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Guided inquiry in school science: a mini review of orchestration, assessment, and AI

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This mini review asks how to orchestrate guidance, assessment, and student agency so that inquiry reliably yields durable understanding and inclusion, moving beyond the inquiry vs. direct instruction debate. It draws on twenty-six peer-reviewed studies from 2017 to 2025 spanning classroom interventions, video studies, large-scale secondary analysis, discipline-specific and teacher-education reviews, flipped and other technology-mediated inquiries, and AI. Studies were coded for inquiry phases, forms of guidance, assessment practices, and outcomes and were synthesized configuratively across four strands: learning and affect, enactment quality, assessment literacy, and technology/AI. The findings revealed that guided, discourse-rich inquiry supported conceptual understanding, higher-order thinking, and motivation, whereas the raw frequency of "inquiry activities" related inconsistently to achievement when quality and guidance were ignored; assessment literacy for scientific practices remained a key bottleneck; and flipped structures and AI copilots helped when they scaffolded prediction-evidence-explanation sequences and preserved learner agency. The review concludes that systems should prioritize phase-specific orchestration; build assessment capabilities for modeling, data analysis, and argumentation; instrument classrooms to capture process quality; and evaluate AI as formative infrastructure rather than as an answer engine.

KEYWORDS

guided inquiry, orchestration, assessment literacy, modeling and argumentation, classroom discourse, flipped learning, AI scaffolds, equity and inclusion in science education

Introduction

Inquiry-based science education (IBSE) is best treated as participation in scientific practices rather than as a single method: asking investigable questions, planning and conducting investigations, analyzing data as evidence, developing models, arguing from evidence, and communicating findings with explicit attention to the nature of science (Jegstad, 2024; Strat et al., 2024). The debate has matured from binaries to orchestration: judicious explanations paired with structured opportunities to generate, test, and revise ideas, tuned to learners, tasks, and goals (de Jong et al., 2024).

International analysis warn against equating the frequency of open inquiry with quality. When guidance is modeled explicitly, "guided inquiry" relates positively to achievement and affect, whereas high-autonomy "independent inquiry" tends to be negative across many systems; effects are activity-specific and curvilinear rather than linear (Aditomo and Klieme, 2020; Cairns, 2019; Wang et al., 2021). Process-oriented classroom studies echo this: inquiry lessons increase participation but often under-resource preparation and consolidation phases and rarely treat the nature of science explicitly in primary (Kersting et al., 2023; Photo, 2025).

Inclusive and domain-specific evidence shows gains when inquiry is well scaffolded. Argument-centered laboratories improve scientific literacy (Eymur and Çetin, 2024); inquiry-based laboratory redevelopment increases relevance and engagement (George-Williams et al., 2020); and long-term trajectories favor well-sequenced inquiries with subject- and gender-sensitive patterns (Teplá and Distler, 2025). Structured routines widen participation for students with disabilities (Taylor et al., 2025). Technology stabilizes inquiry when it structures process, feedback, and reflection without outsourcing thinking (Kamarudin et al., 2022; Lotter and Ramnarain, 2025; Lin et al., 2020), and AI copilots lift higher-order thinking when they constrain moves and elicit evidence rather than provide answers (Li et al., 2025). Teacher beliefs and support shape students' process skills (Li et al., 2024), and national implementation requires attention to context and teacher capacity (Twizeyimana et al., 2024).

The purpose of this mini-review is to synthesize contemporary evidence on inquiry-based science education to specify when and how guided inquiry, alongside explicit explanations, yields durable conceptual learning and inclusion in school science. Drawing on 26 studies (2017–2025), it examines the sequencing and dosage of guidance that optimize outcomes; clarifies how measurement choices, distinguishing guided from independent inquiry and replacing frequency counts with phase-sensitive quality indicators, change conclusions; and identifies enactment and assessment practices, including flipped structures and AI scaffolds, that reliably broaden participation and strengthen modeling, data analysis, and argumentation. By addressing these aims, the review derives practical design principles and a research agenda centered on phase-specific orchestration, practice-focused assessment literacy, and principled, agency-preserving uses of technology.

Method

Review design and reporting

I drafted an a priori protocol that specified the review question, eligibility criteria, study selection, data extraction, appraisal, synthesis, and reporting. I piloted screening and coding on a subset of studies, refined decision rules, and maintained an auditable log of inclusions, exclusions, and coding changes. Given the diversity of designs and measures, I used a configurative synthesis rather than a meta-analysis, with transparency standards informed by the review methods literature as a reporting scaffold, given the non-PICOS character of several questions (Zawacki-Richter et al., 2020).

Corpus and eligibility

The corpus comprised 26 peer-reviewed studies published between 2017 and 2025. Studies have addressed school or initial teacher-education contexts and examined inquiry-centered instruction or assessment with at least one outcome in achievement, conceptual understanding, scientific practices, engagement or motivation, inclusion or equity, or assessment quality. I included quasi-experiments and RCTs, classroom design studies, systematic video studies, secondary analysis of large-scale assessments, discipline-specific and teacher-education reviews, and evaluations of flipped or AI-supported inquiries. Opinion essays without empirical warrants and higher education studies outside initial teacher preparation were excluded.

Search strategy

The searches covered Scopus, the Web of Science Core Collection, and ERIC, with Google Scholar used for forward citation chasing and follow-up on gray leads. The time window was from January 2017 to September 2025. Example search strings combined inquiry terms with assessment and orchestration constructs, for example, ("inquiry-based" OR "guided inquiry" OR "inquiry learning") AND science AND (school OR primary OR secondary OR "teacher education") AND (assessment OR modeling OR argumentation OR "data analysis" OR "scientific practices" OR orchestration). To capture technology-related work, strings were also included (flipped OR "technology-integrated" OR AI OR "artificial intelligence" OR chatbot). The search syntax was adapted for each database.

Coding and appraisal

I extracted the following data for each study: context and participants; disciplinary focus; targeted inquiry phases; forms and timing of guidance and scaffolds; assessment approach and measures; outcomes; implementation support; and focal findings. I operationalised guidance on a continuum from front-loaded conceptual preparation, through teacher- and tool-mediated scaffolds during investigation, to relatively open inquiry. Appraisal focused on clarity and fidelity of enactment, alignment of measures to scientific practices, treatment of comparison conditions, and transparency in support of implementation. In line with methodological advice for configurative syntheses, I weighted interpretations toward studies that specified phase-specific scaffolding and used robust or rigorous procedures while treating frequency-only indicators from large-scale surveys cautiously (Zawacki-Richter et al., 2020).

Analytic strategy

Given heterogeneity, I conducted a two-cycle thematic synthesis: first-cycle descriptive coding against a priori categories (inquiry phases; guidance type and timing; assessment focus; outcomes), followed by pattern coding to develop cross-study themes. To align analysis with reporting, the synthesis was organized into six strands that map directly onto the findings: (a) learning and affect; (b) enactment quality; (c) measurement from systems data; (d) assessment literacy; (e) technology, flipped structures, and AI; and (f) inclusion and participation. Where constructs and measures were commensurable, I added light aggregative contrasts (for example, juxtaposing activity-specific associations in PISA models with classroom effects). Claims of convergence required corroboration across at least two study types (e.g., intervention and observation) or one strong causal design plus consistent ancillary evidence. Sensitivity reads examined whether themes held when down-weighting frequency-only indicators, separating guided from independent inquiries, or excluding single-site outliers. Throughout, I privileged phase-sensitive indicators of preparation, investigation, and consolidation over raw activity counts and treated equity and agency as cross-cutting checks on interpretation.

Findings

Learning and affect

Across designs, guided inquiry that foregrounded evidence use, modeling, and argumentation produced stronger conceptual outcomes and motivation than minimally guided activity or uniformly didactic exposition, a pattern consistent with convergent rebuttal and domain reviews (de Jong et al., 2024; Jegstad, 2024). In lower secondary, argument-driven laboratories improved scientific literacy by making claims, evidence, and warrants public and revisable and by obliging students to compare and defend representations, a mechanism visible in both performance gains and qualitative accounts of reasoning moves (Eymur and Çetin, 2024). System-level modeling has shown that the inquiry activities most predictive of enjoyment and STEM intentions are explaining ideas and applying science, whereas unstructured autonomy is weaker once background factors are controlled, which reinforces the quality-over-frequency reading of inquiry reports (Wang et al., 2021). In a low-resource context, guided inquiry laboratories enhance their science process skills, indicating transferability when task structure, materials, and teacher support are in place (Chengere et al., 2025). Affective mechanisms were also identified: perceived teacher support predicted inquiry engagement via hardiness in technology-embedded settings, suggesting that encouragement, timely feedback, and visible presence bolstered persistence during uncertainty (Lin et al., 2020). In secondary physics, intrinsic motivation increases when designs address both investigative work and operational demands such as apparatus management and time, which often derail novices, and when tasks invite creative ideation and iterative redesign, creativity scores improve (Meulenbroeks et al., 2024; Xu et al., 2024).

Enactment quality in typical classrooms

Video studies of ordinary lessons have shown that inquiry increases participation and autonomy but varies markedly in preparation and consolidation quality, with explicit attention to the nature of science being infrequent in primary classrooms. The strongest lessons prepared conceptual and representational resources before investigation and then engineered whole-class sense-making afterwards; weaker lessons compressed or omitted these phases (Kersting et al., 2023). In South African natural sciences, flipping repurposes class time for investigation, yet discourse and assessment lag behind instruction and curriculum, signaling the need to script evidence-focused questioning, public comparisons of models, and rapid formative checks during consolidation (Lotter and Ramnarain, 2025). Teaching experience shaped enactment: novices tended toward confirmation or tightly structured inquiry, whereas more experienced teachers orchestrated direct explanations with open investigation, attending to safety and purposeful discussion, which implies distinct professional learning trajectories by career stage (Photo, 2025). At scale, the redevelopment of laboratory curricula that increased inquiry, problems, context, and industry elements improved students' perceptions of relevance and engagement, suggesting that authenticity levers matter when they are coupled with explicit reasoning routines (George-Williams et al., 2020). Where teachers attempt open inquiry without support, progress depends on scaffolds that stabilize planning, evidence use, and reflection; otherwise, self-direction dilutes conceptual learning (van Uum et al., 2017).

Measurement from systems data

Analyses of PISA 2015 discouraged reliance on raw frequency indices. When guided and independent inquiry indicators are distinguished, guided forms are related positively to outcomes, whereas independent forms are related negatively across multiple regions, which underscores the confounding introduced by undifferentiated scales (Aditomo and Klieme, 2020). A complementary study reported curvilinear relations in which very high autonomy depressed achievement, which aligns with classroom evidence that the structure and consolidation phases are decisive for sense-making (Cairns, 2019). Multilevel modeling has shown that teachers' beliefs about inquiry and the opportunity structures they create shape students' science process skills, which links macrolevel patterns to mesolevel enactment variables (Li et al., 2024). Over longer horizons, trajectories suggested that progression toward guided inquiry was prudent, with subject- and gender-sensitive differences that call for nuanced sequencing rather than uniform autonomy (Teplá and Distler, 2025).

Assessment literacy as the bottleneck

Across experienced secondary teachers, formative assessment predominated, drawing on reports, presentations, and observations; however, diagnostic assessment was rare, and key practices such as analyzing and interpreting data, modeling, and argumentation were underassessed. Scoring emphasizes correctness and logical coherence over the quality of analysis and modeling, which narrows what students practice and value and helps explain fragile consolidation phases in observation studies (Hung and Wu, 2024; Kersting et al., 2023). A systematic review of inquiry assessment documented movement toward dynamic tasks, simulations, and automated scoring that capture planning, revision, and reasoning but argued for instruments that describe the quality of an inquiry episode rather than count activities, which aligns with the need for phase-anchored rubrics usable in the flow of lessons (Vo and Simmie, 2025). Research on students' understanding of inquiry has indicated that without explicit instruction and assessment, learners can engage in activities while retaining naïve views of what counts as evidence and explanation, which further motivates the explicit assessment of practices, not just products (Concannon et al., 2020).

Technology, flipped structures, and AI

A scoping review in primary science showed that technology-integrated inquiry enhanced engagement and understanding when tools scaffolded data capture, representation, and reflection, provided that tasks were well designed and access was equitable; technology without process scaffolding did not reliably improve outcomes (Kamarudin et al., 2022). Flipped structures freed class time for investigation when preclass media were short and accountable and when in-class routines were pressed for sense-making but required planning to avoid shifting inequities in preparation outside school (Lotter and Ramnarain, 2025). An AI copilot aligned with a prediction–observation–explanation–experimental sequence outperformed an untuned chatbot in terms of higher-order thinking and knowledge construction, possibly because it constrained moves, elicited evidence, and structured reflection, which reduced answer copying and sustained productive struggle (Li et al., 2025). Country-level implementation studies have reinforced that teacher beliefs, resources, and practical guidance remain decisive for uptake and fidelity; thus, technical potential is translated to learning only when it is embedded in teacher-led designs (Twizeyimana et al., 2024).

Inclusion and participation

Compared with business-as-usual instruction, structured argument-centered inquiry widened engagement for elementary students with disabilities, especially when linked to professional development that aligned classroom routines with claim-evidence reasoning and accessible representations (Taylor et al., 2025). Findings on curiosity have shown that individual differences predict knowledge acquisition more than exploration quality does, which implies distinct support for design and for reflective explanations in primary inquiry and cautions against the assumption that curiosity alone guarantees productive investigation (van Schijndel et al., 2018).

Discussion

Orchestration, not orthodoxy

The center of gravity has shifted from a method war to a theory of orchestration. Evidence across designs indicates that guided inquiry, interleaved with well-timed explanations, is more dependable for conceptual understanding than either unguided discovery or uniform exposition (de Jong et al., 2024; Jegstad, 2024). Mechanistically, effective sequences (a) prepare shared conceptual resources and representations, (b) constrain degrees of freedom during investigation to focus on evidence use and modeling, and (c) engineer consolidation talk that compares models and warrants claims. System-level studies reinforce this design logic: activity-specific and curvilinear patterns show that explaining and applying ideas predict positive affect and intentions, whereas high-autonomy "independent inquiry" relates weakly or negatively to achievement when quality is not controlled (Aditomo and Klieme, 2020; Cairns, 2019; Wang et al., 2021). Classroom videos further demonstrate that "how" inquiry is enacted, especially preparation and consolidation, carries more weight than "how often" it appears (Kersting et al., 2023).

Why enactment falters

Two structural gaps depress everyday impact. First, consolidation is underengineered: typical lessons privilege recall over public comparison of competing models and explicit warranting, leaving pivotal sense-making moves tacit (Kersting et al., 2023; Lotter and Ramnarain, 2025). Second, assessment literacy for scientific practices remains underdeveloped. Teachers report formative intentions yet rarely use early diagnostic probes and underassess analyzing/interpreting data, modeling, and argumentation; scoring leans towards factual correctness rather than quality of inference and representation (Hung and Wu, 2024). These weaknesses dovetail: without practice-focused assessment, consolidation has little traction, and without structured consolidation, assessments sample products rather than processes. Reviews of inquiry assessment argue for phase-anchored instruments that describe episode quality rather than tally activities, a shift that would align evidence with the epistemic aims of science (Vo and Simmie, 2025).

Technology and AI as amplifiers

Technology raises the floor when it stabilizes inquiry routines and surfaces process evidence that teachers can act on; it lowers the ceiling when it supplies answers or displaces teacher judgement. Productive uses share three traits: they constrain thinking (e.g., requiring predictions and planned evidence), instrument for feedback (capturing planning, revision, and reasoning), and maintain agency with learners and teachers. Flipped structures satisfy these conditions when preclass media are concise and accountable and when in-class time is protected for sense-making (Lotter and Ramnarain, 2025). An AI copilot aligned with prediction–observation–explanation–experiment improved higher-order thinking and knowledge construction vs. an untuned chatbot by pressing for evidence and structuring reflection (Li et al., 2025). Social dynamics still matter: perceived teacher support predicts engagement via resilience in technology-embedded inquiry, suggesting that digital scaffolds amplify, rather than replace, pedagogical presence (Lin et al., 2020). Implementation studies caution that beliefs, resourcing, and practical guidance mediate uptake; without these, technical potential does not translate to learning (Kamarudin et al., 2022; Twizeyimana et al., 2024).

Equity, inclusion, and progression

Inclusive inquiry is not accidental. Structured argumentation and writing-to-learn routines broaden participation for students with disabilities when teachers receive aligned professional learning (Taylor et al., 2025). Progression matters: moving from confirmation or structured inquiry toward guided inquiry fits observed trajectories and varies by subject and gender, arguing against one-size-fits-all autonomy (Teplá and Distler, 2025). Teachers' beliefs and the opportunity structures they create shape students' science process skills, which links equity to everyday enactment rather than to isolated interventions (Li et al., 2024). Finally, curiosity is not a panacea: in primary settings curiosity predicts knowledge gains more than exploration quality does, indicating the need for distinct support for experimental design and for reflective explanation (van Schijndel et al., 2018). The equity test for any design, including AI-enabled designs, is whether it strengthens participation in modeling, data analysis, and argumentation for those historically least served, without increasing dependence on opaque feedback or unequal access.

Conclusion

This mini review shows that the question in school science is not whether to use inquiry but how to orchestrate it so that learning is robust and inclusive. Across designs, guided inquiry that is prepared with shared ideas and representations, constrained during investigation to focus on evidence and modeling, and consolidated through public comparison of claims, supports conceptual understanding, higher-order thinking, and motivation. The raw frequency of "inquiry activities" is a poor proxy for quality; what matters is phase-sensitive design, calibrated guidance, and engineered discourse. The practical corollary is clear: align curriculum, assessment, and professional learning with the preparation–investigation–consolidation arc and treat technology, including AI, as formative infrastructure that elicits predictions, surfaces evidence, and structures reflection while preserving learner and teacher agency.

The field now needs precision rather than new slogans. At the system and school levels, policy should provide time and tools for consolidation talk; build assessment capabilities for analyzing and interpreting data, modeling, and argumentation; and couple authenticity moves in laboratories and projects with explicit reasoning routines. Flipped structures and AI copilots are productive when they scaffold process and generate actionable evidence, not when they supplant pedagogy. Equity must remain a design constraint: inclusive inquiry requires accessible representations, structured argumentation, and targeted support so that students who are least served participate in the core practices of science.

A focused research agenda follows. First, replace frequency counts with phase-anchored indicators and mixed sources of evidence, linking classroom observations and digital traces to well-aligned assessments of practices and concepts. Second, sequencing and dosage claims should be tested directly by contrasting front-loaded conceptual preparations with contingent scaffolds during investigations and by examining delayed outcomes and transfers. Third, teacher learning progressions for consolidation talk and practice-focused assessment, including moderation routines that travel across schools, should be studied. Fourth, AI and other tools for process quality, retention, and participation gains should be evaluated, with explicit equity checks and cost–benefit analysis. If systems measure what matters and teachers are resourced to orchestrate preparation, investigation, and consolidation, guided inquiry can become a routine feature of science lessons, one that is both conceptually ambitious and fair.

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