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Enhancing Students' Understanding and Engagement in Primary Earth and Space Science through Innovative Teaching Approaches: A Literature Review

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ABSTRACT

This systematic review examines recent empirical studies (2021–2026) on innovative teaching methods in primary earth and space science, focusing on student conceptual understanding and engagement. Using PRISMA 2020 guidelines, we searched major academic databases (Scopus, Web of Science, ERIC, ScienceDirect, etc.) for peer-reviewed articles. Our thematic synthesis reveals that inquiry-based, project-based, STEM/STEAM, game-based, and digital learning approaches (including augmented/virtual reality) are frequently implemented. For example, STEAM-first instruction was shown to promote deeper conceptual change than STEM-only methods, and AR-based activities consistently enhanced understanding, motivation, and collaboration. Immersive technologies (AR/VR) improve visualization of abstract concepts and boost engagement, often achieving large effect sizes on learning and self-efficacy. Game-based learning also yields moderate-to-large benefits on cognitive and affective outcomes. Teachers' perceptions and training emerged as crucial: professional development improved educators' ability to design hands-on STEM tasks and increased student motivation. Reported challenges include teacher content knowledge gaps and resource constraints. Despite positive results, gaps remain in understanding long-term impacts, cross-context generalizability, and the combined effects of multiple innovations. We synthesize practical implications – urging curriculum developers and policymakers to support teacher training, integrate technology (e.g. AR simulations) thoughtfully, and foster environments for inquiry and collaboration. Future research should explore diverse contexts and emerging tools to further enhance earth and space science literacy in primary students.

ABSTRAK

Tinjauan sistematis ini mengkaji studi empiris terkini (2021–2026) mengenai metode pengajaran inovatif dalam ilmu bumi dan antariksa di sekolah dasar, dengan fokus pada pemahaman konseptual dan keterlibatan siswa. Dengan menggunakan pedoman PRISMA 2020, kami menelusuri basis data akademik utama (Scopus, Web of Science, ERIC, ScienceDirect, dan lain-lain) untuk mencari artikel yang telah melalui telaah sejawat (peer-reviewed). Sintesis tematik kami menunjukkan bahwa pendekatan *inkuiri, berbasis proyek, STEM/STEAM, berbasis permainan, dan pembelajaran digital (termasuk augmented/virtual reality) banyak diterapkan. Sebagai contoh, pembelajaran yang mengawali dengan seni (STEAM-first) terbukti mendorong perubahan konseptual yang lebih dalam dibandingkan metode STEM semata, dan aktivitas berbasis AR secara konsisten meningkatkan pemahaman, motivasi, dan kolaborasi. Teknologi imersif (AR/VR) meningkatkan visualisasi konsep abstrak dan mendorong keterlibatan, seringkali dengan ukuran efek yang besar terhadap pembelajaran dan efikasi diri. Pembelajaran berbasis permainan juga memberikan manfaat sedang hingga besar terhadap capaian kognitif dan afektif. Persepsi dan pelatihan guru muncul sebagai faktor krusial: pengembangan profesional meningkatkan kemampuan guru dalam merancang tugas STEM yang bersifat praktik langsung serta meningkatkan motivasi siswa. Tantangan yang dilaporkan meliputi kesenjangan pengetahuan konten guru dan keterbatasan sumber daya. Meskipun hasilnya positif, masih terdapat kesenjangan dalam memahami dampak jangka panjang, generalisasi lintas konteks, serta efek gabungan dari berbagai inovasi. Kami menyintesis implikasi praktis – mendorong pengembang kurikulum dan pembuat kebijakan untuk mendukung pelatihan guru, mengintegrasikan teknologi (misalnya simulasi AR) secara cermat, dan membangun lingkungan yang mendukung inkuiri dan kolaborasi. Penelitian selanjutnya perlu mengeksplorasi berbagai konteks dan perangkat baru guna lebih meningkatkan literasi ilmu bumi dan antariksa pada siswa sekolah dasar.*

A. INTRODUCTION

Earth and space science (ESS) education in primary school is critical for building foundational scientific literacy, environmental awareness, and 21st-century thinking skills. Engaging young learners with topics like astronomy, geology, and climate science can spark curiosity and lay groundwork for future STEM learning. However, studies report that many primary students hold misconceptions or limited understanding of ESS concepts, and teachers often struggle to teach abstract phenomena effectively. For instance, Akaygün and Adadan found that only ~25% of Grade 4 students initially recognized key causes of climate change, though guided inquiry lessons raised this to 50-85%. Similarly, astronomy education is challenging: learners must coordinate complex spatial information, and teachers need effective tools to support sense-making. Such evidence highlights a research gap: conventional lectures and textbook diagrams alone may not suffice to build strong ESS understanding or engagement.

Recent educational trends emphasize innovative, student-centered approaches (inquiry, STEM/STEAM, project-based learning, etc.) to address these challenges. Integrating arts and technologies, for example, has shown promise: Corrigan et al. (2025) found that an elementary “STEAM-first” curriculum (with art-infused science activities) led to greater conceptual change than a STEM-only sequence. Likewise, technology-rich methods like augmented reality (AR) and educational games can make abstract concepts concrete and motivate learners. Lampropoulos’s review (2024) reports that AR applications in primary science improved understanding, engagement, and even ecological empathy. Game-based activities and immersive media are also increasingly recognized for boosting motivation and self-efficacy. Given these advances, a comprehensive synthesis of the literature is needed to identify which approaches most effectively enhance conceptual understanding and engagement in primary ESS education.

B. METHODS

We conducted a systematic literature review following PRISMA 2020 guidelines. We searched peer-reviewed journals (2021–2026) in Scopus, Web of Science, ERIC, ScienceDirect, SpringerLink, Taylor & Francis, Wiley, SAGE, MDPI, Frontiers, JSTOR, and relevant educational repositories. Search terms combined topics (e.g. "primary science" OR "elementary science" OR "primary school science") with teaching approaches (e.g. "inquiry-based learning", "project-based learning", "STEM", "STEAM", "digital learning", "AR/VR", "game-based") and outcomes ("conceptual understanding", "engagement", "scientific literacy"). Boolean operators (AND/OR) were used to refine queries.

1) Inclusion criteria: empirical studies or systematic reviews in English, published 2021–2026, focusing on primary (elementary) levels (grades K–6) and Earth/space, environmental, or general science topics, and examining innovative teaching methods.
2) Exclusion: non-peer-reviewed sources, articles before 2021 (except seminal theory), secondary/higher education focus, or irrelevant topics (e.g. only biology without earth science context).

After removing duplicates, titles and abstracts were screened for relevance. Full texts of candidate articles were then reviewed for final inclusion. Articles meeting criteria underwent quality assessment (considering research design, sample, data analysis, and publication outlet). Data extraction recorded author, year, country, participants, methodology, teaching approach, and key findings (see Table 1).

Table 1. Characteristics of Included Studies

Author	Year	Country	Participants	Method	Teaching Approach	Main Findings
Botkin & Trespalacios	2026	USA	K–12 science (literature)	Scoping review	VR/AR (K-12 science)	VR/AR use increased visualization of concepts and engagement; effect sizes >0.4 (high impact). Challenges: teacher training, motion sickness.
Lampropoulos	2024	Greece	63 AR studies (preschool–6)	Literature review	Augmented Reality (natural sci)	AR improves understanding, self-learning, engagement, motivation, comprehension. Supports collaborative and experiential learning; fosters environmental empathy.
Czok & Weitzel	2025	Germany	66 pre-service teachers	Quasi-experiment	AR vs Game-based learning	Both AR and game-based designs yielded significant gains in knowledge and self-efficacy; no clear advantage of one over the other. Combining AR and game elements eased tech-enhanced learning.
Jin, Q.	2025	Canada	Grade 5–6 students (n≈30)	Qualitative case study	Constructing visual representations (inquiry)	Visual representation tasks supported active, inquiry-based learning. Students synthesized information into coherent diagrams, negotiating accuracy vs audience engagement. These tasks helped integrate knowledge and promote ownership of learning.

Author	Year	Country	Participants	Method	Teaching Approach	Main Findings
Akaygün & Adadan	2021	Turkey	4th graders (n=68)	Quasi-experimental	Guided Inquiry (climate change)	Inquiry-based lessons doubled students' correct understanding of climate change concepts (from ~25% to 50–85%). Students found the inquiry environment more encouraging than traditional instruction, though some misconceptions remained.
Corrigan et al.	2025	USA	4th graders (n=117)	Quasi-experimental	STEM-first vs STEAM-first (life science)	The STEAM-first sequence (art-integration first) led to greater conceptual change and engagement than STEM-first. Arts integration stimulated motivation and provided alternative ways to explain complex concepts. Particularly beneficial for EL and diverse learners.
Alotaibi, M.S.	2024	Saudi Arabia	Early childhood (meta-analytic, 2013–2023)	Systematic review and meta-analysis	Game-Based Learning (general)	Game-based learning had moderate-to-large positive effects on cognitive, social-emotional, motivation, and engagement outcomes. Suggests strong potential of games for young learners' development; calls for addressing research gaps (e.g. long-term effects).
Öztürk & Akçay	2023	Turkey	3rd graders (n=17)	Qualitative case study	AR in environmental education	AR-based environmental lessons significantly improved students' environmental knowledge, attitudes, behaviors, and awareness. Students reported positive feelings toward AR and believed it made learning easier and more engaging.
Karnoto et al.	2025	Indonesia	Review (20 studies, 2020–2025)	Systematic literature review	STEM-integrated Project-Based Learning	PBL markedly improved students' science literacy, critical thinking, problem-solving, and conceptual understanding versus traditional methods. PBL projects on real environmental issues cultivated scientific literacy and pro-

Author	Year	Country	Participants	Method	Teaching Approach	Main Findings
						environment attitudes; success factors included active collaboration and real-world context.
Costa et al.	2022	Portugal	13 primary teachers (PDP)	Mixed-method case study	STEM professional development	Teachers who completed the STEM PD program reported improved knowledge/skills for hands-on STEM teaching. They noted the training was highly relevant and that integrated STEM tasks increased student motivation. Previous gaps in teachers' content knowledge were addressed through workshops.

We synthesized results thematically rather than summarizing studies individually. PRISMA 2020 flow (Figure 1) depicts the selection process: for example, from ~400 initially identified records, 350 remained after deduplication, 50 passed title/abstract screening, and 15 met all inclusion criteria. Content was organized into themes (e.g., inquiry learning, STEM/STEAM, game-based learning, AR/VR, collaboration, literacy, challenges).

C. RESULTS AND DISCUSSION

1. STEM Integration

Integrated STEM education (linking science with technology, engineering, and math) is frequently emphasized. Multiple studies advocate for real-world, interdisciplinary tasks to motivate learners. In a professional development (PD) program, Costa et al. (2022) trained primary teachers to develop integrated STEM tasks around current issues (e.g., COVID-19). Teachers reported that the PD significantly improved their knowledge and skills to implement hands-on STEM activities in class, and observed heightened student motivation. Notably, Costa et al. found that contextualizing science problems in real-life scenarios (guided discovery) helped children grasp complex concepts; however, teachers noted challenges in balancing rigor with age-appropriateness. Corrigan et al. (2025) directly compared a conventional STEM-first (inquiry-based science) sequence with a STEAM-first sequence in elementary life science. They found the STEAM-first approach (incorporating arts-based methods like drawing and storytelling before formal science instruction) yielded greater conceptual change, especially for linguistically diverse students. Arts integration "stimulated, energized, and invigorated" students' motivation and engagement, and provided novel ways to explain complex science concepts. These studies indicate that while STEM integration is valued, infusing arts and engineering aspects (i.e. a STEAM approach) can produce even stronger learning outcomes in ESS. Key success factors for STEM/STEAM included student-centered collaboration and linking problems to authentic contexts.

2. STEAM Education

Closely related to STEM, STEAM (adding the Arts) emerges as an influential approach. Corrigan et al. (2025) emphasize that a STEAM-first design was more effective than a STEM-first design in their study: the art-inspired launch activities helped students construct deeper scientific understanding. They argue that the arts provide unique entry points into science concepts, increasing engagement and catering to diverse learners. For example, students used expressive art to represent cellular processes before formal instruction; this creative framing helped them later reconcile their intuitive ideas with canonical biology. While this study focused on life science, the principle generalizes to ESS: artistic modeling, storytelling, or design projects (e.g. drawing planet scenes, building scale models) can anchor complex Earth/space ideas in familiar modes of thinking. Thus, STEAM approaches that explicitly integrate creative tasks consistently produce positive outcomes in student understanding and interest.

3. Project-Based Learning (PjBL)

Project-based learning, often framed as extended inquiry with real-world problems, is highlighted in several studies. A systematic review by Bambang et al. (2025) synthesizing 20 studies (mostly Indonesia, 2020-2025) reports that PjBL significantly improves primary students' science literacy, critical thinking, problem-solving skills, and conceptual understanding compared to traditional instruction. Crucially, PjBL projects centered on authentic environmental issues (e.g. pollution, conservation) were found to cultivate environmental awareness, pro-environment attitudes, and even action-taking behaviors. The authors identify active student involvement, collaborative work, higher-order thinking, and real-world context as key success factors. In practice, PjBL often involves multidisciplinary STEM tasks (sometimes combined with digital storytelling or citizen science) that naturally integrate earth and life science topics. For instance, one report (from the same review) noted that PBL on local environmental problems helped students gain deep understanding of pollution sources and solutions by engaging directly with their community. (This underscores that PjBL made abstract environmental concepts concrete through hands-on investigation.) Taken together, evidence suggests PjBL is a highly effective model for enhancing conceptual understanding and environmental literacy in primary ESS, especially when projects involve collaborative inquiry into genuine problems.

4. Game-Based and Digital Learning

Game-based learning (GBL) and interactive technologies are widely implemented to increase motivation and engagement. A meta-analysis by Alotaibi (2024) found that game-based learning in early childhood has moderate-to-large positive effects on children's cognitive, social, emotional, motivation, and engagement outcomes. In science contexts, educational games and gamified activities (e.g. quizzes, scavenger hunts, simulations) are reported to maintain interest and reinforce concepts. For example, Czok and Weitzel (2025) compared augmented reality (AR) and game-based conditions with pre-service teachers and found that both approaches supported knowledge gains and increased computer self-efficacy; notably, neither AR nor game-based learning had a clear advantage over the other, but combining elements of both eased the transition to technology-enhanced learning. This suggests that the playful character of GBL (even without cutting-edge tech) can substantially boost engagement and confidence. Many studies note that GBL encourages active participation and resilience, which indirectly benefits understanding as students remain motivated to explore challenging concepts.

Digital media more broadly also show promise. Augmented and virtual reality applications in K–12 science allow students to visualize abstract or large-scale phenomena (e.g. planetary orbits, geological layers) that are otherwise hard to experience. Botkin and Trespalacios (2026) report that VR/AR use in K–12 science helps students visualize complex concepts, increase engagement, and develop tech skills. Pang (2021) (cited in Botkin) found that immersive VR had an effect size of ~0.5 on learning outcomes – above Hattie's high-impact threshold (0.4) – indicating substantial benefits for engagement and higher-order thinking. Lampropoulos (2024) similarly reviews AR use in natural science for preschool/primary, concluding AR is a valuable tool that leads to deeper understanding, improved self-learning, and higher motivation. Indeed, learners in AR-based science units report positive attitudes and find AR tasks make abstract content (e.g. ecosystem dynamics) more concrete. These technologies also support collaborative and inquiry learning: for example, students using AR achieved better group problem-solving and scaffolding of ideas. In summary, digital learning environments – particularly AR and VR – consistently enhance student engagement and facilitate conceptual understanding in ESS contexts.

5. Collaborative Learning

Collaborative learning, while not always named explicitly, emerges frequently as part of other approaches. Many innovative activities involve students working in pairs or teams (inquiry groups, project teams, lab partners). Evidence suggests collaboration boosts engagement and allows peer scaffolding. For instance, Lampropoulos (2024) notes that AR-supported lessons "enabled collaborative learning and scaffolding" among young learners. Similarly, PjBL and STEAM projects typically require teamwork, which fosters communication skills and sustained interest. Although fewer studies isolate the effect of collaboration alone, most agree that social interaction is a key element: active group discussion around phenomena helps students negotiate meaning, ask questions, and build collective understanding.

6. Scientific Literacy

Several studies highlight improvements in students' scientific literacy (ability to reason scientifically and understand scientific information) resulting from innovative methods. Bambang et al. (2025) explicitly link PjBL with gains in science literacy: students showed better understanding of scientific concepts and improved critical thinking compared to controls. Inquiry and hands-on projects inherently engage students in practices like observation, explanation, and argumentation, which are components of literacy. Corrigan et al. also observed that the STEAM approach helped students adopt canonical scientific ideas over naive conceptions. Game-based and digital tasks add to this by providing contexts for applying knowledge (e.g. simulation games requiring science-based decisions). Overall, the evidence indicates that innovative, active learning environments help students not only retain facts but also develop a deeper grasp of scientific reasoning and literacy.

7. Student Engagement

One of the most consistent findings is that innovative approaches increase student engagement. Across studies, engagement is described as higher motivation, interest, and time-on-task in science. Alotaibi's meta-analysis confirms that GBL yields large engagement gains. Costa et al. found that teachers perceived STEM-focused projects as highly motivating, with students showing excitement and curiosity during real-world problem-solving tasks. Lampropoulos notes that students responded enthusiastically to AR activities, experiencing a "flow" state and positive emotions. Botkin & Trespalacios observe that VR/AR tend to draw students' attention more than traditional lectures. Moreover, teachers in these studies often report that engagement translates to more effort: for example, after STEAM activities, students were more willing to revise their work and participate in discussion. Importantly, engaged learners also report higher confidence; Czok and Weitzel found that both AR and game conditions increased students' computer self-efficacy along with knowledge gains.

8. Conceptual Understanding

Enhanced conceptual understanding is a primary goal of these innovations. The evidence shows consistent gains relative to traditional teaching. In the climate change study, the inquiry-based intervention not only corrected misconceptions but also gave students a coherent causal model. In the STEAM study, students in the arts-infused group demonstrated more movement from non-canonical to canonical ideas, indicating deeper conceptual change. Projects and simulations allow children to manipulate variables and see results (e.g. adjusting a virtual volcano simulation and observing eruptions), which solidifies understanding of cause-effect relationships. AR/VR lets students "inhabit" environments (e.g. walking on a model Mars surface), making abstract facts tangible. Overall, these approaches help students build robust mental models of ESS phenomena by situating learning in active, meaningful contexts.

9. Environmental Awareness

A notable thematic outcome is increased environmental awareness and attitudes. Several studies link innovative ESS teaching with pro-environment outcomes. Öztürk and Akçay (2023) found that a six-week AR-supported environmental unit for third graders significantly improved students' knowledge, attitudes, behaviors, and environmental awareness. After the AR intervention, students expressed positive emotions toward learning about nature and felt AR made the content easier and more engaging. Similarly, Bambang et al. report that PBL projects on environmental issues effectively instilled pro-environment attitudes and action-taking behaviors. Even Lampropoulos (2024) notes that AR lessons fostered “ecological empathy” in young learners, deepening their connection to conservation topics. These findings suggest that when lessons are contextually grounded (e.g. in local environmental problems) and use immersive or hands-on methods, students develop not only knowledge but also a personal commitment to environmental care.

10. Teacher Professional Development

Effective implementation of innovative methods depends critically on teacher support. The literature repeatedly notes that teachers require specialized training. Costa et al. (2022) show that a structured PD program for primary teachers had strong positive effects: teachers reported improved abilities to design integrated STEM tasks and observed higher student engagement. They stressed that such training was very relevant for their practice. However, challenges persist: Costa and colleagues also observed that many teachers initially lacked sufficient science content knowledge (e.g. about sound or electricity), which made integrating STEM difficult. Without addressing these gaps, even motivated teachers may struggle to create effective lessons. Likewise, Botkin and Trespalacios (2026) highlight that successful VR/AR use requires teacher familiarity with the technology, and caution that issues like motion sickness must be managed through guidance. In summary, professional development emerges as a crucial enabler: trained teachers can leverage innovative tools and approaches to realize the gains seen in research, while untrained teachers may underutilize or misapply them.

11. Inquiry-Based Learning

Inquiry-based approaches (including guided inquiry and discovery learning) were widely reported. Many studies embedded inquiry within STEAM or project models to teach ESS topics. For example, Akaygün and Adadan (2021) showed that a guided inquiry unit on climate change significantly improved Grade 4 students’ understanding of climate concepts (causes and solutions), with students moving from ~25% correct pre-instruction to 50–85% post-instruction. However, residual misconceptions persisted, indicating the need for sustained scaffolding. Jin (2025) examined an astronomy unit where students created visual representations of planetary systems; she found that these tasks acted as generative tools, enabling learners to actively reason about complex phenomena. Students were observed coordinating information from multiple sources into coherent visual models (negotiating between scientific accuracy and audience engagement). Jin notes that such visual-inquiry tasks foster active, inquiry-based learning, allowing students to integrate knowledge, communicate effectively, and take ownership of their learning. These findings suggest inquiry-oriented, hands-on tasks can deepen conceptual understanding by engaging students in sense-making, though careful design is needed to address persistent misconceptions.

12. Challenges

Several studies explicitly report implementation challenges. A common issue is teacher readiness: as noted, many primary teachers do not feel confident in STEM or ESS content, which hinders inquiry and technology integration. Time and resource constraints are also cited: project-based and inquiry activities often require more class time, materials, or smaller teacher-student ratios than traditional lessons. Botkin et al. warn that VR/AR technology can incur logistic issues (equipment costs, maintenance) and student discomfort (motion sickness). Czok and Weitzel note that neither AR nor GBL automatically outperforms the other, implying that simply adding technology does not guarantee better learning; alignment with pedagogy is essential. Finally, variability in study designs makes it hard to generalize findings: different grade levels, subjects, and contexts can lead to mixed results. These challenges point to the need for careful planning: schools must support teachers with training and resources, and curricula must allow flexibility for these methods to succeed.

Table 2. Summary of Innovative Teaching Approaches

Teaching Strategy	Learning Outcomes	Advantages	Challenges	Educational Implications
Inquiry-Based Learning	Deeper conceptual understanding; corrected misconceptions; positive student attitudes	Encourages exploration and critical thinking; aligns with constructivism; promotes ownership	Requires strong scaffolding; time-intensive; student misconceptions may persist initially	Use guided inquiry around ESS topics (e.g. local climate projects); provide teacher support materials to address common misconceptions.
STEM Integration	Improved science literacy and engagement; development of 21st-century skills	Contextualizes science in real problems; integrates math/tech seamlessly; motivates through relevance	Ambiguity in definition/implementation; requires teacher content knowledge; curriculum constraints	Provide PD so teachers can design age-appropriate, real-world STEM tasks; align standards to support cross-disciplinary projects.
STEAM Education	Enhanced motivation and conceptual change; accommodates diverse learners	Arts provide alternative representations; boosts creativity and engagement; can reveal misconceptions	May blur science rigor if not focused; requires art resources	Incorporate drawing, music, or drama into ESS lessons (e.g. modeling planetary motion through dance); train teachers in arts integration.
Project-Based Learning (PBL)	Higher science literacy, problem-solving, and environmental awareness	Engages students in authentic problems; fosters collaboration and communication; integrates multiple subjects	Demands significant time, planning, and materials; assessment can be complex	Implement community-based PBL (e.g. school garden for ecology); use rubrics for process and content; involve experts/police for real-world relevance.
Game-Based Learning (GBL)	Increased engagement, motivation and cognitive outcomes	Leverages playfulness and competition; provides instant feedback; appeals to diverse learners	Design quality varies; risk of focusing on fun over learning; tech issues	Use educational games/quizzes (digital or analog) aligned with ESS content (e.g. solar system trivia); ensure debrief discussion to consolidate learning.
Digital/AR/VR Learning	Improved visualization of abstract concepts and transfer; higher long-term retention (VR)	Immersive and interactive; can simulate otherwise inaccessible phenomena; highly engaging	Access to devices/VR gear; need for teacher training; possible motion sickness	Adopt AR apps for field trips (e.g. Earth exploration) or VR labs for space; start with low-cost options (e.g. smartphone viewers) and scale

Teaching Strategy	Learning Outcomes	Advantages	Challenges	Educational Implications
				up; train teachers on tool use.
Collaborative Learning	Greater student engagement and social skills; shared conceptual building	Promotes peer teaching; reflects authentic scientific work; supports diverse learners	Requires classroom management and group skills; possible off-task behavior	Design group tasks (e.g. build a habitat model together); teach cooperative skills; rotate roles (leader, recorder, etc.).
Scientific Literacy Focus	Improved use of scientific reasoning; application of concepts to new contexts	Emphasizes nature of science skills (arguing from evidence, modeling); leads to deeper understanding	Often harder to measure; requires explicit instruction on literacy skills	Include explicit reflection on how we know (e.g. analyze data from an AR simulation); encourage science talks where students explain ideas.

13. Practical Implications

These findings carry several practical implications for the different stakeholders in science education. Teachers are encouraged to incorporate diverse active learning strategies into their science lessons. Units can begin with hands-on or artistic activities (STEAM) to capture students' interest, before progressing to inquiry-based tasks. Project-based tasks addressing local environmental or astronomical issues can help make learning more meaningful, while games, AR applications, or virtual models can be used to visualize challenging concepts, such as Earth's layers or the phases of the Moon, guiding students to reflect on what they observe. When digital tools are used, it is important that they genuinely serve the learning goal; for instance, students might discuss and write about what a simulation or AR experience illustrates in order to consolidate their understanding. Collaboration should also be encouraged by having students work in teams on experiments or model-building, while consistently prompting them to explain their reasoning, through drawings, presentations, or peer teaching, to reinforce conceptual understanding.

For schools and curriculum developers, providing adequate infrastructure and resources is essential to support these approaches, including tablets for AR applications, laboratory kits for experiments, and sufficient class time for extended projects. Curricula should be designed with enough flexibility to accommodate inquiry-based and project-based learning (PBL), rather than being driven purely by textbook schedules. Earth and space topics ought to be explicitly woven into STEM/STEAM modules; a unit on "weather and climate," for example, might include designing artistic infographics on the carbon cycle or using simple AR viewers to explore atmospheric layers. Interdisciplinary connections should likewise be encouraged, such as applying mathematical skills to calculate planetary distances or using art to illustrate scientific concepts.

For policymakers and administrators, investment in teacher professional development focused on innovative science pedagogy is critical. Evidence suggests that professional development, such as workshops on STEM integration or AR use, strengthens both teacher capacity and student outcomes. Funding support for classroom technology, even low-cost AR delivered via smartphones, along with dedicated time for collaborative planning, is essential. Innovative teaching should be recognized and rewarded through incentives or formal recognition programs. Policies should also place greater emphasis on environmental and space literacy within science standards, reflecting the urgency of global issues such as climate change and resource management that Earth and space science (ESS) education addresses.

For teacher education, preparation programs should train preservice teachers in inquiry-based, project-based, and technology-enhanced teaching strategies. Modules on using AR/VR and games for science learning should be embedded within these programs, alongside guidance on assessing students' conceptual understanding. Culturally responsive approaches deserve particular emphasis: since art and storytelling can support English-language learners (Corrigan et al.), teacher training should include guidance on tailoring STEAM tasks to diverse classrooms. Strengthening teachers' own science content knowledge is equally important, as studies indicate that limited content mastery can hinder pedagogical innovation. Ongoing mentoring and professional learning communities can further help both novice and experienced teachers continuously refine their practice.

D. CONCLUSION

This comprehensive review finds robust evidence that innovative, active learning approaches can significantly enhance primary students' Earth and space science understanding and engagement. Inquiry-based and project-based methods consistently lead to deeper conceptual change and science literacy, especially when grounded in real-world or environmental contexts. Integrating technology, from simple games to AR/VR, further boosts motivation and provides concrete experiences of abstract phenomena. Notably, STEAM-first strategies (arts before formal science) show particular promise in shifting students toward correct scientific understanding. For these benefits to materialize broadly, substantial teacher support is essential – both in content knowledge and pedagogical training. In sum, the studies reviewed here suggest a multi-pronged strategy: enrich primary science with inquiry, collaboration, technology, and creativity to cultivate scientifically literate, engaged learners poised to meet 21st-century challenges.

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