FOP teachers perceive as naturally aligned with IBL practices, and to examine the challenges that constrain the full realization of these principles in classroom contexts.

The integration of FOP

The findings indicate that while teachers do not always explicitly articulate FOP principles, many of their instructional approaches inherently reflect future-oriented values. Personalization and collaboration were particularly prominent, with teachers showing student agency and teamwork as essential to effective inquiry. Similarly, dimensions such as globalism and change emerged in discussions about real-world relevance and adapting to uncertainty in lab contexts. However, the principles of inclusion and informality appeared less fully realized, suggesting that teachers may require additional support and training to intentionally incorporate these aspects into their IBL design.

Alignment with IBL

The findings of this study indicate that IBL instruction naturally aligns with several key dimensions of FOP. Teachers described how inquiry activities increased personalization, as students selected research topics and made decisions about experimental procedures, leading to increased ownership and intrinsic motivation. Likewise, collaboration was a central feature of laboratory work, with students working in groups, distributing roles, and supporting one another both during and beyond class time. The change dimension was also strongly evident, as students regularly encountered unexpected results and learned to manage uncertainty, reflect on errors, and develop resilience. Inquiry tasks further supported integration, encouraging learners to connect scientific understanding to meaningful real-world issues such as environmental sustainability and community health. Additionally, informality was observed through students' continued engagement with biology-related topics outside of formal lessons, supported by teachers acting as mentors rather than information transmitters. Only globalism appeared as a partially realized dimension; while some activities linked local investigations to global challenges, explicit development of global citizenship and ethical literacy was less consistent across classrooms.

The strong alignment between IBL instruction and personalization reflects how student autonomy promotes ownership, intrinsic motivation, and self-regulated learning. In this study, teachers emphasized giving students choice in research questions, pacing, and methods, which encouraged them to take responsibility for their learning. This supports prior research showing that inquiry-based learning positions students as active constructors of knowledge and enhances intrinsic motivation and agency (Dobber et al., 2017; Beck et al., 2014). When students are afforded meaningful choice, they are more likely to persist, reflect, and invest in the learning process.

Inquiry-based activities also fostered collaboration, as students worked in groups to exchange ideas, divide responsibilities, and troubleshoot problems. These peer interactions extended beyond formal class time, demonstrating that learning was social, sustained, and co-constructed. This finding aligns with existing literature emphasizing that inquiry laboratories create natural spaces for cooperative learning and communication skill development (Strat, Henriksen, & Jegstad, 2024). Group work in science contexts has been shown to support both academic learning, and the development of interpersonal, teamwork, and negotiation skills that are essential in future professional environments.

The connection of inquiry tasks to real-world issues allowed students to construct meaningful understanding and see biology as relevant to everyday life. Teachers described projects relating to environmental sustainability, community health, and local ecological problems, illustrating how inquiry can function as a bridge between personal experience and global challenges. This finding supports research demonstrating that inquiry-based instruction can promote scientific literacy and global citizenship, especially when learning is contextualized in authentic environmental or social issues (Manishimwe et al., 2018; Chikaluma et al., 2022). However, the study also showed that the global and ethical dimensions were not consistently emphasized, suggesting that intentional pedagogical framing is needed to deepen global citizenship learning, in line with international science education reform goals (OECD, 2024).

The prominence of unexpected results in laboratory work showed the role of inquiry in developing resilience and emotional adaptability. Teachers described how students initially experienced frustration when results differed from expectations, but learned to analyze discrepancies, revise procedures, and accept uncertainty. This aligns closely with research suggesting that authentic scientific inquiry requires learning through trial, error, and reflection, and that failure is an important driver of conceptual growth and scientific reasoning (Sachyani et al., 2024). Developing comfort with ambiguity is a core competency for future-oriented learning and is essential for preparing students to navigate complex scientific and societal challenges.

The study also showed that informal learning played a central role, as students continued discussions outside class, formed independent study groups, and engaged in self-directed online research. This suggests that inquiry learning can activate a broader ecosystem of learning that extends beyond the classroom. This finding resonates with research describing how FOP encourages flexible, networked learning experiences across formal and informal contexts (Bound et al., 2024).

Challenges

Despite the strong alignment between IBL instruction and multiple dimensions of FOP, several challenges limited the full realization of these principles in practice. Teachers consistently reported constraints related to time, materials, and laboratory support, noting that inquiry-based lessons require extensive preparation and access to equipment that is not always available. The absence of structured teacher collaboration systems further restricted interdisciplinary projects and shared planning, even though teachers expressed a strong desire for professional exchange and co-teaching. In addition, while inquiry encouraged students to engage with uncertainty, many learners struggled emotionally when experiments produced unexpected results, leading to frustration or avoidance rather than reflective problem-solving. These challenges stem from broader systemic pressures, including curriculum pacing demands, limited professional development in inquiry facilitation, and the prioritization of standardized assessment outcomes over exploratory learning.

CONCLUSIONS

This study demonstrates that IBL instruction naturally aligns with key dimensions of FOP, particularly personalization, collaboration, resilience in the face of uncertainty, meaning-making, and informal learning. These connections suggest that IBBE is well positioned to cultivate the competencies students need to navigate an increasingly complex and dynamic world. However, the partial realization of the globalism dimension and the challenges teachers encounter indicate that intentional support and structural conditions are required to enable inquiry-based practices to reach their full potential.

Based on our findings, educational authorities in Kazakhstan should place greater emphasis on strengthening the globalism dimension of inquiry-based biology education by developing curriculum materials that connect laboratory investigations with global sustainability, ethical decision-making, and citizenship issues. Schools should

also create structured opportunities for interdisciplinary teacher collaboration, as participants repeatedly highlighted the value of working with colleagues across subjects. Furthermore, professional development programs should help teachers support students in coping with uncertainty, failure, and unexpected experimental outcomes, which emerged as important aspects of inquiry-based learning. Finally, schools should recognize and encourage informal learning opportunities, such as science clubs, online collaboration, and community-based projects, which teachers identified as natural extensions of classroom inquiry.

This study has several limitations that should be acknowledged. First, the sample consisted exclusively of teachers in high schools, which may not reflect the conditions of rural or under-resourced contexts. Second, the study focused specifically on biology teachers and may not generalize to educators in all science disciplines. The contextual nature of biology as a lab-based subject may have influenced how FOP principles were enacted. Third, the integration of FOP was not always explicitly known or named by the teachers themselves. Their practices were interpreted through the FOP framework by the researchers, which, although methodologically grounded, introduces an interpretive layer that may not fully align with participants' intended meanings. Fourth, the study did not include classroom observations, which limits the ability to verify how inquiry practices and student behaviors manifest in real-time instructional settings.

Future research should therefore expand to rural and diverse school environments to better understand contextual variation in inquiry implementation. Including students' perspectives would offer a critical complementary view of how agency, collaboration, and resilience are experienced from the learner standpoint. Additionally, classroom-based observational studies would allow researchers to analyze interaction patterns, teacher scaffolding strategies, and the role of emotional regulation during inquiry.

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Ethical statement

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Competing interests

The authors confirm that there are no competing financial or non-financial interests that could have influenced the conduct or reporting of this study.

Author contributions

All authors contributed to the conception and design of the study. Author 1 was responsible for the study conceptualization, methodology, and research design. Author 2 contributed to data collection and investigation. Author 3 was responsible for data analysis and interpretation of the results. Author 4 contributed to the literature review, manuscript drafting, and critical revision of the manuscript. Author 5 contributed to manuscript review, editing, and final approval of the version to be published. All authors reviewed and approved the final manuscript and agreed to be accountable for all aspects of the work.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI disclosure

The authors declare that no artificial intelligence (AI) tools or AI-assisted technologies were used in the research, analysis, or preparation of this manuscript.

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APPENDIX

Interview questions

1. Can you describe an inquiry-based lab activity you've recently implemented in your biology class?
2. In what ways do you think such inquiry-based activities help students prepare for the future?
3. Do your students have any choice or say in shaping their inquiry projects? If so, how do you manage this?
4. How do your students collaborate during lab work, and do you see this collaboration extending beyond the classroom?
5. Have you ever connected your lab projects to global or community issues? Could you give an example?
6. What happens when things don't go as planned in the lab? How do students respond to unexpected results?
7. Do you find students reflecting on the meaning or broader implications of their lab work?
8. Do any of your students explore biology topics beyond what's required in class? What role do you play in encouraging this?
9. What do you find most rewarding, and most challenging, about teaching through inquiry-based labs?
10. In your view, what support would help you better align your teaching with future-oriented goals?