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From Listeners to Investigators: A Critical, Evidence-Based Synthesis of Project-Based Learning (PjBL) in the Science Classroom

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Abstract

Background and Aim: In many education systems, science classrooms have traditionally followed a transmission model in which teachers explain content and students listen, copy notes, and memorise facts for tests. This model teaches knowledge but does not always teach students to think and work like real scientists. Existing reviews of project-based learning (PjBL) in science education tend to catalogue its reported benefits without systematically weighing the strength of the evidence behind them, or clarifying how PjBL differs from closely related approaches such as inquiry-based and problem-based learning. This article addresses that gap: rather than claiming PjBL is a universally superior alternative, it critically synthesises the literature to ask under what conditions shifting responsibility from teacher-led delivery toward student-led inquiry is justified, and where the evidence is thinner than the enthusiasm surrounding it might suggest.

Materials and Methods: This is a literature-based academic article employing document study and narrative synthesis. Sources were located through structured searches of the Scopus, ERIC, and Google Scholar databases using terms including project-based learning, science education, scaffolding, and student outcomes, and were included where they reported empirical or conceptual work on project-based science learning published mainly between 2008 and 2026. Each source was also read critically for the strength of its research design, so that claimed benefits could be weighed rather than simply reported.

Results: The literature converges on a plausible, though not unanimous, account: a science project is an extended, student-driven inquiry into a real problem producing a concrete product, in which teachers act as facilitators whose guidance shifts with students' age and experience, while students plan, investigate, collaborate, and report as active researchers. What is less settled is the strength of evidence behind the many claimed benefits: reported gains in process skills, creativity, motivation, self-efficacy, collaboration, real-world skills, and sustainability awareness recur across studies, yet many rely on quasi-experimental designs, small or single-site samples, and short interventions, a tension this article treats as central rather than incidental to its conclusions.

Conclusion: Rather than declaring PjBL simply effective or ineffective, this article argues that the balance of evidence favours treating project work as a deliberate restructuring of responsibility between teacher and student, one whose value for classroom practice and teacher-education policy depends on careful design, realistic scaffolding, and honest engagement with the limits of current evidence.

Keywords: Project-Based Learning; Science Education; Student Agency; STEM Integration; Sustainable Development Goals

Introduction

Science is not only a subject to be read about in a textbook; it is a way of exploring the real world, asking questions, and searching for evidence-based answers. For much of the history of formal schooling, however, science classrooms have followed a different pattern: the teacher explains the content, and students listen, copy notes, and memorise facts for a test (Colley, 2008). This method can transmit information efficiently, but it does not automatically teach students how to think, question, and work the way real scientists do (Kurt & Akoglu, 2023).

In response to this limitation, project-based learning (PjBL) has become one of the most widely discussed instructional approaches in science education over the past two decades (Al-Qoyyim & Kurniawan, 2025). Instead of receiving knowledge passively, students in a PjBL classroom investigate a real, meaningful question over an extended period and finish with a concrete product, such as a report,

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a working model, or a public presentation (Andriyani et al., 2019). This shift changes not only what students do in class but also who is responsible for learning: the student moves from the position of a listener to the position of an investigator, while the teacher moves from the position of a lecturer to the position of a guide (Colley, 2008). Yet the popularity of PjBL in the research literature is not, by itself, evidence of its superiority: an approach can be widely discussed and still rest on evidence that is uneven in quality, so the more useful question is not whether PjBL is fashionable, but under what conditions the shift in responsibility it demands is actually justified by the data. This shift also rests on theoretical ground broader than constructivism alone: Vygotsky's socio-cultural theory frames the collaborative, tool-mediated nature of project work as a driver of higher-order thinking, while self-determination theory helps explain why the autonomy, competence, and relatedness that well-designed projects can offer translate into the motivational gains reported throughout this literature.

Despite the volume of research on PjBL in science education, most existing reviews catalogue reported outcomes without systematically weighing the quality of the evidence behind them, and rarely clarify how PjBL differs in practice from closely related approaches such as inquiry-based learning, problem-based learning, or general hands-on activity, terms that are frequently used interchangeably in both research and classroom practice. This article addresses that gap through a structured document study: sources were located through searches of the Scopus, ERIC, and Google Scholar databases using combinations of the terms project-based learning, science education, scaffolding, student agency, and learning outcomes, and were included where they reported empirical findings or substantive conceptual analysis of project-based science learning, published mainly between 2008 and 2026. The resulting sources were then synthesised narratively and read critically for research design, so that reported benefits could be weighed rather than simply catalogued.

This article addresses four questions that matter for anyone shaping science instruction, whether a classroom teacher, a teacher educator, or a curriculum designer. First, what exactly is a science project, and why should it have a place in the science classroom at all? Second, what should the teacher actually do to support students who are carrying out a project, given that support can look very different depending on the students involved? Third, what does an active student role look like in practice, from choosing a question to reporting findings? Fourth, what do students genuinely gain from this way of learning, beyond the content knowledge that a single test might measure? By drawing together evidence from more than twenty studies conducted across different countries, grade levels, and subject areas, this article aims to give a grounded, evidence-based answer to each question, and to argue that science classrooms benefit from treating project work as a central pillar of instruction rather than an occasional add-on. In pursuing these questions, this article treats the literature not as a uniform verdict in favour of project-based learning, but as a body of evidence to be interpreted, compared, and, where necessary, questioned, so that the conclusions drawn are earned rather than assumed. Framed more analytically, these four questions converge on a single evaluative one: under what conditions, and with what evidentiary support, does shifting responsibility from teacher-led delivery toward student-led inquiry actually improve science learning, and where does the literature's enthusiasm for PjBL outrun what its own evidence can bear?

Content

The four sections that follow build cumulatively rather than standing alone: they move from what a science project actually is, to who is responsible for supporting it, to what active engagement looks like from the student's side, and finally to what is genuinely gained, and at what evidentiary cost, from teaching this way. Readers who work through all four will find that the case for project-based learning is strongest not in any single section, but in how consistently the same theme- that responsibility, evidence, and support must be calibrated rather than assumed- recurs across every one of them.

What Is a Science Project, and Why Teach Through Projects in the Science Classroom?

Before the value of project-based learning can be judged, and before its costs to teacher time and curriculum coverage can be justified, the term itself needs to be pinned down more precisely than everyday classroom usage allows. This subsection defines what a science project is, distinguishes it

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from neighbouring approaches that are routinely used as if they were interchangeable, and sets out why the underlying rationale for teaching this way deserves to be taken seriously rather than assumed.

A science project is not a single lesson or a single hands-on activity; it is an extended learning process in which students investigate a real problem and produce a tangible outcome (Andriyani et al., 2019). Reviewing many earlier definitions, Kurt and Akoglu (2023) note that although researchers do not agree on one single definition of project-based learning, most agree on its core features: students engage with a challenging, authentic problem; they sustain their inquiry over time; they help choose or shape the project; they reflect on and revise their work; and they create a product meant for an audience beyond the teacher. Andriyani et al. (2019) add that a science project typically poses a real problem, asks students to explore the real world, requires self-regulation, calls on a range of skills, and produces a concrete product. This lack of a single, shared definition is not a minor academic quibble: when different studies label quite different classroom activities as 'project-based learning,' comparing their outcomes side by side, as much of the literature reviewed here does, risks overstating how consistent the evidence for its benefits actually is.

This definitional looseness has a further, more specific consequence: PjBL is routinely used interchangeably with inquiry-based learning, problem-based learning, and simple hands-on activity, even though the four are not the same thing. Inquiry-based learning centres on students posing and answering their own scientific questions, which may or may not culminate in a tangible product; problem-based learning, more common in professional and medical education, anchors learning around solving a single, often ill-structured problem, typically over a shorter timeframe than a full project cycle; and hands-on activity can be as brief as a single lesson's demonstration, with no requirement for sustained student ownership of the driving question at all. PjBL, on Kurt and Akoglu's (2023) own account, requires authentic problem framing, sustained inquiry, student voice and choice, reflection, and a product for a public audience, together, which is a considerably higher bar than any of its neighbours demand alone. Conflating these approaches makes it too easy to borrow the motivational appeal of a short, fun activity while quietly claiming the more rigorous, and more evidence-demanding, benefits associated with full PjBL. This distinction also bears on a long-standing concern in the broader learning-sciences literature: instruction with minimal guidance can impose a heavier cognitive load on novice learners than well-structured direct instruction, because working memory is consumed by search and trial-and-error rather than by building the schema a lesson is meant to teach. Read against this concern, the case for PjBL rests on its scaffolding being genuinely present and well designed, not on the absence of teacher guidance; a project without adequate structure risks the very cognitive overload its critics warn against, while a well-scaffolded one, as the next subsection argues, can avoid it.

Colley (2008) usefully distinguishes between different types of projects according to their main purpose. Some are design or engineering projects, in which students plan, build, and test a device, tool, or structure to solve a practical problem. Others are content or subject-matter projects, designed mainly to help students understand a specific scientific concept in greater depth. In practice, a single project can serve both purposes at once: if students design a simple water filter, they are completing an engineering task while also learning content about filtration and water quality. Robinson (2013) shows that this flexibility holds across education levels: in one university chemistry course, students were asked to test whether a sports drink truly contained the amount of a substance stated on its label, and because the question had a genuine real-world answer, students had to design their own testing method rather than copy a fixed laboratory procedure. Robinson's example is persuasive precisely because the outcome mattered outside the classroom; whether the same motivating effect holds for projects with a less obviously 'real' stake, such as many classroom-bound design tasks, is a question the literature addresses far less convincingly.

Why, then, should science classrooms be organised around this kind of work rather than around lecture-based delivery of content? The literature offers a consistent answer: the aim of science education is not only to transmit facts but to raise individuals who can notice everyday problems, look at them from a scientific viewpoint, make careful observations, reason analytically, and apply what they learn to daily life (Kurt & Akoglu, 2023). A purely transmission-based classroom struggles to develop this kind of thinking, because students rarely practise the full cycle of asking a question, planning an

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investigation, collecting evidence, and drawing a conclusion. Al-Qoyyim and Kurniawan (2025) describe project-based learning as grounded in constructivism, the view that learners build their own understanding through active, contextualised engagement with real problems, rather than by absorbing ready-made explanations. Sormunen et al. (2023), reporting on a primary school invention project, found that students who designed and built their own technological inventions encountered rich, interdisciplinary science-learning opportunities that a standard achievement test could not fully capture, even when gains in test scores were modest. It is worth noting, however, that 'not fully captured by a test' is also precisely the kind of claim that is difficult to falsify: if a test shows a gain, PjBL is credited with producing it, and if a test does not show a gain, the explanation offered is that the test was measuring the wrong thing. Readers should weigh this interpretive move carefully rather than accept it uncritically, even as the broader argument that authentic tasks surface forms of learning invisible to short, standardised assessments remains a reasonable one.

Taken together, these considerations suggest that the strongest justification for teaching through projects is not that the approach is inherently superior to direct instruction, but that, when its definition is held to a reasonably strict standard, and its guidance is deliberately engineered rather than left to chance, it offers a route to authentic inquiry that looser, shorter activities cannot match. Whether that promise is realised, however, depends heavily on what the teacher does with it, which is the question the next subsection takes up.

The Teacher's Role in Supporting Student-Led Science Projects

If the definition of a science project sets the bar, the teacher is the one who has to clear it in practice. This subsection examines what supporting a student-led project actually demands of a teacher, moving from the general shift in role, through the specific forms that scaffolding can take, to the practical and assessment-related burdens that make this shift harder than it first appears.

If students are expected to take the lead in a science project, it is fair to ask what is left for the teacher to do. The answer, according to Colley (2008), is that the teacher's role changes rather than disappears: the teacher is expected to facilitate, advise, guide, monitor, and mentor, rather than simply lecture or run a fixed laboratory procedure. Lesson planning therefore shifts away from a sole focus on delivering and testing content, and instead includes defining the area of study, identifying an appropriate learning environment, selecting resources and time, anticipating likely learning challenges, and designing fair, ongoing ways of assessing a process that unfolds over weeks rather than in a single class period (Colley, 2008).

An important and often overlooked part of this supporting role is orientation. Before students begin collecting any data, Colley (2008) recommends a stage in which the teacher and students discuss what collaboration should look like, how information will be shared, what safety rules apply, and how the final work will be judged. Skipping this stage can leave students unsure of their responsibilities, so that they either feel lost or simply wait for the teacher to give step-by-step instructions, which defeats the purpose of project work.

Crucially, the amount and kind of support a teacher provides should not be fixed; it should vary according to students' age, prior experience, and whether they are working individually or as part of a group. Al-Qoyyim and Kurniawan (2025) describe how the appropriate balance of guidance shifts noticeably across educational levels. At the elementary level, students are largely teacher-dependent, and the teacher acts as a full facilitator and activity leader, using visual aids, simple templates, and structured group roles. At the middle-school level, students begin to work more independently in groups, and the teacher becomes more of a discussion guide, still offering scaffolding such as guiding questions and sample checklists, but gradually reducing that support as students grow in confidence. At the high-school level, students can be given more independence with teacher supervision, tackling technical design and testing tasks, while at the university level students are expected to work with almost full independence, and the instructor's role shifts toward that of a research mentor and academic supervisor who guides the process of proposal writing, execution, evaluation, and dissemination (Al-Qoyyim & Kurniawan, 2025). This progressive reduction of support as students mature is sometimes called scaffolding, and it applies as much to how a teacher manages a whole class of different individuals as it does to how a teacher supports one student's growth over several years of schooling.

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The scaffolding this progression depends on is not a single, undifferentiated form of help. It is useful to distinguish hard scaffolding, the fixed, pre-planned supports built into a project's materials, such as templates, checklists, and worked examples, from soft scaffolding, the responsive, in-the-moment guidance a teacher improvises when a particular group gets stuck, a distinction that matters because hard scaffolding can be designed once and reused, while soft scaffolding depends entirely on a teacher's moment-to-moment judgement and subject expertise. A related distinction separates procedural support, help with the logistics of running a project, timelines, roles, materials, from conceptual support, help with the underlying science itself; a teacher can be excellent at the former while still lacking the pedagogical content knowledge (PCK) needed for the latter, particularly when a project drifts into territory outside their own specialism. None of this is free: institutional time limitations mean that thoughtful, differentiated scaffolding of the kind described above competes directly with curriculum coverage demands, and assessment anxiety, the pressure teachers feel to produce gradeable, comparable evidence of learning from an inherently open-ended process, can push even well-intentioned teachers back toward tighter, more prescriptive control than genuine student autonomy would require.

It is tempting to read the progression from full facilitation at the elementary level to near-total independence at university as a tidy, linear ladder that any teacher can simply climb. In practice, the picture is almost certainly messier than the model suggests: a first-year university student who has never previously designed an independent inquiry does not automatically become a confident, self-directed investigator merely by enrolling in a course that assumes that competence, and a highly capable ten-year-old may be ready for more independence than a strict age-based model would assign. The more defensible reading of this literature, then, is not that age or grade level determines the right amount of support, but that age functions as a reasonable starting proxy for something that ultimately has to be judged case by case: how much prior experience with open-ended inquiry a given group of students actually has.

Supporting students well also means managing group dynamics fairly. Because not every student naturally contributes equally to teamwork, teachers need to monitor group processes actively, using tools such as team contracts, individual reflection logs, and structured peer feedback to keep participation equitable (Al-Qoyyim & Kurniawan, 2025). At the same time, assessment itself becomes more demanding, since a fair evaluation of project work must capture not only the final product but also collaboration, creativity, problem-solving, and reflection, often through rubrics and staged, formative check-ins rather than a single end-of-unit test (Al-Qoyyim & Kurniawan, 2025).

These same assessment tools, however, are where some of the least examined risks in PjBL sit. Peer and self-assessment are attractive precisely because they distribute the grading burden and make collaboration visible, but both are vulnerable to well-documented biases: social loafing, in which some students coast on a group's collective output while contributing little themselves, can go undetected when the final product is graded as a whole; and friendship grading, in which peers rate each other generously out of social obligation rather than accurate judgement, can quietly erase the very differences in effort and contribution the assessment was meant to capture. A teacher who adopts these tools without also building in some form of individual accountability, an individually authored reflection, a randomly probed viva, or a grade component tied to demonstrably individual work, risks rewarding the appearance of collaboration rather than its substance.

None of this is a small undertaking: Colley (2008) notes directly that project-based science instruction requires extensive preparatory work from the teacher, especially at the start of the learning cycle, though this workload tends to ease once students grow used to taking responsibility for their own learning. This concession deserves to be taken seriously rather than treated as a footnote: if the up-front burden of designing and managing scaffolded, differentiated project work falls unevenly on teachers who already have the least preparation time, the largest class sizes, or the fewest instructional resources, then the model's benefits may be least accessible precisely where they are most needed, a tension the literature synthesised here acknowledges but does not fully resolve.

The picture that emerges from this subsection is not that teachers become dispensable once a project is underway, but that their work becomes harder to see and harder to standardise: differentiated by

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scaffolding type, constrained by their own subject knowledge and the school timetable, and exercised through assessment tools that carry real risks of their own. Whether students can actually rise to meet this kind of support, and what the experience feels like from their side of the desk, is the question the next subsection turns to.

The Student's Role in Carrying Out a Science Project

Having examined what teachers are asked to do, this subsection turns the lens around to ask what is actually asked of students, and, just as importantly, what it costs them. The account that follows resists the temptation to present student ownership as a smooth, uniformly positive progression from question to report; it instead traces the stages of that progression alongside the friction that genuine ownership tends to produce.

Where the teacher facilitates, the student investigates. In a well-designed science project, the student does not wait passively to be told what to do at every step; the student becomes an active researcher who contributes to the whole learning process, from the first question to the final report (Colley, 2008). This active role unfolds across several recognisable stages.

The process typically begins with students taking part in choosing and shaping the driving question themselves, rather than simply being handed one. Colley (2008) describes a classroom example in which students who noticed a water-quality issue in a park near their school wrote their own research question and explained, in their own words, why the issue mattered to their community. This kind of ownership matters because a poorly defined question, chosen without student input, almost always leads to a poorly designed investigation later on. Once a question is chosen, students move into planning, which typically includes writing down the research question, explaining why it matters, outlining a step-by-step method, listing the tools and materials required, setting a timeline, and dividing responsibilities within the team (Colley, 2008). Writing this plan forces students to think ahead and notice potential problems before they start collecting data, rather than discovering them midway through the investigation.

None of the stages just described unfolds as smoothly for students as a tidy stage model can suggest. Choosing and shaping a question of one's own is disorienting for students accustomed to being told exactly what to do, and the early planning phase in particular is where frustration, uncertainty about whether an idea is even feasible, and outright cognitive conflict- the uncomfortable sense that new evidence does not fit a student's existing understanding- tend to concentrate. These affective states are not incidental noise around the 'real' cognitive work of the project; in a genuinely student-led investigation they are frequently the mechanism through which deeper learning happens, since resolving a genuine impasse, rather than being handed the answer, is what forces students to reorganise their thinking. A teacher who reads early-stage frustration as a sign the project has failed, rather than as a predictable and potentially productive part of it, risks intervening too quickly and quietly handing the ownership back that the project was designed to build.

During the hands-on stage, students use tools, collect data, and record observations, most often working in small teams with clearly divided responsibilities. Al-Qoyyim and Kurniawan (2025) note that in secondary and university-level projects, students may be responsible for every phase, from problem identification and proposal writing to execution, evaluation, and even publication of results, with instructors acting mainly as mentors. Sormunen et al. (2023) illustrate this kind of ownership concretely: in their primary school invention project, thirteen student teams designed and built a working prototype meant to solve a real problem in their daily lives, drawing on physics knowledge as well as broader interdisciplinary science learning along the way. Luneeva and Zakirova (2017) add an important cross-subject dimension to this active role, showing that in many science projects students must decide for themselves which subject's tools to use at each step, for example, when they need to measure, calculate, or model something as part of their investigation; this responsibility encourages students to see school subjects as connected rather than as separate, disconnected boxes of knowledge. This cross-subject work asks more of students than simply picking the right tool for the job; it asks them to negotiate real differences in how disciplines construct and justify knowledge. Applying a mathematical model to an empirical biological investigation, for instance, means reconciling mathematics's tolerance for idealised, exact assumptions with biology's tolerance for variability,

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uncertainty, and exceptions, two disciplines that treat error very differently. Students who have only ever been taught mathematics and biology as separate, self-contained subjects are rarely given explicit help in making this epistemological shift, and a project that assumes the transfer will happen automatically may be asking for something the standard curriculum has not actually prepared students to do.

The final stage of a project's cycle is documentation and reporting. Colley (2008) explains that once data analysis is complete, students usually present their findings for peer review, meaning they present their work to classmates and the teacher and answer questions about it. This is a notable shift in classroom roles: during a presentation, the teacher listens and asks questions to check understanding, while the students explain and defend their own conclusions, almost like young scientists themselves. Learning to organise information clearly enough for others to follow, and to defend one's own reasoning in front of an audience, is a skill that extends well beyond the science classroom itself.

This final stage is also where classroom power dynamics become most visible, and most consequential. Not every student arrives equally ready to defend a position in front of peers: language proficiency, prior confidence with public speaking, and status within the peer group all shape who is heard, who is interrupted, and whose reasoning is taken seriously, in ways that have little to do with the quality of the underlying science. Treating this stage as a straightforward simulation of authentic scientific argumentation risks overlooking the fact that professional scientific discourse itself is not immune to these same dynamics, and that a classroom presentation, without deliberate structuring, can reproduce rather than correct them. Whether this level of ownership is realistic within the time and curriculum constraints most science teachers face is a separate question that the cited studies, several of which describe well-resourced, purpose-built programmes rather than an ordinary timetabled class, do not fully answer.

Read together, these accounts of student ownership are best understood not as a guarantee that autonomy produces learning, but as a description of the conditions, emotional, epistemological, and social, under which it plausibly can. Whether those conditions translate into outcomes that are large enough, consistent enough, and well measured enough to justify the effort is precisely the question the evidence on benefits, examined next, must answer.

Benefits Students Gain from Doing Science Projects

This subsection is where the promise of project-based learning is most often oversold, and where a critical reader has the most reason to slow down. Rather than treating each reported benefit as separate, self-evident good news, the discussion that follows asks, benefit by benefit, how strong the underlying evidence actually is, drawing on the specific studies this article has already introduced to illustrate both what they show and what they do not.

The literature on project-based science learning points to benefits that go far beyond a single test score, spanning academic, cognitive, social, and even attitudinal dimensions of student development. The strength of this evidence, however, varies considerably from one claimed benefit to the next, and treating all of the areas discussed below as equally well established would overstate what the underlying studies can actually support; the discussion that follows therefore weighs each benefit alongside the kind of evidence it rests on.

The most frequently studied benefit is academic achievement. Ergül and Kargın (2014) taught a unit on electricity to sixth-grade students using project-based learning with one group and standard instruction with a comparison group, and found that the project-based group scored significantly higher on the achievement test afterwards. At a larger scale, Kanter and Konstantopoulos (2010) examined a project-based science curriculum used with urban middle-school students from groups underrepresented in science careers, and found that it was linked with real gains in science achievement, particularly when teachers also had strong content knowledge. This last point carries an important caution, echoed by Kanter (2010) in a separate study: a project can keep students busy and even produce an impressive final product without necessarily building a meaningful, usable understanding of the underlying science content. In other words, the benefits of project work are not automatic; they depend on how carefully a project is designed so that students genuinely need the science content to complete it. The scale of these studies is worth stating plainly rather than leaving implicit: Ergül and Kargın's

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(2014) often-cited result comes from 92 sixth-graders across two schools, with a statistically significant but modest effect ($F = 6.57$, $p < .05$) once pre-test differences were controlled for, and comparable undergraduate research by Bilgin et al. (2015) worked with 66 students split into two intact classes of 33. These are respectable numbers for classroom-based, quasi-experimental research, but they are far smaller, and far more local, than the confident, general language often used to summarise PjBL's achievement effects would suggest. Part of the variation across these studies is also plausibly a matter of implementation fidelity- how closely a given classroom's version of PjBL actually matched the model being tested- and assessment alignment, whether the test used to measure the outcome matched what students actually practised; neither factor is easy to verify from a published study alone, which is a further reason to treat any single achievement figure as illustrative rather than definitive.

A second, closely related benefit is stronger science process skills, meaning the ability to observe, question, test, analyse, and conclude. Andriyani et al. (2019), reviewing many studies, found that project-based learning consistently improves these skills, together with related competencies such as teamwork, problem-solving, communication, and creativity, because a real project usually calls on several of these skills at once rather than one at a time in an isolated lesson. Creativity in particular receives close attention in the literature: Purba and Zunidar (2025) found that fifth-grade students who learned science through project-based learning showed significantly greater gains in creativity than a comparison group taught conventionally, while Raksapoln and Suttiwan (2021) reported that primary school students who learned through STEM-based engineering design tasks achieved high average scores in both creativity and collaboration, categorised as very good on validated assessment measures.

The numbers behind Purba and Zunidar's (2025) result illustrate the same point from another angle: the study drew on 54 fifth-graders, 27 per group, in a single school, over a four-week intervention, with creativity scores rising from a mean of 10.67 to 19.04 in the experimental group against 7.44 to 11.78 in the control group. The direction and size of this difference is genuinely striking, but a single school, over four weeks, is a narrow evidentiary base on which to generalise about creativity gains across grade levels, subjects, and cultural contexts, particularly since creativity assessments are inherently more interpretive than a multiple-choice achievement test, and are therefore more sensitive to the judgement of whoever is doing the scoring.

A third area of benefit concerns motivation and self-belief. When students help choose and steer part of their own learning, they typically feel more invested in the outcome, developing what researchers call intrinsic motivation, meaning that they want to complete the work because they find it meaningful, not only because it is graded (Lachebo et al., 2024). This sense of ownership is closely tied to self-efficacy, or confidence in one's own ability. Bilgin et al. (2015) found that undergraduate education students who learned a science-teaching course through project-based learning developed significantly stronger beliefs in their own ability to teach science, and also achieved higher course scores, compared with students taught in a traditional format. It is worth flagging that motivation and self-efficacy are typically measured through self-report questionnaires, which capture how students say they feel rather than how they would perform under pressure, and it is also worth asking whether published intervention studies of this kind are representative in the first place: research that finds a positive motivational effect is, on balance, more likely to be written up and accepted for publication than research that finds none, a pattern known as publication or selection bias, and a novel, one-off project is, almost by definition, more exciting to take part in than the routine instruction it is compared against, regardless of its underlying pedagogical merit.

A fourth benefit lies in social-emotional growth and character development. Because science projects usually require extended teamwork, students have repeated opportunities to practise empathy, accountability, perseverance, and respect for differing viewpoints (Al-Qoyyim & Kurniawan, 2025). These outcomes matter for a student's development as a person, not only as a future scientist, and they align closely with broader educational goals concerned with moral and civic growth. Much of this particular evidence comes from teacher observation and student reflection rather than validated psychological instruments, which leaves open the possibility that teachers who already favour project-based learning are also more inclined to notice, and to report, the social behaviours that confirm its value; this is not a reason to dismiss the claim, but it is a reason to hold it a little more loosely than the more tightly measured achievement findings discussed above.

A fifth benefit relates to real-world and professional skills. Robinson (2013) reports that university students who completed a project-based laboratory course gained practical skills such as accurate measurement, careful record-keeping, problem-solving when an experiment goes wrong, and clear scientific communication, all of which transfer directly to future scientific or technical careers. In

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one brewing-analysis project described in the same study, teams were graded partly on a shared group score and partly on individual contribution, closely mirroring how accountability works in a real workplace. Robinson's account is compelling as a description of thoughtful laboratory pedagogy, but it is fair to ask how much of the reported gain comes specifically from the project format, as opposed to simply spending more structured, hands-on time in the laboratory than a traditional, recipe-style course allows; the study does not fully separate these two possible explanations, which limits how confidently the benefit can be attributed to project-based learning as such.

A sixth, increasingly important benefit concerns positive attitudes toward science and toward science-related careers. Kanter and Konstantopoulos (2010) found that a project-based science curriculum shaped not only achievement but also students' attitudes toward science and their thinking about future study and careers, particularly among students from groups underrepresented in science fields. Lachebo et al. (2024) make a related point in the specific context of science project competitions, describing students who take part in such activities as potential contributors to future knowledge and technology in their societies. Attitude shifts of this kind are encouraging, but they are also among the most vulnerable to novelty effects: an unusually engaging unit of any kind, project-based or not, can temporarily brighten students' attitudes toward a subject, and only studies that track students well beyond the intervention itself can show whether such shifts persist into actual subject choices or career paths, something the studies reviewed here were not designed to test.

Finally, a growing number of recent studies connect science projects to sustainability awareness and responsible citizenship, an area of benefit that reaches beyond the traditional boundaries of a science curriculum. Suttiwan et al. (2026) designed a food-waste science learning activity that used a real, disorienting problem in school canteens to connect Grade 10 science content to Sustainable Development Goal 12 on responsible consumption, aiming to shift students from simply knowing facts about waste to genuinely thinking about the systemic impact of their choices. In a related study conducted with junior high school students in Indonesia, Munawar et al. (2026) found that an action-oriented learning approach to food consumption, closely related in spirit to project-based learning, significantly increased students' sustainability-related actions over four weeks, with the largest gains seen in students' stated intentions for future behaviour. Similarly, Hamimi et al. (2026) and Suttiwan et al. (2025) describe STEM-based projects on topics ranging from orangutan habitat conservation to local corn-based nutrition, showing that when a project is anchored in a genuine local or global issue, students' learning extends naturally into environmental and social responsibility, alongside their science content knowledge. Even where the direction of the effect is clear, as in Munawar et al.'s (2026) result, the distance between a documented shift in stated intention and a documented change in sustained behaviour outside the classroom remains largely untested in this literature, and closing that distance depends on factors- household routines, peer norms, and the practical availability of sustainable choices- that a four-week science unit has limited power to change on its own.

None of this amounts to a case against project-based learning; if anything, naming these limits precisely is what makes the remaining evidence more, not less, persuasive, because a claim that survives honest scrutiny is a stronger claim than one that was never scrutinised at all. What it does argue against is treating any single number, an achievement gain, a creativity score, a motivation index, as a finished verdict. The pattern that survives across achievement, process skills, creativity, motivation, character, professional skills, career attitudes, and sustainability awareness, uneven and imperfectly measured as each strand is on its own, is consistent enough across genuinely different researchers, countries, and methods that dismissing it wholesale would be its own kind of overreach. It is this cumulative, cross-checked pattern, not any one study, that the conclusion now draws together.

Across all four of the subsections above, a single thread holds: project-based learning does not succeed or fail as a monolithic method, but as a chain of specific, checkable design decisions, how tightly the term itself is defined, how deliberately scaffolding is engineered, how honestly student difficulty is acknowledged, and how carefully claimed benefits are weighed against the studies that produced them. That chain, and what it means for practice and policy, is where this article now turns.

Conclusion

Having traced that chain of decisions through definition, teacher support, student experience, and evidence, this conclusion draws the threads together and turns from summary toward a more pointed set of implications for practice, teacher education, and future research.

This article set out to answer four connected questions about the place of projects in the science classroom: what a science project is and why it belongs there, how teachers should support it, what an active student role looks like, and what benefits students gain from the experience. The evidence

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reviewed here does not point to a single, uncontested conclusion so much as to a reasonably convincing balance of probabilities: on the whole, and with the caveats raised throughout this article, a science classroom appears most likely to support deep learning when it moves beyond delivering content and becomes a space where students take on the role of active investigators, supported, but not directed at every step, by their teacher.

This does not mean that content knowledge no longer matters, nor that the teacher's role becomes less important. On the contrary, as Kanter (2010) warns, students can complete an impressive project without truly understanding the science behind it, unless the teacher deliberately designs the task so that using the content is genuinely necessary. What changes is where responsibility sits: the teacher's task shifts from delivering information to designing conditions in which students must think, question, plan, and revise for themselves, while remaining close enough to notice when a group is struggling and to step in with the right kind of help at the right moment.

Crucially, the right kind of help is not a fixed formula. As the literature on project-based learning across education levels shows, teacher support should be adjusted according to students' age, their prior experience with independent inquiry, and whether they are working alone or within a group, gradually shifting from close, structured guidance toward mentorship as students demonstrate readiness for greater autonomy (Al-Qoyyim & Kurniawan, 2025). A first-grade class exploring a simple question about magnets needs a very different kind of teacher presence than a university team designing a renewable-energy prototype, even though both are, in a meaningful sense, doing science projects. What the literature does not yet offer is a reliable, practical way for a teacher to diagnose, in the middle of a busy term, exactly how much independence a particular group of students is ready for; until better classroom-level diagnostic tools exist, this remains a matter of professional judgement informed by evidence, rather than a formula the evidence itself can supply.

None of the design decisions discussed throughout this article happens in a vacuum, and it would be misleading to close without naming the systemic barriers that make good PjBL harder to achieve than the pedagogical literature alone implies. Standardised, high-stakes testing regimes reward content coverage and easily scored recall over the slower, messier process of genuine inquiry, and a teacher who invests weeks in a single project is, under such systems, taking a real risk with their students' measured performance. Rigid curriculum timetables, built around fixed periods and fixed content sequences, leave little natural room for a project to run past its allotted slot when students, as they often do, need more time than planned. And resource disparities between schools, in materials, in class sizes, in teachers' own preparation time, mean that the model of scaffolded, differentiated support described throughout this article is considerably easier to deliver in a well-resourced school than in an under-resourced one, a form of inequality the PjBL literature discusses far less than it should.

Finally, even allowing for the methodological caveats raised throughout this article, the accumulated pattern of benefits reviewed here, spanning achievement, process skills, creativity, motivation, character, career readiness, and sustainability awareness, makes a reasonably persuasive case for treating project work not as an isolated activity confined to a single unit or a single subject, but as an approach worth integrating across disciplines and connecting to the wider world students will inherit. Interdisciplinary approaches such as STEM education, in which science, technology, engineering, and mathematics are brought together around a single authentic problem, offer one natural way to extend project-based learning beyond the boundaries of a single science topic (Raksapoln & Suttiwan, 2021; Suttiwan et al., 2025). Likewise, anchoring projects in globally recognised concerns such as the United Nations' Sustainable Development Goals, as seen in recent work on food waste and sustainable consumption, gives students' investigations a sense of relevance that reaches beyond the classroom wall and into the shared challenges of the world they are growing up in (Suttiwan et al., 2026; Munawar et al., 2026). Realising this potential, rather than merely gesturing at it, requires more than adding a sustainability theme to an existing project template; it requires ensuring that the global framework genuinely shapes the content students investigate, the data they collect, and the audience they report to, rather than being retrofitted as a label once the project is otherwise complete. A project that briefly mentions the Sustainable Development Goals in its introduction, without asking students to grapple with a locally meaningful version of the problem those goals describe, risks the same kind of superficial coverage this article has cautioned against throughout: the appearance of relevance substituting for its substance.

This article's own limitations deserve the same honesty it has asked of the studies it reviews. As a narrative synthesis of mainly published sources located through Scopus, ERIC, and Google Scholar, it is subject to the same selection and publication biases discussed above, and its conclusions should be read as a reasoned interpretation of the available evidence rather than an exhaustive or statistically

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pooled account. Three directions for future research follow directly from these limits. First, the field would benefit substantially from longitudinal studies that track students well beyond a single project's end, since almost none of the evidence reviewed here can distinguish a lasting shift in skill, attitude, or behaviour from a short-lived response to novelty. Second, cross-cultural comparative research is needed to test whether the patterns synthesised here, drawn disproportionately from a handful of national contexts, hold with similar strength in the very different systems, resource levels, and assessment cultures found elsewhere. Third, and perhaps most practically, research is needed on scalable professional development frameworks that can equip ordinary science teachers, not only the highly motivated early adopters typically studied, with the scaffolding skills, subject knowledge, and assessment literacy this article has argued genuine PjBL requires.

Taken together, these directions call for a science classroom that treats knowledge, skill, and global relevance as parts of a single, connected learning experience, one in which the science project is not an occasional event, but a central and recurring way that students come to know, and to care about, the world around them. None of this amounts to a guarantee that any given project will deliver these outcomes; it is, instead, a case for treating project-based learning as a deliberately and critically designed practice, one whose considerable promise for science education, and for the students who stand to gain most from learning to think like investigators rather than listeners, is worth the careful, evidence-informed effort it demands.

Knowledge Contribution

This article contributes an integrative conceptual framework explaining how project-based learning (PjBL) can support students' transition from listeners to investigators in science classrooms. Its central contribution is to connect project design, adaptive teacher scaffolding, student agency, and the quality of evidence used to evaluate learning. Drawing on a critical narrative synthesis, the framework proposes that educational benefits depend on how these elements work together within particular classroom and institutional conditions.

First, the synthesis identifies authenticity and conceptual necessity as complementary requirements for meaningful science projects. A project should address a relevant problem while requiring students to apply scientific concepts to investigate it. Producing an attractive model or completing a practical activity provides insufficient evidence of scientific understanding unless students can explain the concepts, evidence, and reasoning underlying their work.

Second, the framework positions adaptive scaffolding as the link between project opportunities and productive student agency. Teachers combine planned supports, such as templates and assessment criteria, with responsive guidance during investigation. The appropriate balance depends on demonstrated inquiry readiness, prior knowledge, and group needs. Responsibility can therefore shift progressively toward students as they develop the capacity to plan, investigate, interpret evidence, and defend conclusions.

Third, the synthesis conceptualises student agency as responsibility for constructing and justifying knowledge. Agency becomes visible when students formulate questions, make methodological decisions, analyse data, negotiate interpretations, and revise explanations. Reflection and formative assessment connect these activities, enabling teachers to adjust support while preserving meaningful student ownership.

Finally, the framework connects these processes to multidimensional but conditional learning outcomes: scientific understanding and achievement; inquiry, creativity, and problem-solving; motivation and self-efficacy; collaboration and communication; and sustainability awareness and responsible action. The evidence supporting these outcomes varies in strength. Consequently, the framework distinguishes reported short-term improvements from claims about sustained learning, transfer, or behavioural change that require further investigation.

The resulting contribution is a set of relationships that can guide instructional design and future research. It suggests examining whether authentic, conceptually demanding projects generate stronger learning when scaffolding responds to learner readiness and assessment captures both individual understanding and collaborative inquiry. These relationships remain propositions derived from the reviewed literature rather than an empirically validated causal model.

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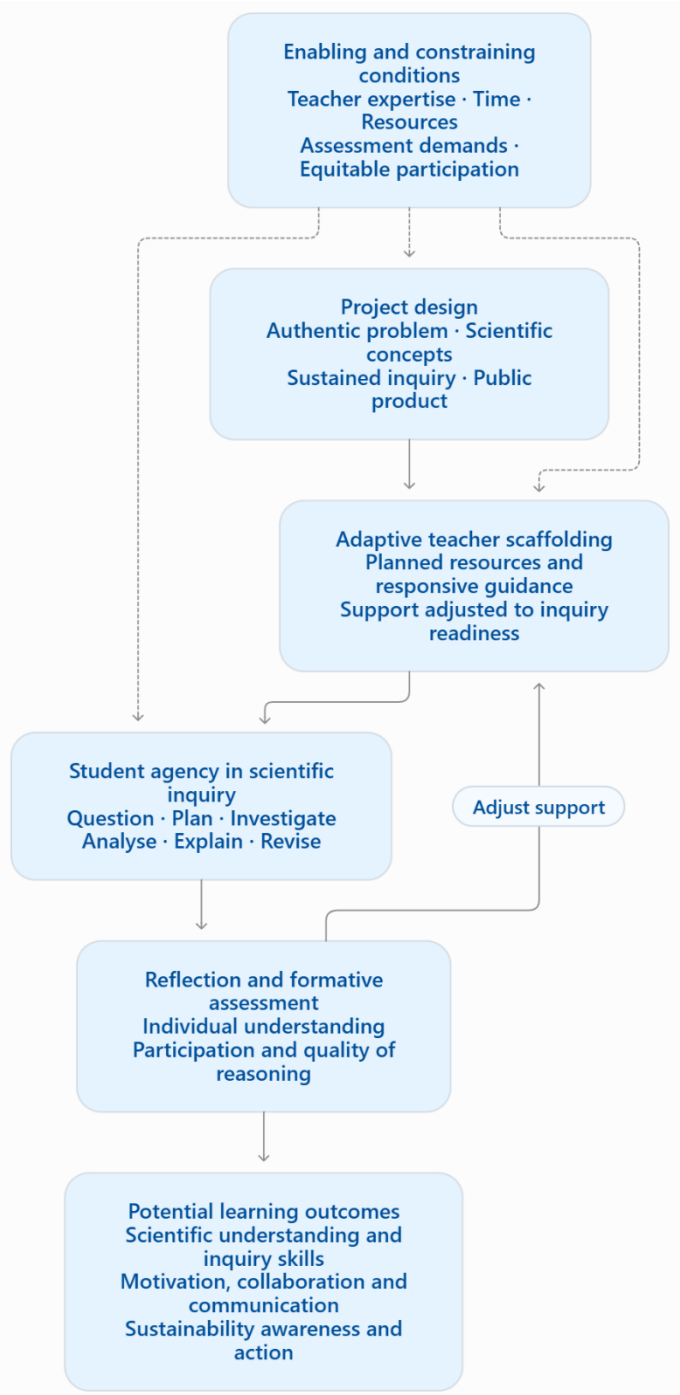


Figure 1. Integrative framework of project-based science learning

Note. Author-developed conceptual synthesis of the reviewed literature. Arrows represent proposed relationships, not established causal effects. Evidence varies across outcomes; sustained transfer and behavioural change require further verification.

Figure 1 shows how the transition from listener to investigator depends on the relationship between project design and instructional support. Authentic problems create opportunities for inquiry, while the deliberate inclusion of scientific concepts gives that inquiry intellectual substance. Teachers then adjust guidance to students' readiness, enabling learners to assume increasing responsibility for scientific decisions and explanations.

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The feedback loop between inquiry, formative assessment, and scaffolding represents the framework's central mechanism: teachers use evidence of students' reasoning and participation to recalibrate support throughout the project. Learning outcomes emerge within conditions shaped by teacher expertise, available resources, time, assessment demands, and equitable participation. The figure therefore presents PjBL as a practice whose benefits depend on coherent design, responsive teaching, and credible assessment.

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