



 Research Article

Didactic Foundations Of Individualization Technology In School Biology Education

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ABSTRACT

The diversification of learners' needs in contemporary schools has made the search for effective models of individualization one of the central tasks of didactics. This issue is especially important in biology education, where students differ not only in pace and achievement, but also in interest, prior knowledge, scientific language proficiency, and readiness for inquiry-based and laboratory work. The purpose of this study is to substantiate the didactic foundations of individualization technology in school biology education and to clarify the methodological conditions under which it can improve learning outcomes, learner agency, and conceptual understanding. The study employs theoretical analysis, comparative interpretation, and content synthesis of key international sources on differentiated and personalized learning, digital education, teacher preparation, and biology teaching. The results show that the didactic foundations of individualization in school biology rest on several interconnected principles: diagnostic orientation, variability of content and task complexity, scaffolded inquiry, multimodal representation of biological phenomena, flexible organization of classroom interaction, and continuous formative assessment supported by feedback. The analysis also demonstrates that digital tools become pedagogically meaningful only when they strengthen these foundations rather than replace teacher judgment. In biology education, individualization is particularly productive when abstract concepts are linked with visual models, experimentation, simulations, and context-based tasks. The study concludes that individualization technology in biology should be understood not as isolated differentiation techniques, but as a coherent didactic system that coordinates aims, content, methods, learning environments, and assessment

according to the learner's educational profile. Such a system can increase accessibility, engagement, and scientific literacy in school biology.

KEYWORDS

School biology education, individualization technology, differentiated instruction, didactic foundations, personalized learning, formative assessment, digital tools, biology teaching methodology.

INTRODUCTION

The contemporary school classroom is characterized by cognitive, motivational, linguistic, and social heterogeneity. Students enter biology lessons with different levels of readiness, different experiences with scientific observation, and different degrees of confidence in working with abstract concepts, models, and experimental procedures. Under these conditions, the traditional one-speed, one-task model of teaching becomes increasingly limited. International discussions on personalized and student-centered education have therefore moved toward approaches that adapt teaching to learner needs while preserving common curricular goals. OECD materials on personalising education frame this shift as a response to profound questions about the purposes and possibilities of education, while the OECD Future of Education and Skills project places student agency, well-being, and competencies at the center of curricular and pedagogical design.

Within this broader context, differentiated and individualized teaching has become a major pedagogical-didactic approach. A systematic review in *Frontiers in Psychology* defines differentiated instruction as planned adaptations in process, learning time, content, product, or learning environment for groups of students or individual learners on the basis of readiness, prior knowledge, interests, or learning preferences. The same review shows that, although the empirical

base is still developing, most well-designed studies in secondary education report small to moderate positive effects of differentiated instruction on achievement. At the same time, research also shows that teachers find implementation difficult because it requires strong subject knowledge, diagnostic competence, time for preparation, and organizational support.

For school biology, the issue is even more acute. Biology includes concrete and visible topics, such as organism structure, but it also involves invisible and multilevel processes such as respiration, genetics, endocrine regulation, ecological cycles, and cellular division. Students often experience difficulties when they have to coordinate verbal explanations, symbolic representations, diagrams, laboratory observations, and causal reasoning. Research on students' views of biology learning found recurring difficulty in topics such as matter cycles, endocrine systems and hormones, aerobic respiration, cell division, and genes and chromosomes, with difficulties linked not only to content complexity but also to teaching style, study habits, attitudes, and lack of resources. This suggests that effective biology teaching cannot be reduced to content delivery; it requires didactic adaptation to different learner profiles.

Recent literature also indicates that school and higher biology education increasingly use digital



and technology-supported forms of individualization. UNESCO's work on technology in education emphasizes that technology influences learning through multiple channels, but its value depends on meaningful, human-centered, ethical, and equitable use. In parallel, a 2025 systematic review of technology-supported differentiated biology education found growing research interest in the area, especially from 2022 onward, and reported that technology-supported approaches in biology can enhance understanding, engagement, learning outcomes, observation, and scientific explanation skills. This convergence of didactic differentiation and digital mediation creates a strong basis for rethinking how biology lessons are designed.

The purpose of this study is to identify and interpret the didactic foundations of individualization technology in school biology education. The central research question is how individualization can be conceptualized as a coherent didactic system rather than a fragmented set of techniques. A related objective is to clarify the pedagogical role of digital resources, simulations, and virtual laboratories in supporting individualized learning pathways in biology. The article argues that the didactic value of individualization lies not in simplifying content for different students, but in organizing access, inquiry, representation, and assessment in ways that preserve scientific rigor while increasing learner inclusion and participation.

This study is theoretical and analytical in design. It relies on comparative analysis, content interpretation, and conceptual synthesis of international policy documents and peer-reviewed research on personalized education, differentiated instruction, teacher preparation, school science, and biology education. The selected source base includes OECD and UNESCO publications as well as

research reviews and empirical studies devoted to differentiated instruction in secondary education and biology classrooms. Such a design is appropriate because the aim of the article is not to test a classroom intervention experimentally, but to substantiate the didactic foundations that should guide methodological improvement in practice.

The analytical procedure consisted of three stages. First, core definitions of personalisation, differentiation, and individualization were compared in order to identify their common didactic structure. Second, the specific demands of school biology were examined through studies on conceptual difficulty, laboratory learning, digital tools, and differentiated biology instruction. Third, the findings were synthesized into a system of didactic foundations that could explain how individualization technology should be built in school biology education. The criteria for interpretation were conceptual relevance, methodological clarity, and practical applicability to secondary-school teaching.

The analysis shows that the didactic foundations of individualization technology in school biology education begin with diagnostic orientation. Individualization is impossible when teaching is planned only from the standpoint of the curriculum and not from the standpoint of the learner's starting position. In biology, diagnostic work should include not only achievement measurement, but also identification of misconceptions, prior conceptual structures, scientific vocabulary difficulties, motivation for inquiry, and readiness for practical or virtual laboratory tasks. The literature on differentiated instruction repeatedly emphasizes that proactive adaptation depends on assessment of readiness and related learner characteristics. In biology, this principle becomes especially important because

many student errors are not random; they reflect persistent conceptual obstacles about invisible processes and systems.

A second foundation is the variability of content and cognitive demand. Individualization does not mean different curricular goals for every learner; rather, it means varied pathways toward shared disciplinary understanding. In biology, the same topic may be approached through different entry points: text, diagram, model, experiment, case study, field observation, or simulation. The teacher can vary task complexity, tempo, depth of explanation, and degree of scaffolding while maintaining conceptual coherence. Tomlinson's classic model of differentiation through readiness, interest, and learning profile remains didactically influential because it treats variation as principled planning rather than improvised accommodation. The systematic review of differentiated instruction in secondary education also confirms that effective differentiation commonly involves planned adaptation of content, process, product, environment, or learning time rather than spontaneous assistance alone.

A third foundation is scaffolded inquiry. Biology as a school subject is inseparable from observation, classification, explanation of living systems, and evidence-based reasoning. Yet inquiry tasks are often too demanding when introduced in an undifferentiated manner. The didactic logic of individualization therefore requires incremental scaffolds that support learners differently depending on their preparedness. Technology-supported biology education research shows that differentiated biology learning increasingly incorporates tools that help students observe, analyze, and explain biological phenomena at different levels of support. Related research on biology lessons has also shown that scaffolded instructional approaches can enhance scientific

performance, engagement, and interest. Thus, individualization in biology should not move away from inquiry; it should make inquiry accessible through structured variation in prompts, representations, and procedural guidance.

A fourth foundation is multimodal representation. Biology knowledge is built through constant movement between observable organisms, microscopic structures, symbolic notation, diagrams, models, and causal explanations. Many students fail not because the topic itself is impossible, but because the teaching does not help them translate across these representational modes. Individualization technology becomes didactically sound when it provides alternative representational channels and teaches students how to coordinate them. The literature on virtual laboratories and digital biology education supports this point. Reviews of virtual labs in biology conclude that they are especially useful for abstract topics such as cell and molecular biology, genetics, microbiology, dissection, and biotechnology, where visualization and safe repeated experimentation can strengthen conceptual understanding, practical skills, and motivation.

A fifth foundation is flexible organization of learning interaction. Individualization is often misunderstood as purely individual seatwork, but the evidence suggests a more flexible arrangement. In practice, school biology benefits from a dynamic combination of whole-class explanation, small-group differentiation, paired inquiry, teacher-guided mini-lessons, and individual feedback. Research on teacher implementation of differentiated instruction shows that successful practice is strongly influenced by professional support, collaboration, and the ability to manage diverse classroom structures. Action research with secondary teachers indicates that educators can learn to implement differentiated instruction, but

they need coaching, reflection, and practical routines. For biology, this means that methodological improvement should focus not only on learning materials but also on lesson architecture: when the whole class should work together, when subgroups should pursue tasks at different levels, and when students should move into independent or digitally mediated activity.

A sixth foundation is formative assessment and feedback continuity. If biology individualization is planned only at the beginning of a unit, it risks becoming static and inaccurate. Learners change as they work, and biology understanding develops through successive refinements. Therefore, ongoing assessment, brief diagnostic checks, observation of explanations, and feedback on models, experiments, and problem solving are central components of the didactic system. Technology-supported differentiated biology education increasingly uses automated or semi-automated tools for feedback, assessment, and progress tracking, but the literature also makes clear that such tools should support teacher judgment rather than replace it. UNESCO's human-centered approach to digital education and recent biology education reviews both stress that technology becomes valuable when it expands meaningful learning opportunities while preserving ethics, equity, and human agency.

Finally, the analysis shows that digital tools are not themselves the foundation of individualization, but they can intensify every didactic foundation already mentioned. They can improve diagnosis through quizzes and analytics, support variability through adaptive tasks and branching resources, make inquiry safer through simulations and virtual labs, strengthen multimodal representation through animation and interactive visualization, and enhance feedback through immediate responses and revision opportunities. At the same

time, UNESCO warns against assuming that more technology automatically means better education. The didactic center remains the learner, the subject, and the teacher's pedagogical decision-making. For that reason, individualization technology in school biology must be designed as a pedagogy first and a digital environment second.

The results of the analysis allow individualization technology in school biology education to be interpreted as a didactic system with a clear internal logic. Its starting point is not fragmentation of the class, but preservation of common biological learning goals while diversifying routes toward those goals. This interpretation is important because in school practice differentiation is sometimes reduced either to giving stronger students more difficult tasks or to simplifying material for weaker learners. Such reductionist practice fails to address the deeper didactic issue, namely how biological knowledge is accessed, constructed, represented, and assessed by learners with different profiles. The reviewed literature supports a broader view in which differentiation concerns content, process, product, environment, time, and support structures.

Biology as a discipline gives this system a special character. Unlike some subjects in which differentiation may remain at the level of pacing or text complexity, biology requires adaptation across conceptual scale, empirical inquiry, visualization, and ethical or ecological interpretation. A learner may understand a diagram but struggle with causal explanation; another may succeed in observation but fail in symbolic generalization; a third may learn effectively through virtual experimentation. Therefore, the didactic foundations identified in this article are not interchangeable fragments but mutually dependent elements. Diagnostic work informs task variation; task variation must be

connected with scaffolding; scaffolding works best when representations are multimodal; and all of this requires formative assessment and flexible organization of interaction.

The discussion also suggests that teacher preparation is decisive. Reviews of differentiated instruction and teacher development indicate that teachers need sustained professional learning, reflection, collaboration, and realistic implementation conditions if they are to adapt instruction well. This has direct implications for school biology methodology. Teachers need support not only in general didactics but also in subject-specific differentiation: selecting which topics require visualization, where laboratory alternatives are needed, how to diagnose misconceptions in genetics or physiology, and how to design tiered inquiry tasks without diluting scientific meaning. In this sense, the improvement of biology methodology is inseparable from the professional development of biology teachers themselves.

Another important implication concerns digitalization. Current educational discourse often presents personalization as a technological achievement, but the reviewed evidence suggests a more cautious conclusion. Digital tools can powerfully extend individualization in biology, especially in abstract topics and laboratory contexts, yet they cannot independently generate sound didactics. UNESCO's emphasis on human-centered and equitable technology use aligns with the biology education literature showing that virtual labs, simulations, and adaptive resources are most effective when integrated into purposeful instructional design. Consequently, the methodological improvement of individualization technology in school biology should avoid both technocentrism and traditionalism. It should instead seek a balanced synthesis in which

pedagogical reasoning governs the use of digital means.

The study has shown that the didactic foundations of individualization technology in school biology education are systemic rather than episodic. They include diagnostic orientation, variability of instructional routes, scaffolded inquiry, multimodal representation, flexible classroom organization, and formative assessment supported by feedback. In biology, these foundations are especially significant because the subject combines abstract concepts, empirical work, visual reasoning, and multilevel explanation. Individualization becomes pedagogically productive when it helps every learner reach biologically meaningful understanding without lowering disciplinary standards. Digital tools, including virtual laboratories and adaptive platforms, can significantly strengthen this process, but only when they operate within a human-centered didactic design. Thus, the methodological improvement of school biology teaching should focus on building coherent individualized learning systems rather than isolated techniques. Such an approach can improve conceptual understanding, motivation, inclusion, and scientific literacy, while also making biology education more responsive to the diverse realities of the modern classroom.

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