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Learning theories relevant to science teaching

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Science Education in Theory and Practice: An Introductory Guide to Learning Theory, 2nd edition, 2025 (Springer); editors, Ben Akpan and Teresa. J. Kennedy

The 2nd edition (2025) provides an expanded and updated synthesis of 30 learning theories relevant to science teaching, organised across the major psychological and educational traditions – humanistic, behaviourist, cognitivist, constructivist, with the addition of intellectually/skills-based theories. The book offers a *single, comprehensive resource* that brings these diverse theoretical viewpoints together and demonstrates how each theory can inform effective science teaching strategies, curriculum design, and classroom practice.

This edition maintains the structure of the earlier version while expanding its scope, incorporating updated insights from global contributors across 14 countries, and strengthening the connection between theory, pedagogy, and the emerging demands on science education. Each chapter includes explanatory text, worked examples, reflective questions, and classroom-focused interpretations to help educators understand how learning theory can be translated into practice. The book continues to support teachers, teacher educators, and researchers by addressing the persistent need for a coherent, accessible reference that links foundational learning research with the realities of modern science classrooms.

The 2nd edition includes a chapter on Virtual Technology, added in response to shifts in science education driven by the COVID-19 pandemic. This chapter addresses the use of virtual labs, simulations, and technology-supported learning environments, signalling the book's responsiveness to contemporary challenges and the evolving landscape of digital science education.

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The purpose of the book is threefold:

1. To bridge theory and practice, enabling science educators to ground instructional decisions in an established learning theory rather than intuition.
2. To support the development of effective, equitable science teaching, by highlighting how each theory can enhance learning outcomes, engagement, and inclusivity.
3. To prepare the next generation of STEM learners and educators for a rapidly changing world, emphasising critical thinking, inquiry, technology integration, and diverse ways of knowing.

The book seeks to serve as a comprehensive guide and practical toolkit, equipping science educators with theoretical insight, pedagogical strategies, and reflective frameworks necessary for high-quality, theory-driven science instruction in contemporary classrooms in its 5 sections.

These sections are highlighted:

Section I includes 4 humanistic theories

Maslow – human motivation (hierarchy of needs)

Maslow frames learning as contingent on meeting safety, belonging, and esteem needs before expecting higher-order thought; the text positions these conditions as the preface to effective inquiry-rich science lessons. In a laboratory setting, teachers can open with quick well-being and safety check-ins, co-construct norms, and stage "micro-credentials" (e.g., *Lab Safety*) to build efficacy prior to complex tasks. The advantage is a calmer, more participatory class in which students take intellectual risks during investigation. A caveat is that care is not coddling; the maintenance of high cognitive demands, alongside psychosocial support, is essential.

Glasser – choice theory

Glasser's needs for belonging, power, freedom, and fun translate into agency-rich classrooms; the book treats choice as a practical motivator for science inquiry. Teachers may offer a menu of investigation methods (e.g., sensors, syringes, or simulations for gas laws) and common rubrics that hold evidence standards constant. Students typically persist longer and produce stronger explanations when they own the method and product. The risk is "choice without rigour," so boundaries and shared criteria are non-negotiable.

Malone – intrinsically motivating instruction

Malone's levers – challenge, curiosity, fantasy, and control – map neatly onto phenomena-first science units designed as puzzles with student-set goals. A practical enactment is the "unknown powder" analysis with limited tests and a cost ledger to force strategic planning. Expect higher time-on-task and voluntary practice as students experience mastery. Over-gaming can trivialise content; narrative needs to serve, not replace, scientific reasoning.

Bildung – from von Humboldt to Klafki

Bildung ('*educating the whole person*') situates science as self-formation for democratic life, encouraging socio-scientific issues that link evidence to ethics and culture. In class, learners can monitor local air quality, weigh trade-offs, and publish a public brief to stakeholders. Students gain relevance, civic voice, and a sense that science matters beyond grades. The challenge is guarding disciplinary standards so ethical debate does not eclipse evidence and mechanisms.

Section II includes 3 behaviourist theories

Pavlov/Skinner – classical & operant conditioning

The volume presents behaviourist routines as tools for establishing safe, reliable lab behaviours through modelling, repetition, and reinforcement. In practice, teachers script micro-skills (e.g., lighting a burner), rehearse with immediate feedback, and reinforce error-free trials. This produces safer labs and frees cognitive space for meaning-making. The limitation is that behaviour shaping alone cannot yield conceptual change; it should scaffold, not substitute, sense-making.

Bandura – social learning theory

Bandura's modelling, attention, retention, and reproduction explain why visible demonstrations and peer exemplars accelerate the uptake of scientific practices. A teacher can think aloud through a titration, then switch to coached peer trials guided by a process checklist. Students internalise both procedure and scientific talk moves more rapidly. If overused, demonstration may foster passivity – hands-on practice must follow swiftly.

Thorndike – connectionism (law of effect)

Connectionism supports brief, frequent practice with immediate knowledge-of-results to consolidate symbolic fluency (conversions, mole ratios, scale readings). Daily three-minute "science sprints" before inquiry keep

fundamentals automatic. Learners then devote working memory to modelling, argumentation, and multi-step design. The downside is inert knowledge if fluency isn't integrated with conceptual problems, so interleave drills with explanation tasks.

Section III includes 7 cognitivist theories

Miller & colleagues – information-processing

The text highlights cognitive-load-aware design – signalling, dual coding, chunking, and spaced retrieval – to help students navigate complex scientific representations. In a photosynthesis lesson, a simplified diagram plus concise narration and retrieval prompts ("Explain this figure") can anchor memory. Expect clearer mental models and fewer overwhelmed learners. Oversimplification is a risk; clarity must not compromise disciplinary precision.

Piaget – stage theory of cognitive development

Piaget's concrete-to-formal trajectory recommends starting with manipulatives and measurable phenomena before abstract laws. For forces, students push low-friction carts, collect data, and only later formalise $F = ma$. This sequencing reduces brittle memorisation and supports durable intuition. Age isn't a perfect proxy for readiness, so use formative evidence to decide when to generalise.

Bloom – mastery learning

Bloom's premise – most learners can master essentials with time, feedback, and corrective instruction – translates to micro-targets, quick checks, and reassessment windows. A circuit unit might require a safety/procedure mastery check before open design tasks. Students experience success, gaps narrow, and lab risks drop. The caution is time management: prioritise "must-know" outcomes so mastery cycles don't stall the syllabus.

Ausubel – meaningful learning

Because prior knowledge governs new learning, Ausubel advocates advance organisers, concept maps, and carefully bounded analogies. In electricity, a traffic-flow analogy can prime current and resistance, then be refined to avoid misconceptions. Learners integrate new ideas into stable conceptual networks. Mis-anchored prior conceptions require early diagnosis; otherwise, the organiser cements error.

Bruner – discovery learning

Bruner positions learners to infer the discipline's structure from data and phenomena; for gas laws, classes graph P versus V and propose the inverse relation before formalising. Discovery can heighten ownership and transfer. Pure discovery can frustrate novices, so couple this with judicious hints and checks. The text juxtaposes this approach with guided variants elsewhere in the volume to maintain accessibility.

Gagné – guided discovery (nine instructional events)

Gagné's sequence – attention, recall, stimulus, guidance, performance, feedback, assessment, transfer – offers a blueprint for structuring inquiries. In a circuits lesson, a discrepant event launches exploration, scaffolded builds follow, feedback is immediate, and a novel transfer task closes. Students know what to do next and why it matters. Over-specification can limit agency; plan to fade scaffolds quickly.

Perry & Kuhn – intellectual development & scientific thinking

This is a trajectory from dualism to evaluative emphasis, evaluating claims with evidence and managing uncertainty. Structured academic controversy on climate solutions, with warrants and counter-arguments, builds epistemic cognition. Learners change their minds with evidence – a scientific virtue. Without explicit criteria, debate can devolve into rhetoric; anchor discourse in data and mechanisms.

Section IV includes 11 constructivist & learning-sciences theories

Dewey – pragmatism

Dewey ties learning to purposeful, community-connected activity; school energy audits or water-quality monitoring situate science in lived problems. Students collect local data, iterate on designs, and present them to authentic audiences. Expect motivation, transfer, and civic identity. The pitfall is drifting into "service without science"; disciplinary ideas must remain central.

Kolb – experiential learning cycle

Kolb's cycle (experience, reflection, conceptualisation, experimentation) captures the rhythm of good labs. In enzyme studies, learners analyse anomalies, adjust models, and retest. The payoff is metacognition and iterative improvement. Reflection must be structured (with prompts and evidence), or it risks becoming vague journaling.

Bruner – social constructivism

This variant emphasises language and cultural tools in knowledge construction; dialogic talk moves and representation translation (graph ↔ table ↔ text ↔ model) are core classroom practices. Students practice scientific discourse and co-construct meaning. Participation alone is insufficient – teachers must press for accuracy and warrants. The approach strengthens both conceptual grasp and communication.

Vygotsky – social development / ZPD

Vygotsky's mediated learning suggests scaffolded supports enable performance beyond independent levels. Sentence stems ("The trend suggests… because…") and expert-novice pairing can be faded as competence grows. Students experience success at ambitious tasks and internalise strategies. Over-scaffolding breeds dependence, so plan explicit fade points.

Situated cognition & cognitive apprenticeship

Learning is participation in authentic practice with a scaffolding sequence e.g. where the teacher goes from 'modelling'→'coaching'→'fading'; a teacher might model troubleshooting outliers, then coach small groups before independent replication. Students acquire expert habits, not just answers. Authentic constraints (limited time, noisy data) keep tasks real. Avoid contrived "apprenticeships" that mimic form without the substance of scientific practice.

Activity theory – Vygotsky–Leontiev–Engeström

The Activity Theory analyses the whole system – subject, tools, rules, community, division of labour – so teachers design the lab "ecology," assign rotating roles, and hold retrospectives on workflow snags. Coordination improves, and participation becomes more equitable. Students see science as a social, tool-mediated endeavour. Beware rigid role silos; cross-training sustains flexibility.

Multiliteracies – New London Group

The book underscores science as multimodal and multilingual; students can explain with videos + captions, bilingual infographics, or data visualisations, graded by common scientific criteria. Multiliteracies enable access for multilingual learners and strengthen representational competence. Flashy products can mask weak reasoning, so rubrics must privilege accuracy and evidence. When balanced, expression broadens without diluting science.

Project-/problem-based learning

PBL organises extended inquiry around a driving question, critique–revise cycles, and a public product, e.g., reducing campus heat islands via thermal mapping and prototyping. Students integrate modelling, investigation, and argumentation with purpose. Time costs are real, so milestones and targeted mini-lessons keep content robust. Properly guided, PBL yields durable understanding and collaboration skills.

Ernst von Glasersfeld – radical constructivism

Here knowledge is judged by viability – explanatory and predictive power – rather than rote correctness. In gases, learners propose competing particulate models and test which better predicts novel conditions. Creativity and deep sense-making flourish. The risk is sliding into relativism; viability criteria (coherence, parsimony, prediction) must be explicit.

George Kelly – personal construct theory

Students hold personal "constructs" that filter experience; instruction elicits, tests, and revises them. Repertory grids on "what counts as a force" across contexts make thinking visible and set targets for change. Expect sharper metacognition and more targeted conceptual shifts. Without empirical confrontation, reflective practice may become disconnected from classroom evidence.

Andrea diSessa & David Hammer – knowledge-in-pieces (KiP)

KiP reconceives misconceptions as context-sensitive resources ("p-prims") that instruction should recruit and refine. Contrasting cases (frictionless vs friction-heavy motion) and resource-focused feedback help pivot "motion needs force" toward net-force reasoning. Students feel respected and change ideas more robustly. Designing good diagnostics takes time, but the payoff is durable conceptual growth.

Section V includes 5 other intellectually & skills-based theories

Howard Gardner – multiple intelligences

MI widens access by legitimising multiple strengths (spatial, kinaesthetic, naturalist, musical, etc.), which the volume situates among the "other" approaches for inclusive science. Teachers can rotate modalities – field sketching ecosystems, enacting particle models, composing wave soundscapes – while

assessing with a single scientific rubric. Students who struggle with text-heavy tasks often shine here, raising overall engagement. Avoid pigeonholing learners; rotate modalities so everyone stretches.

Systems thinking

Systems thinking equips learners to analyse feedback, delays, and interdependence in complex phenomena like climate or disease spread. In class, students draw causal-loop and stock–flow models and test interventions. Anticipate better reasoning about unintended consequences and leverage points. Vagueness ("everything connects") is a danger; define boundaries and variables tightly.

Gender/sexuality (equity lens)

An explicit equity lens examines representation and participation, pushing teachers to rotate high-status lab roles, monitor talk-time, and choose inclusive contexts. Students from marginalised groups report higher belonging and achievement when participation is designed rather than assumed. Equity work must be data-informed and ongoing rather than a one-off lesson. The book's placement underscores its cross-cutting relevance to all units.

Chapter 28 also focuses on the **role of Virtual Technology in science education**, introduced in the 2nd edition in direct response to shifts brought about by the **COVID-19 pandemic**. The chapter examines how virtual laboratories, simulations, augmented and virtual reality tools, and other digital environments can support science learning when physical access to equipment, materials, or school facilities is limited. It highlights the potential of these technologies to enhance conceptual understanding by enabling students to visualise abstract processes, repeat experiments safely, and manipulate variables that are too costly, dangerous, or impractical in real laboratories.

The chapter emphasises equity and accessibility, noting that virtual tools – when thoughtfully implemented – can broaden participation in science by providing consistent learning experiences regardless of school resources. At the same time, it critiques overreliance on virtual environments, cautioning educators to balance digital tools with hands-on, inquiry-based experiences whenever possible. Ultimately, Chapter 28 positions virtual technology not as a replacement for traditional science teaching but as an expanding set of **pedagogical possibilities** that can strengthen resilience, flexibility, and quality in contemporary science education.

Indigenous knowledge systems

The volume recognises Indigenous knowledge as a valid partner to Western science, encouraging place-based, community-co-designed inquiries and dual-evidence explanations. A weather or ecology unit can pair local observations with instrument readings and invite community review. Students gain cultural relevance, ethical awareness, and a richer ecological understanding. Tokenism is a risk; genuine partnership, permissions, and reciprocity are required.

STEAM & 21st-century skills

STEAM integrates arts/design into STEM, while 21st-century frameworks embed collaboration, communication, creativity, and ethics; the book presents these as modern extensions of core theory into practice. A design on low-cost water filtration, with data-art visualisations and a dual (content + skills) rubric, exemplifies integration. Students practice innovation while consolidating disciplinary ideas. Glossy products can mask shallow science – rubrics must anchor on accuracy and evidence.

Potential additions

Nevertheless, there is the potential that further contemporary theories could be considered, e.g.

In the Humanistic Theories Section, consideration could be given to:

(a) Culturally Relevant Pedagogy (Ladson-Billings) – builds directly on humanistic ideas of centring learners and valuing their cultural backgrounds.
(b) Culturally Sustaining Pedagogy (Paris & Alim) – extends the humanistic focus toward sustaining cultural and linguistic practices.
(c) Funds of Knowledge (Moll et al.) – strongly aligns with humanistic interest in learners' lived experiences and community connections.

These theories deepen the book's humanistic framing by ensuring cultural and experiential dimensions are explicitly theorised.

In the Behaviourist & Cognitivist Sections, consideration could be given to:

(a) Science Identity Theories (Carlone & Johnson, Brickhouse, etc.) – links cognition and motivation with how learners see themselves in relation to science.

(b) Community Cultural Wealth (Yosso) – repositions learners' prior experiences as intellectual assets that shape cognitive engagement.
(c) Universal Design for Learning (UDL) – provides an inclusive cognitive framework for supporting diverse learners' access to content.

These theories ensure that discussions of cognitive development include equity-focused views of how learners engage differently based on cultural, structural, or identity factors.

In the Constructivist Theories Section, consideration could be given to:
(a) Sociocultural Discourse Theories (Gee, O'Connor & Michaels) – perfectly complements Vygotsky, Activity Theory, and Multiliteracies chapters.
(b) Critical Pedagogy (Freire) – adds a political dimension to constructivist concerns about power, participation, and student voice.
(c) Decolonising Science Education Frameworks – build on the existing indigenous knowledge chapter noted in the book description. (This strengthens the conceptual grounding rather than simply presenting indigenous knowledge as supplemental).
(d) Socio-Scientific Issues (SSI) Theory – aligns with project-based and constructivist approaches; engages learners in authentic, culturally and politically relevant problems.

The constructivist chapters currently focus on learning processes, but not on who participates or whose knowledge is legitimised. Equity theories make those processes inclusive and justice-oriented.

In the Skill-Based and Intellectually Oriented Theories Section. consideration could be given to:
(a) Feminist Science Pedagogy – supports examination of gendered participation patterns in advanced scientific reasoning.
(b) Critical Race Theory (CRT) in Science Education – provides a structural analysis of why intellectual opportunities in science are not equitably distributed.

These additions expand the understanding of how structural, racial, and gendered dynamics shape students' opportunities to develop scientific reasoning.