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REVIEW ARTICLE

Curriculum Philosophy, Textbook Content, and Assessment Mechanisms of Primary and Secondary Science Education in Singapore

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Abstract

Singapore's primary and secondary science education is widely recognized for its high performance through systemic reform. The synergistic innovation of its curriculum philosophy, textbook content, and assessment mechanisms warrants in-depth investigation. In terms of curriculum philosophy, Singapore has accomplished a value shift from being "driven by national needs" to "serving life and society," embodying holistic education as scientific practice through the "3'IN'" framework. The construction of textbook resources has transcended the boundaries of traditional print media, establishing a four-in-one ecosystem comprising "textbooks, activity books, digital platforms, and inquiry kits," and relies on a spiral curriculum to facilitate the cognitive progression of cross-cutting concepts. The assessment mechanisms have undergone a paradigm shift from norm-referenced to standards-referenced testing. Through an achievement level grading system, Full Subject-Based Banding, and process-oriented feedback empowered by artificial intelligence, excessive competition is mitigated while individual growth is fostered. Singapore's practice demonstrates that deep reform of primary and secondary science education depends on promoting a shift in curriculum philosophy from knowledge-based to competency-based approaches, constructing a multi-dimensional textbook system to bridge the gap between in-school and out-of-school learning, and reshaping the educative function of assessment so that it genuinely becomes a dialogic tool for fostering students' scientific inquiry and value cultivation.

Keywords: Singapore, science education, curriculum philosophy, textbook content, assessment mechanism.

1 Introduction

Against the backdrop of intensifying knowledge economy and technological competition in the 21st century, primary and secondary science education is not only the foundation for cultivating individuals' rational thinking and inquiry abilities, but also a strategic linchpin of national innovation capacity and global competitiveness [1]. Surveying the

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global trends in educational reform, how to enable primary and secondary science education to transcend knowledge transmission and routine experimentation, shifting instead toward fostering students' deep scientific literacy and critical agency, has become one of the core challenges confronting all nations [2].

Within this global quest, Singapore's performance has been particularly remarkable. In the 2022 Program for International Student Assessment (PISA 2022), 15-year-old students in Singapore ranked first among all participating education systems in science, mathematics, and reading. Their mean science score was 561, with the proportion achieving Levels 5 or 6 reaching 24% [3]. Similarly, the 2023 Trends in International Mathematics and Science Study (TIMSS 2023) shows that Primary 4 and Secondary 2 students in Singapore ranked first among all participating education systems in science, achieving results significantly above the international average [4]. These achievements are no accident; rather, they are the result of Singapore's long-standing commitment to systematic science education reform. From the forward-looking design of its curriculum philosophy and the judicious organization of its textbook content to the multi-dimensional synergy of its assessment mechanisms, Singapore has progressively built a distinctively characterized and demonstrably effective system of primary and secondary science education.

A review of relevant international research reveals multi-layered academic explorations surrounding science education in Singapore, research topics encompass STEM curriculum development, classroom teaching practices, textbook system evaluation, and other dimensions. In terms of the implementation of STEM curricula, it is common practice in Singapore for Applied Learning Programmes to embed disciplinary knowledge into real-world problem-solving contexts, thereby stimulating students' intrinsic motivation and inquiry abilities [5]. From the perspective of classroom teaching practices, primary science education in Singapore is oriented around inquiry as its core, emphasizing the cultivation of students' higher-order cognitive and critical reasoning abilities [6]. Focusing on the structural coherence of textbook content, it is evident that the Integrated Science curriculum in Singapore demonstrates a high degree of internal consistency in content organization and subject matter emphasis [7]. However, existing studies have largely focused on chronicling the historical evolution of science education reform in Singapore or summarizing policy experiences, while lacking a coherent and systematic analysis of core elements such as the profound transformation of curriculum philosophy, the structural design of textbook content, and the paradigm shift in assessment mechanisms. Therefore, this paper focuses on three core elements: curriculum philosophy, textbook content, and assessment mechanisms in primary and secondary science education in Singapore. It seeks to answer three sequentially progressive questions: What curriculum philosophy underpins science education in Singapore? How is this philosophy embedded in the content structure and presentation of textbooks? And how do the assessment mechanisms synergize with these through systemic reform? Through a systematic analysis of the aforementioned issues, this paper aims to provide a reflective and actionable reference framework for the reform of primary and secondary science education.

2 Curriculum Philosophy of Primary and Secondary Science Education in Singapore

2.1 Historical Evolution of Curriculum Philosophy: From Streaming to Teaching According to Aptitude

Tracing the more than half a century of science education reform in Singapore, the curriculum philosophy can be broadly divided into four phases. In the first phase (1965–1978), following independence, Singapore positioned industrialization as the core path to national modernization. Science and technology education were regarded as strategic cornerstones for manufacturing development. Science courses were included in the primary and secondary school system for the first time, with students receiving systematic science education from Primary 1 onward [8]. At this stage, the legitimacy of science education was still contingent on national economic demands, yet a complementary educational landscape between school and out-of-school settings had begun to take shape. The second phase (1979–1997) was a period of streaming institutionalization characterized by "efficiency-driven" approaches. In response to the demand for differentiated talent from technology-intensive industries, Singapore introduced a streaming system, channeling students into different streams based on academic performance [9]. The original intention of this systemic design was to achieve differentiated customization of curricula and reduce dropout rates. However, while enhancing efficiency, it inevitably engendered a "labeling effect," with certain streams being socially perceived as "inferior," undermining students' confidence and self-identity. The third phase (1997–2010) was an "ability-driven" period focused on connotative development. Facing the advent of the knowledge economy, Singapore proposed the educational vision of "Thinking Schools, Learning Nation," aiming to cultivate young people's creative thinking abilities, lifelong learning passion, and national identity. The fourth phase (2010 to the present) is a period centered on "student-centric, values-driven" holistic education. In the second decade of the 21st century, the Singapore Ministry of Education explicitly advocated transcending knowledge and skills for "holistic education." It introduced Applied Learning Programmes and Learning for Life Programmes, placing values and character development at the core of curriculum design [10]. Among these, as a crucial practical vehicle for science curricula, STEM Applied Learning Programmes are driven by real-world problems, prompting students to integrate science, mathematics, and technology knowledge to explore and find solutions. The goal is not only knowledge transfer but also the systematic cultivation of students' scientific inquiry skills, reasoning and problem-solving abilities, design thinking, computational thinking, data analysis skills, and technological application capabilities, thereby internalizing interdisciplinary concepts into transferable practical competencies [11].

Throughout this evolutionary journey, the fulcrum of Singapore's primary and secondary science education curriculum philosophy has progressively shifted from "national needs" to "individual development," from "external discipline" to "intrinsic motivation," and from "competency training" to "value cultivation." If the first two phases addressed the external proposition of "what kind of person to cultivate for the nation," the latter two phases answer the internal question of "what kind of person to become for oneself." It is precisely under the impetus of this philosophical turn that Singapore's science education has been able to transcend the performance anxiety of international assessments and move towards a deeper concern for people's science literacy and value rationality.

2.2 Core Philosophy's Connotation: "Science for Life and Society"

The curriculum philosophy ultimately turned towards the core framework of "Science for Life and Society." The Singapore Ministry of Education places this central expression at the heart of the framework, encompassing all goals of science education (Figure 1). Hence, Singapore's science education no longer presupposes that students are future scientists or engineers. Instead, it takes every learner as the subject of education, striving to cultivate science literacy that serves everyday life decisions and social participation [12].

Around this core philosophy, the Singapore science curriculum framework constructs a threefold vision of "Inspire, Inquire, Innovate"—the "3'IN'" framework. First, "Inspired by Science" focuses on the affective dimension and meaning-making of students' science learning. The goal of science education is not for students to passively memorize scientific facts but to discover the fascination and explanatory power of science from everyday phenomena, understand how science and technology change the world and improve lives, and maintain an open attitude towards science-related careers. Second, "Inquire like Scientists" concentrates on cultivating scientific practice capabilities. Singapore emphasizes that students should not only master scientific knowledge but also engage in scientific practices like scientists, conduct evidence-based critical analysis, weigh different viewpoints, and suspend judgment when evidence is insufficient. Third, "Innovate using Science" points to a higher-order literacy dimension, requiring students to apply scientific knowledge to generate creative solutions to real-world problems based on a solid foundation of science and practical methods.

The "3'IN'" framework is not merely a list of isolated teaching objectives; it constructs a mutually coordinated concentric structure. The inner ring is the core philosophy of "Science for Life and Society." The three "IN"s support each other, while the outer ring is a foundational science system composed of three pillars: Core Ideas, Practices of Science, and Values, Ethics and Attitudes. Among these, "Practices of Science" includes three interconnected modules: Ways of Thinking and Doing in Science, Nature of Scientific Knowledge, and Science, Technology, Society and Environment. This structural design aligns with the centrality of scientific inquiry in Singapore's curriculum framework, as evidenced by classroom research showing that primary science teachers are expected to enact inquiry-based lessons in which students engage in evidence-based reasoning rather than passive knowledge reception [13].

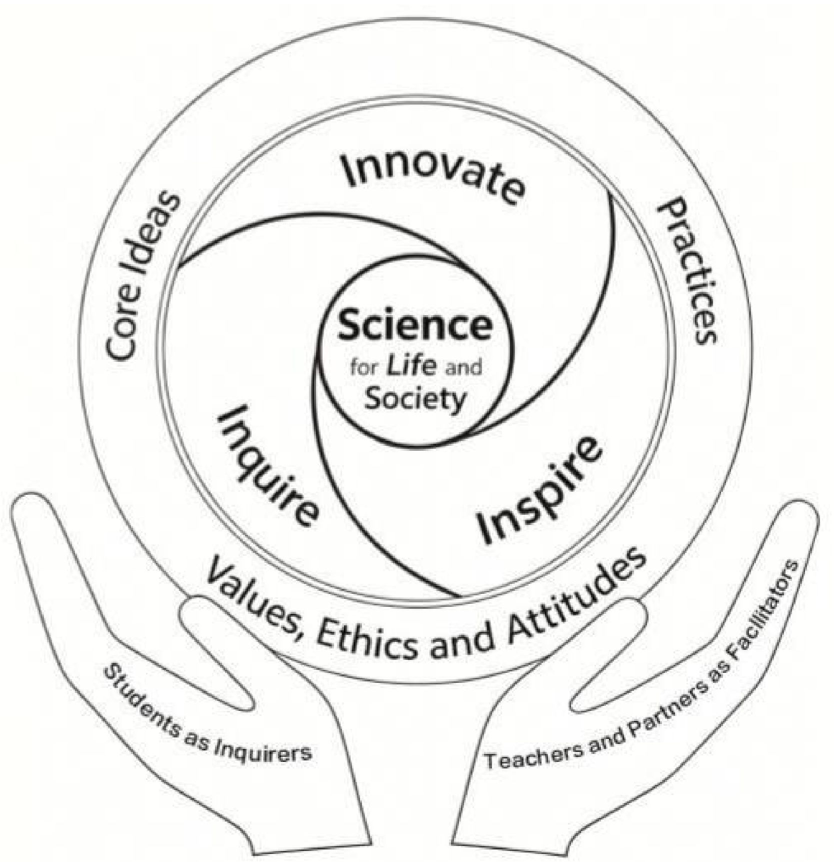

Figure 1. Curriculum framework of the 2023 Edition of the Primary Science Syllabus, Singapore.

2.3 Institutionalization of the Philosophy: Flexible Curriculum System and Teacher Role Reconceptualization

The transition from external disciplinary logic to intrinsic motivational logic, from stratified screening to teaching according to aptitude, and from knowledge-based to competency-based approaches—the effective implementation of Singapore's primary and secondary science curriculum philosophy relies precisely on the synergistic support of two institutional pivots: a flexible curriculum system design and teacher role reconceptualization.

Regarding the curriculum system, the most critical reform initiative is the implementation of Full Subject-Based Banding (Full SBB) [14]. From 2024 onwards, all secondary schools in Singapore have replaced the streaming system, which lasted over four decades, with Full SBB. The new system divides subjects into three difficulty levels: G1, G2, and G3. Students can independently choose different combinations of subject levels based on their subject-specific strengths and interests. For example, a student could choose a G3-level science course while concurrently taking a G2-level mathematics course and a G1-level humanities course. This institutional arrangement acknowledges the unevenness of students' abilities and provides them with opportunities to "develop their strengths" in the subjects they excel in, rather than binding all abilities together through a single total score. Matching the curriculum flexibility, report cards and the evaluation system have been simultaneously reformed [15]. Starting in 2018, Singapore progressively abolished mid-year examinations in primary and secondary schools and introduced the Achievement Level (AL) scoring system to replace the former T-score ranking, weakening peer competition and encouraging students to focus on their own progress and growth.

At the teacher level, the implementation of Singapore's science education philosophy relies heavily on a reconceptualization of the teacher's role. The Singapore science curriculum standards explicitly state that teachers are "facilitators" of student inquiry, not "transmitters" of knowledge. This role transformation is reflected not only in pedagogical innovations, such as teaching strategies driven by contextualized problems and experimental inquiry, but also in the systemic design of curriculum resource development and teacher professional development systems [16]. The Singapore Ministry of Education adjusts teacher training programs every three years based on curriculum review results, covering dimensions including subject knowledge updating, inquiry-based pedagogy training, information technology integration, and education for digital literacy. Moreover, the National Institute of Education (NIE) and the Ministry of Education maintain a close collaborative relationship to ensure that teacher preparation remains synchronized and aligned with curriculum reform.

3 Content Architecture of Primary and Secondary Science Textbooks in Singapore

3.1 Multi-dimensional Construction of the Textbook System

At the traditional print media level, each new syllabus release is accompanied by the simultaneous development and updating of corresponding textbooks, student activity books, and teacher's guides. For example, for the 2023 revised primary science syllabus, the Singapore Ministry of Education, in collaboration with the National Institute of Education (NIE) and the Science Centre Singapore, co-developed a resource package called Sparkle—short for Science Pack Activity Resource Kits for Learning. This package covers 19 themes across 18 units for Primary 3 to 6, with each school receiving 23 sets of hands-on inquiry materials per theme [17]. In fact, the Sparkle kit is not merely "teaching aids"; it is an organic component of the textbook system itself, deeply integrated with the content of textbooks, activity books, and the SLS digital platform.

In terms of digital resources, since 2018, the Singapore Ministry of Education has been building the Singapore Student Learning Space (SLS) for students from primary to pre-university levels. The SLS platform encompasses science curriculum content among all subjects. It provides interactive simulation tools, video resources, e-books, and collaborative learning modules, enabling students to autonomously explore scientific concepts and conduct simulated experiments [18]. From 2023, artificial intelligence technologies have begun to be embedded in this platform, with the science curriculum being the first to pilot these features. According to the EdTech Masterplan 2030, the platform will progressively integrate four major modules: teaching assistance, intelligent feedback and assessment, AI learning partners, and adaptive learning systems, providing students with a space for autonomous exploration anytime, anywhere [19].

The four-in-one structure of "textbooks + activity books + digital resources + inquiry kits" evolves textbook content from a static knowledge carrier into a dynamic learning ecology. First, integration of knowledge and action. Each Sparkle kit corresponds to a specific scientific concept module, allowing students to transform abstract principles into embodied experiences through hands-on materials. For instance, the kit on "light" includes a collapsible dark box, LED bulbs, and batteries for students to experiment with shadow formation and light properties; the kit on the "circulatory system" uses panels and red/blue strings to simulate the path of blood circulation. In such instructional designs, the textbook is no longer an object "to be read" but a tool "to be used." Second, complementarity between print and digital. The SLS platform's advantage lies in its interactivity and adaptivity. Students can use simulations to manipulate complex

Table 1. Progression of cross-cutting concepts in Singapore Science Textbooks.

Concept	P3, P4	P5, P6	S1, S2
Systems	Identify the compositional components of simple systems and how they work together.	Understand the function of each component in a human system (e.g., digestive system).	Analyze input-output relationships and functional characteristics across different systems.
Cycles	Observe the basic patterns of life cycles in plants and animals.	Understand the basic processes of matter cycles and the water cycle.	Analyze material and energy cycles within ecosystems.
Energy	Identify phenomena of light propagation and heat transfer.	Understand energy formation and conversion in photosynthesis.	Analyze relationships of energy conversion efficiency and conservation within systems.
Interactions	Experience the interaction of magnetic forces.	Distinguish the mechanisms of frictional force, gravitational force, and elastic spring force.	Understand abstract interaction concepts such as force fields and electromagnetic waves.
Diversity	Distinguish the basic characteristics of living and non-living things.	Systematically classify organisms using multi-dimensional classification criteria.	Understand the functional significance of diversity for ecosystem stability.

variable relationships that cannot be represented in textbooks and activity books; the platform's built-in Learning Assistant (LEA) can help students clarify their conceptual understanding through iterative questioning [20]. The relationship between print textbooks and digital platforms is not substitutive but complementary: print textbooks are responsible for the structured presentation of knowledge, while digital platforms handle personalized extension and immediate feedback.

Third, articulation between in-school and out-of-school learning. Both the Sparkle kits and the SLS platform are designed to be usable by students outside the classroom, blurring the boundary between formal and informal learning. The openness and transferability of Singapore's science textbooks largely stem from the core philosophy of "for life and society": the endpoint of science learning should not be the moment an exam ends but should extend throughout life.

3.2 Spiral Organization of Textbook Content

At the level of content structure, the five themes—Diversity, Cycles, Energy, Interactions, and Systems—are vertically integrated from Primary 3 to 6 by means of a spiral curriculum (Table 1). This integrated implementation pathway within a subject-based curriculum can confer a comprehensive cognitive perspective on disciplinary content without breaking subject boundaries, through the integration of cross-cutting concepts, authentic problem integration, and engineering practices [21].

It combines the advantage of subject-based instruction—the integrity of the knowledge system—while overcoming the cognitive fragmentation problem inherent in traditional subject-based instruction. Taking the "Energy" theme as an example, students are first introduced to basic forms of energy (e.g., heat and light) in the lower grades, then progressively deepen their understanding to energy conversion, energy conservation, and the relationship between energy and socioeconomic activities. This spiral design has two main advantages. First, it moves subject knowledge from fragmentation to integration, helping students construct cross-unit cognitive schemas. Second, it provides operational space for differentiated instruction: students at different ability levels can pursue inquiry paths of varying depths within the same theme.

At the secondary level, the science curriculum continues with the spiral design while further differentiating. Secondary 1 and 2 feature an integrated science curriculum with inquiry-based learning as the primary teaching method, covering basic concepts in physics, chemistry, and biology. In Secondary 3 and 4, students can opt to pursue specific branches such as physics, chemistry, or biology, or choose combined science (e.g., chemistry/physics), depending on their interests and aptitudes. The Singapore Ministry of Education and the Singapore Examinations and Assessment Board (SEAB) independently develop curriculum syllabi and examination syllabi, which are updated regularly.

4 Assessment Mechanisms in Primary and Secondary Science Education in Singapore

4.1 Assessment Philosophy Transformation: From Norm-Referenced to Standards-Referenced Testing

A profound transformation in assessment philosophy serves as the starting point for understanding Singapore's science education assessment mechanisms.

Table 2. Correspondence between science achievement levels and score ranges under the new AL scoring system.

AL Level	Corresponding Raw Score Range (Percentage)	Performance Description
AL 1	≥ 90	Highest level; best performance in the standards-referenced system.
AL 2	85–89	Approaching excellence.
AL 3	80–84	Good level.
AL 4	75–79	Satisfactory level.
AL 5	65–74	Above average.
AL 6	45–64	Meets the standard; average.
AL 7	20–44	Below standard level; needs improvement.
AL 8	< 20	Lowest level; substantial improvement needed.

For a long time, the assessment of basic education in Singapore was characterized by high-stakes standardized testing. Its T-score (Transformed Score) system placed each student's results precisely along a normal distribution curve. While this system achieved efficient selection and precise resource allocation, it also brought about negative effects that could not be ignored [22]. Defining student "success" by examination results inevitably generated high academic anxiety.

In 2021, Singapore significantly reformed the PSLE scoring system, comprehensively replacing the former T-score system with an Achievement Level (AL) system, moving from norm-referenced to standards-referenced testing. Under the former system, a student's results depended on relative comparison with other test-takers; scores and rankings were differentiated infinitesimally along a continuum, with a one-point difference potentially meaning a significant change in ranking and a substantial difference in secondary school posting opportunities. Under the new AL system, each subject is divided into eight achievement levels, AL1 to AL8, based on raw scores on the examination paper(Table 2).For example, AL1 corresponds to 90 marks and above, AL2 to 85–89, and so on [23]. A student's final PSLE score is then the sum of the AL levels for the four subjects (English, Mathematics, Science, and Mother Tongue), ranging from 4 to 32 points.

The introduction of the AL system echoes the shift in Singapore's science education curriculum philosophy from "efficiency priority" to "holistic development." By replacing the fuzzy and uncertain relative comparison with a clear and definite description of absolute performance levels, the function of assessment shifts from generating anxiety to measuring growth. Building on this foundation, the Singapore Ministry of Education further abolished mid-year examinations for all levels of primary and secondary education. Since 2024, there have been no mid-year examination arrangements at the primary or secondary level [14]. The teaching time freed up by this measure is reallocated to students' inquiry-based learning and project-based practice, institutionally resonating with the spirit of "Teach Less, Learn More" embedded in the curriculum philosophy. This shows that when assessment is no longer solely devoted to streaming and selection, but aims to enable and promote growth, the educational horizon can shift from a logic of competition to a logic of development.

4.2 Systemic Advancement and Social Effects of Assessment Reform

The establishment of the AL system is embedded within a reform chain that interlinks assessment philosophy, scoring mechanisms, progression pathways, and classroom practices. First, the "bandwidth" of the levels is designed to deliberately blur the fine differentiation of the previous scoring system. The old T-score system was highly sensitive to point differences; small differences between test-takers could cause large fluctuations in ranking. The AL system sets clear scoring intervals (e.g., AL5 corresponds to 65–74 marks), collapsing similar scores into the same level. Second, the scoring result shifts from being the "sole criterion" for progression to a "reference criterion" for progression. Within the AL framework, a student's PSLE score is no longer the only variable determining their progression path; subject choice preferences and school admission quotas also constitute key moderating factors. Even more transformative, the Full SBB system, fully implemented from 2024, allows students to flexibly choose courses at G1, G2, or G3 difficulty levels in secondary school based on their actual ability in each subject [24]. For example, a student who receives an AL5 in science at the PSLE can still choose to take science at the G3 level in secondary school. The flexible design of the scoring system combined with multi-channel progression pathways constitutes the substantive breakthrough in assessment reform. Third, the abolition of mid-year examinations releases valuable time and space for inquiry-based teaching. In the former system, frequent periodic examinations forced teachers into a short-cycle pattern of "lecture–drill–examine," with students' scientific inquiry and practical exploration often being squeezed out or even cancelled. After the abolition of mid-year exams, teachers can more deliberately design project-based learning, arrange laboratory investigations, and organize out-of-school science practice activities. Fourth, the evaluation of practical skills has undergone strategic adjustments. The new policy restored the school-based practical assessment, which was previously conducted multiple times a year, to a single assessment per year. However, it raised more explicit requirements for higher-order inquiry skills, including experimental design, data analysis, and result evaluation. This adjustment does not diminish the status of practical teaching; rather, it shifts the focus of assessment from "frequency of laboratory operations" to "quality of experimental thinking."

Of course, any assessment reform will find it difficult to completely eradicate deeply entrenched societal notions in a short period. In the period following the implementation of the AL system, several potential tensions deserve attention. First, social competition for "elite schools" has not automatically disappeared just because the scoring method has changed. Second, parents and some teachers still habitually convert AL levels into "old scores" to understand students' academic performance, reflecting a "time lag" effect of cultural habitus in assessment. Third, the abolition of mid-year examinations may, in some cases, lead to insufficient self-monitoring ability among some students during long-term inquiry tasks. These gaps between reform effectiveness and social cognition underscore an important lesson: assessment reform cannot stop at technical tinkering; it is fundamentally a cultural transformation process requiring the gradual accumulation of consensus among multiple stakeholders.

4.3 Embedding and Enabling Digital Assessment Technologies

If the AL system is dedicated to the conceptual innovation of assessment, then the embedding of AI-powered assessment tools, as exemplified by the SLS platform, responds to new possibilities at the technical level of assessment. The assessment functions of the SLS platform now extend far beyond traditional homework marking and score statistics. The platform's built-in Short Answer Feedback Assistant (ShortAnsFA) can automatically analyze student responses to open-ended questions and provide immediate feedback; the Learning Assistant guides students toward the crux of a problem through iterative questioning [25]. Additionally, the platform provides functions such as student progress tracking and comparative analysis of module completion rates, allowing teachers to identify students' learning difficulties and provide targeted interventions. Driven by generative AI technology, the SLS platform is evolving in a direction that integrates "instruction management, instructional design, intelligent tutoring, adaptive learning, teaching assessment, and data management."

The true value of digital assessment technologies lies in their transcendence of the spatial and temporal boundaries of traditional assessment. Traditional assessments are mostly concentrated at the end of a semester or academic year, and their results are often used to "finalize" rather than "promote" learning. In contrast, AI tools embedded in the SLS platform enable assessment to accompany the entire learning process. Students receive specific suggestions for improvement immediately after completing a simulation, and teachers can check the class learning status at any time. This "ongoing formative assessment" aligns well with the goal of "inquiring like scientists" embedded in the curriculum philosophy: scientific inquiry is essentially an iterative process of hypothesizing, testing, revising, and re-testing; assessment should function as a feedback loop embedded within that process, not as an external judgmental act.

5 Implications and Insights

The systemic reform of Singapore's primary and secondary science education system has forged an internally consistent synergistic logic across three dimensions: curriculum philosophy, textbook content, and assessment mechanisms. At the level of curriculum philosophy, it has accomplished a value shift from "national efficiency-driven" to "serving life and society," anchoring science education in holistic development rather than examination performance through the "3'IN'" framework. At the level of textbook content, it has transcended the boundaries of traditional print media, constructing a four-in-one learning ecology comprising textbooks, activity books, digital platforms, and inquiry kits, while achieving cognitive progression of cross-cutting concepts through a spiral curriculum. At the level of assessment mechanisms, it has realized a paradigm shift from norm-referenced to standards-referenced testing. By leveraging achievement level grading, Full Subject-Based Banding, and formative feedback empowered by artificial intelligence, the function of assessment has been redirected from sorting and stratification towards enabling growth. The value of this system lies not only in its impressive performance on international assessments, but more importantly, in its provision of transferable design principles and a referential pathway for contextualized adaptation to education systems worldwide, particularly those transitioning from knowledge-based to competency-based paradigms and seeking breakthroughs within high-stakes examination cultures.

5.1 Promoting a Value Shift in Science Curriculum Philosophy

Singapore's curriculum philosophy of "Science for Life and Society" reveals that the ultimate value of science education should be anchored in human development rather than the competitive ranking of examination performance. In many education systems, the revision of curriculum standards has begun to position core competencies as educational goals, and the conceptual shift from a knowledge-based to a competency-based paradigm is gradually becoming an international consensus. However, between the renewal of curriculum philosophy and the realities of classroom practice, deep-seated barriers of institutional inertia and examination culture often persist. The Singapore experience demonstrates that a philosophical shift requires institutional support to be effectively implemented. The introduction of achievement level grading and the abolition of mid-year examinations constitute the institutional pathway through which the curriculum philosophy is operationalized. For any education system seeking to transcend the logic of examinations, assessment reform should not stop at reducing examination frequency or adjusting scoring rules. Rather, it must systematically construct a new assessment system aligned with the goals of core competencies—shifting from measuring knowledge reproduction to assessing scientific inquiry abilities, and from norm-referenced relative ranking to standards-referenced descriptions of proficiency levels.

5.2 Enabling the Ecological Leap of the Science Textbook System

Singapore's four-in-one textbook system of "textbooks + activity books + digital platforms + inquiry kits" demonstrates a form of knowledge organization that transcends traditional print media. In this ecology, the textbook is no longer merely a tool for storing and transmitting knowledge; rather, it becomes a cognitive scaffold for students to actively construct knowledge and develop inquiry abilities. In recent years, many countries have invested heavily in the development of digital educational resources, with various smart education platforms and virtual laboratory systems being launched one after another. However, the abundance of resources does not automatically equate to effectiveness in use, nor does platform accessibility necessarily lead to deep integration with instruction [26]. The design thinking behind Singapore's Sparkle kit is particularly instructive. It is not merely a simplistic use of virtual resources, but rather a fully integrated, end-to-end design that incorporates hands-on inquiry tools, print learning materials, and digital platform content. This suggests that optimizing the structure of science textbooks should not rely solely on isolated breakthroughs in digital platforms. Instead, grounded in the authentic needs of science instruction, a collaborative development mechanism should be established among textbooks, lab manuals, digital resources, and inquiry kits, enabling different learning materials to play their respective roles and complement one another, collectively serving the authentic enactment of inquiry-based learning.

5.3 Enhancing the Educative Function of Science Assessment

The purpose of assessment is not to rank students' academic achievement levels but to create space for the possibility of each student's growth. This value stance runs through every level of Singapore's science education systemic design and technological implementation, from the blurring of fine-grained score differences via AL levels, to the institutional arrangement of multiple progression pathways via Full SBB, and the technological empowerment of process-oriented feedback via SLS platform AI tools. Each step transforms "assessment" from "judgment" into "dialogue." In many education systems, tensions between "grades" and "competencies," as well as between "selection" and "development," remain pronounced. Drawing on Singapore's experience, assessment reform needs to be advanced in depth across four dimensions. First, appropriately expand the "error tolerance" of scores by introducing a level-based system in key examinations, avoiding unnecessary anxiety and competition caused by excessive score differentiation. Second, broaden multiple progression pathways and increase the weight of process-oriented assessment in progression decisions, so that different types of talents can find development pathways suited to them. Third, strengthen teachers' abilities in formative assessment, shifting the focus of daily assessment from "assessment of learning" to "assessment for learning." Fourth, harness AI technologies to empower assessment processes responsibly, while maintaining vigilance against technicist tendencies, ensuring that the introduction of digital assessment tools genuinely serves student growth.

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Conflicts of Interest

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AI Use Statement

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Ethical Approval and Consent to Participate

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