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Mathematics beyond the Classroom: Realistic Mathematics Education, Science and Mathematics Theme Parks, Public Spaces, and Educational Leadership for Curriculum Integration

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Abstract: Mathematics learning is frequently organised around classroom-based representations, although public parks, squares, streets, science centres and purpose-designed mathematics installations can provide rich situations for measurement, modelling, reasoning and collaborative problem-solving. This conceptual and integrative review examines how such environments might contribute to the development of learners' mathematical potential within Realistic Mathematics Education (RME), and how educational leadership can support their equitable, sustained and curriculum-aligned use. It synthesises foundational RME theory with selected empirical work on mathematics trails, science-centre exhibitions, informal STEM learning, place-based education and school–community partnerships, while considering the Greek educational context. A five-domain framework is proposed: (1) authentic mathematical affordances of place, (2) RME-informed learning trajectories, (3) accessible and participatory design, (4) collaborative governance and professional capacity, and (5) curriculum alignment and evidence-informed evaluation. The available literature supports the educational promise of well-designed out-of-school activities, particularly for situational interest, engagement and opportunities for mathematical reasoning; it does not establish that theme parks alone reliably cause sustained gains in mathematical achievement. The article therefore offers a feasible implementation architecture and a prospective mixed-methods evaluation agenda across educational levels, rather than reporting original intervention results. The central argument is that public space becomes an educational resource when mathematical task design, inclusive access, teacher preparation, inter-institutional coordination and follow-up classroom work are deliberately combined.

Keywords: Realistic Mathematics Education; outdoor mathematics; mathematics trails; science and mathematics parks; public space; mathematical literacy; distributed leadership; curriculum integration; place-based learning.

1. Introduction

Mathematics is encountered beyond formal education in architecture, routes, urban transport, public art, markets, landscape design, environmental data, mobility systems and the distribution of shared resources. Yet these situations are not automatically recognised as opportunities for mathematical learning. The educational question is how familiar surroundings can be converted into intellectually demanding experiences in which learners formulate questions, generate representations, test assumptions, defend solutions and generalise ideas. In Realistic Mathematics Education (RME), situations that students can meaningfully imagine function not simply as illustrations of already taught concepts, but as starting points for the progressive construction of mathematical meaning (Treffers, 1993; van den Heuvel-Panhuizen & Drijvers, 2020).

Purpose-built science and mathematics theme parks, permanent interactive installations, temporary educational routes and ordinary public spaces represent a continuum of potential learning environments. A public square may invite work on scale, proportion and geometry; a fountain may support questions about flow and rates; a playground may offer data collection and analysis; and an accessible trail may facilitate comparisons of distance, slope and route choice. The central educational value lies less in the novelty of the location than in the quality of the mathematical problem and the discussion that connects experience with formal knowledge (Gravemeijer, 2004, 2020).

Research provides reasons for taking these possibilities seriously, but also for interpreting them cautiously. A study of 793 pupils participating in a mathematics exhibition examined learning and situational interest, indicating that the interaction between individual and situational interest is relevant to outcomes

(Vainikainen et al., 2015). A meta-analysis of informal STEM programmes identified a positive average association with students' STEM interests and attitudes, but substantial between-study variability; these results cannot be treated as direct evidence that every mathematics park improves achievement (Xia et al., 2025). Qualitative studies of mathematics trails similarly show both opportunities and difficulties, including the limits of automatic digital feedback in producing deeper mathematical explanations (Jablonski, 2024).

A second, equally important issue is institutional. A successful visit does not itself establish an enduring programme. Access to public space, partnership with municipalities and universities, curriculum mapping, safety arrangements, staff development, timetabling, financial sustainability and inclusive design are organisational decisions. Research on place-based education and educational leadership suggests that connecting schools with their territory requires collaboration, participation and attention to local contexts (Yemini et al., 2025; Traver-Martí et al., 2023). Accordingly, this article reframes the administration-focused starting manuscript around a new problem: how can educational leaders make out-of-school mathematics a structured, equitable and assessable part of educational provision?

2. Purpose, Scope and Research Questions

The purpose of this study is to develop a theoretically grounded framework for designing and integrating outdoor mathematics and science/mathematics theme parks within RME, with particular emphasis on the educational use of public spaces and the role of leadership across preschool, primary, secondary and higher education. Here, "mathematical potential" is operationalised as a multidimensional and developable capacity, including conceptual understanding, modelling, mathematical reasoning, problem-solving, representations, transfer to new contexts, productive mathematical dispositions and participation. It is not treated as a fixed characteristic or a single examination score.

The synthesis is guided by five questions: (RQ1) Which principles of RME can inform mathematical tasks in parks and other public spaces? (RQ2) What is known about the learning outcomes and limitations of mathematics trails and informal science-centre experiences? (RQ3) How can public spaces be assessed and designed as accessible, sustainable mathematics learning environments? (RQ4) What forms of participatory and distributed educational leadership are needed for partnerships, staff preparation and implementation? (RQ5) How might such experiences be connected to curriculum objectives and evaluated rigorously across educational levels?

3. Theoretical Framework

3.1 Realistic Mathematics Education as a design perspective

RME regards mathematics as a human activity and treats students' informal strategies as resources for developing more formal methods. Its central design heuristics include guided reinvention, didactical phenomenology and emergent modelling (Gravemeijer, 2020). Guided reinvention means that learners reconstruct important mathematical ideas under purposeful instructional guidance rather than merely receiving final procedures. Didactical phenomenology concerns the selection of phenomena and contexts that can organise the mathematical concepts to be learned. Emergent modelling involves the development of models that initially describe a particular situation and subsequently become tools for more general mathematical reasoning (Gravemeijer, 2004; van den Heuvel-Panhuizen & Drijvers, 2020).

In this sense, "realistic" does not simply mean physically present in the real world. A context can be realistic when learners can imagine and mathematise it; conversely, standing beside a real object does not ensure that a question is mathematically meaningful (van den Heuvel-Panhuizen & Drijvers, 2020). An RME-informed park activity must therefore contain an intentional trajectory: notice a phenomenon, pose an accessible but non-trivial question, generate informal strategies, produce and test representations, compare solutions, and move toward a mathematical generalisation. For example, students may first estimate the surface area of a public plaza using paving patterns, then refine their estimate through decomposition and measurement, and finally formalise relationships between unit area, scale and error.

This distinction guards against the superficial use of public spaces as attractive backdrops for standard worksheets. The educational task should be rooted in the site yet capable of supporting mathematics beyond the site. Gravemeijer (2004) emphasises the importance of local instruction theories in connecting students' activity, emerging reasoning and instructional design. The role of the teacher remains decisive: guided discussion, strategic intervention, selection of representations and subsequent classroom consolidation make the mathematics visible.

3.2 Outdoor mathematics, mathematical trails and informal learning

Mathematical trails organise a sequence of site-dependent tasks around objects or phenomena that participants can observe, measure, compare and model. The same mechanism can function in a city, schoolyard,

botanical garden, cultural space or purpose-built mathematics park. Dalton and Yantz (2025) describe the use of campus trails to help learners recognise mathematical patterns and connect reasoning with everyday phenomena. A Greek pilot study reported the design and implementation of a mobile-supported mathematics trail in a park with primary pupils; its contribution is particularly pertinent because it explicitly connects place-based tasks, cooperation and RME (Karta & Fesakis, 2017).

Digital tools may support navigation, measurement, hints, documentation and feedback, but should remain pedagogical means rather than the organising purpose. Jablonski (2024) studied students' verification and elaboration in MathCityMap activities and found that negative digital feedback could prompt checking and alternative solution strategies, while full explanations were less frequent. This finding suggests a design principle: correct/incorrect feedback is not a substitute for prompts asking why a model works, what assumptions were made and whether the answer is plausible. The broader research synthesis by Jablonski (2025) underlines that modelling, argumentation and problem-solving need to be examined as distinct learning processes rather than inferred from engagement alone.

Science centres offer an additional source of evidence. Vainikainen et al. (2015) investigated learning at a mathematics exhibition with substantial numbers of school pupils. Sturm and Bogner (2010) compared learning at museum and classroom workstations, while Whitesell (2016) analysed relationships between field trips and science achievement. Such studies support the value of investigating setting, task and follow-up, but their disciplinary and design differences mean that science achievement findings cannot be directly generalised to mathematics theme parks. The National Research Council (2009) likewise characterises informal science learning as taking place across different environments and outcomes, rather than through a single universal intervention mechanism.

3.3 Place-based learning, participation and mathematical agency

Place-based education integrates the social, spatial, cultural and environmental characteristics of a location into teaching and learning (Yemini et al., 2025). From an RME perspective, this can make mathematics relevant to collective decisions: Is a public route accessible? How much shade does a playground provide? How should water use be estimated? Can two designs be compared fairly? Such problems link measurement and modelling to questions that learners can debate as members of a community. The educational aspiration is not simply acquisition of isolated techniques but also the ability to judge evidence, articulate assumptions and participate in reasoned decisions.

The OECD mathematical literacy framework emphasises the ability to reason mathematically and formulate, employ and interpret mathematics in real-world contexts (OECD, 2023). This does not mean that every civic issue should be reduced to a calculation; it means that relevant quantities, representations and uncertainty can become legitimate objects of inquiry. Mathematics trails and public installations may create additional opportunities for mathematical agency when students choose strategies, justify approximations and critique claims. However, the extent to which these opportunities lead to lasting transfer remains an empirical question.

4. Methodology: A Focused Integrative and Conceptual Review

This paper is a focused integrative review and conceptual design study, not an experimental report or registered systematic review. Its evidence base combines classic theoretical literature on RME with selected peer-reviewed empirical and review studies on outdoor mathematics, mathematics trails, mathematics exhibitions, informal STEM learning, place-based education and educational leadership, together with relevant educational guidance. Sources were examined for conceptual relevance, the population and setting studied, reported outcomes, study design and potential transfer to the proposed Greek public-space context. The synthesis intentionally brings together bodies of literature that are often discussed separately.

The selection was purposive rather than exhaustive. No database-wide search log, preregistered protocol, independent double screening or pooled effect-size analysis was undertaken for this manuscript. Accordingly, the thematic findings below are reasoned propositions derived from the selected evidence, not numerical estimates of the effects of mathematics parks. Studies from science centres and general outdoor STEM education are explicitly distinguished from studies addressing mathematical learning. The emerging model is proposed for future empirical evaluation and should not be represented as already validated.

A further methodological precaution concerns the source document: its original focus on inclusive and distributed leadership in Special Education is not treated as direct evidence about outdoor mathematics. Only the theoretically transferable issue of collaborative governance is retained and reinterpreted. Unrelated legislation and findings are excluded to maintain consistency between the revised research questions, claims and references.

5. From Public Space to Mathematics Learning Environment

5.1 Mapping the educational potential of a place

The first design decision is whether a space contains phenomena capable of generating authentic, safe, accessible and curriculum-relevant mathematical questions. A site audit should document its geometry, surfaces, structures, materials, distances, movement patterns, seasonal changes, acoustic conditions, maintenance status and access restrictions. Particular attention is needed for the distinction between fixed infrastructure, such as permanent mathematical sculptures or measurement stations, and low-cost or temporary interventions, such as task signage, removable markers, teacher guides and digital trails. A theme park may combine both, but neither physical permanence nor technological sophistication is a precondition for mathematics learning.

Suitable installations include scaling surfaces for proportional reasoning; tessellation zones; large geometric solids that can be measured; sundials for angles, time and change; probability experiments; bridges or ramps for slope and gradient; observation points for estimating inaccessible heights; and data stations for environmental measurement. These examples are design possibilities, not evidence-backed claims that any one installation will produce a particular achievement gain. The critical question is the mathematical trajectory supported at each station.

5.2 Accessibility, safeguarding and ecological sustainability

Public learning environments must be planned for a heterogeneous population. Universal Design for Learning calls for multiple means of engagement, representation, and action and expression (CAST, 2024). In a mathematics park this may translate into step-free routes, tactile and high-contrast information, easy-to-read and multilingual instructions, adjustable task complexity, seating and rest points, alternatives to phone-only participation and multiple formats for recording mathematical thinking. Inclusive design must also consider sensory overload, physical fatigue, weather, supervision, privacy and access for learners who cannot safely complete the entire route.

Equity cannot be reduced to a statement that the space is publicly accessible. Transport costs, the availability of accompanying staff, digital-device requirements, school timetables and uneven neighbourhood provision may determine who actually participates. Municipalities and educational authorities should therefore assess both the distribution of learning spaces and the capacity of schools to use them. Low-maintenance installations and reusable lesson materials may improve sustainability, provided that accessibility and safety are not sacrificed to cost reduction.

5.3 A graduated curriculum across educational levels

The same setting can support successive levels of mathematisation if the tasks change. Preschool learners may classify and create patterns; primary pupils can measure and compare; lower-secondary students may work with scale, rate, spatial reasoning and data; upper-secondary learners can develop functions, optimisation or statistical models; teacher-education and university students can design, test and critique the trails themselves. This progression is a curriculum proposal and not a claim that an identical intervention has been validated for all levels.

Level	Illustrative site-based inquiry	Mathematical focus	RME transition
Preschool / early years	Find, create and describe repeating paving patterns	Classification, shape, sequence	Concrete pattern → spoken rule
Primary education	Estimate the area of a plaza using tiles and measurements	Units, multiplication, perimeter, area	Informal counting → area models
Lower secondary	Estimate the height of a sculpture and compare strategies	Ratios, similarity, measurement error	Estimation → proportion and justification
Upper secondary	Optimise a park route or model daily shade variation	Functions, optimisation, statistics	Context model → general mathematical model
Higher / teacher education	Design, pilot and assess a mathematically rich trail	Task design, modelling, assessment	Empirical observation → refined local instruction theory

Table 1: Proposed curriculum progression in public-space mathematics. Examples are illustrative and require local curriculum mapping.

6. The Role of Educational Leadership and Public-Sector Governance

6.1 From isolated visits to shared educational infrastructure

Curricular integration changes the role of educational leadership. School principals and education directorates cannot limit their involvement to approving a visit. They need to create conditions in which teachers can collaboratively design learning goals, choose tasks, organise safety and inclusion, collect evidence of

learning and reflect on outcomes. The original leadership framework is therefore repositioned: distributed leadership becomes a mechanism through which mathematics teachers, science educators, special educators, municipal technical services, universities, parents and local organisations jointly develop a coherent educational resource. This does not remove formal administrative responsibility; it clarifies where shared expertise is needed.

An investigation of distributed leadership and school improvement linked school-level leadership arrangements with growth in mathematics achievement, suggesting the value of examining organisational processes rather than the individual principal alone (Heck & Hallinger, 2009). This research does not test mathematics parks, but it offers a plausible governance perspective. Traver-Martí et al. (2023) show that school–territory links can be facilitated by participatory school leadership. More directly, Meerts-Brandsma et al. (2026) identify operational fit, shared goals, trust and stewardship among the conditions needed for strong outdoor-education partnerships. Recent teacher-focused research also highlights leadership, suitable space and professional development as perceived supports for curricular outdoor learning (Prince et al., 2026).

6.2 An allocation of institutional responsibilities

A realistic implementation arrangement could involve a municipality that provides or manages space, an education directorate that coordinates school participation, an academic partner that supports RME task design and evaluation, and individual schools that adapt lessons to student needs. A cross-sector steering group should include teacher and student voices, disability-access expertise and relevant parent/community representatives. The group should have a written mandate addressing permission to use space, safety assessments, maintenance, teaching resources, data protection, funding, evaluation and decision-making. Specific legal approvals must be checked against the provisions in force before any implementation; this paper does not presume an automatic right to install structures in public space or alter mandated curricular hours.

Actor	Illustrative responsibilities
Municipal / public-space authority	Site permissions; technical safety; access and maintenance; environmental and heritage considerations
Education directorate / regional support	Cross-school coordination; equity of access; professional learning; shared monitoring framework
School leadership team	Timetables, supervision, family communication, teacher collaboration, school-level evaluation
Teachers / subject advisers	Curriculum mapping, RME task sequences, student discourse, formative assessment, adaptation
Universities / research teams	Co-design, trial protocols, instrument validation, independent analysis, dissemination
Students, families and community	Participatory design, accessibility feedback, locally meaningful problems and stewardship

Table 2: Proposed participatory governance structure; actual legal competences and agreements require local verification

6.3 Professional capacity and organisational continuity

An educational park has little long-term value if teachers receive only a map of attractions. Capacity building should include workshops on RME, designing high-cognitive-demand questions, managing group work outside the classroom, supporting learners with diverse needs, documenting mathematical discourse and transferring outdoor observations into formal lessons. Teacher professional learning should include piloting, peer feedback and revision of tasks. Leadership should protect this development time and establish a shared bank of quality-assured activities with clear links to learning outcomes, accessibility options and assessment prompts.

A stewardship model can make the initiative more resilient. Rather than expecting one enthusiastic teacher or one principal to maintain everything, responsibilities can be distributed across a mathematics working group, a municipal coordinator and an academic adviser. Continuity can be reviewed annually using transparent criteria: attendance, access barriers, maintenance records, teacher uptake, curriculum fit, task quality and evidence of learning. Where resources are limited, a small number of well-designed stations may be preferable to an ambitious but underused permanent park.

7. Curriculum Integration: Before, During and After the Visit

A mathematics park becomes curricular—not merely extracurricular—when learning objectives, sequencing and assessment are intentionally linked to the ordinary programme of study. The Greek Institute of

Educational Policy provides curriculum and teaching guidance by educational level; the relevant documents in force for the particular school year and grade must be checked when a local programme is planned (Institute of Educational Policy, 2026). Curriculum alignment should therefore be documented for each grade and learning objective, including how outdoor mathematical inquiry supports classroom learning and assessment. The availability of curriculum guidance does not, by itself, establish that mathematics park activities are formally incorporated into national programmes of study.

Before an outdoor experience, learners should encounter a motivating problem and the mathematical ideas or representations needed to investigate it, without being given a complete procedure. At the site, mixed-ability groups can collect measurements, produce sketches, compare strategies, use appropriate tools and justify results. After returning to class, the teacher should structure a discussion that tests the adequacy of methods, identifies errors or assumptions, generalises the relevant concepts and connects them with formal notation. Reflection and transfer are essential: a solution that worked for one fountain, ramp or sculpture should be examined in a second or more abstract situation.

Assessment needs to capture several dimensions. A conventional calculation test can indicate procedural or conceptual development but may miss modelling competence. Conversely, an enthusiastic student report is not a substitute for evidence of mathematical learning. Assessment should therefore combine curriculum-aligned tasks, short written explanations, observation rubrics for reasoning and cooperation, mathematical portfolios and appropriately designed follow-up problems. Where participation is voluntary or sites vary, comparisons must acknowledge selection effects and differences in prior knowledge.

8. Proposed Integrated Model: PUBLIC–RME

The conceptual contribution of this article is an integrated, non-linear framework termed PUBLIC–RME (Public-space Use, Learning, Inclusion, Collaboration and Curriculum through RME). It comprises five interdependent domains. First, “place affordances” concerns the mathematical structures and phenomena that can be investigated on-site. Second, “RME learning design” connects those phenomena with guided reinvention, emergent models and mathematical discourse. Third, “inclusive participation” requires accessible tasks, physical access and meaningful learner agency. Fourth, “collaborative leadership” coordinates responsibilities, professional learning and partnerships. Fifth, “curriculum and evaluation” makes the sequence repeatable, educationally accountable and open to improvement.

The domains are deliberately reciprocal rather than sequential. A new access barrier may require redesigning the tasks; assessment evidence may reveal that a station is motivating but too mathematically shallow; teachers’ observations may prompt alterations to the space; changes in municipal maintenance may require different routes. The proposed model therefore rejects a simple causal chain in which constructing a park automatically raises mathematical performance. Public infrastructure is a potential enabling condition, mathematical learning is a mediated process, and administrative capacity determines whether those processes can operate consistently.

Three propositions follow for future testing. Proposition 1: curriculum-aligned, RME-informed outdoor tasks will offer stronger opportunities for mathematical modelling and transfer than visits centred on unguided observation alone. Proposition 2: teachers’ pedagogical preparation and subsequent classroom discussion will mediate any association between visits and mathematical learning. Proposition 3: access, inter-institutional partnership quality and leadership continuity will shape whether programmes are implemented equitably across different schools and educational levels. These are hypotheses, not findings from the present article.

9. Research Agenda for Empirical Investigation

A future doctoral or multi-site research programme could follow a sequential mixed-methods and design-based approach. The first phase would map potential public spaces, conduct stakeholder interviews and identify curriculum objectives. The second would co-design a limited set of RME trails or park installations with teachers, university partners, municipal personnel and pupils, followed by small-scale feasibility pilots. Tasks would be refined on the basis of documented solution strategies, observed difficulties, inclusion issues and teacher feedback. A third phase would evaluate the adapted programme in several schools, preferably with comparable classes or sites and with pre-specified outcome measures.

A credible quantitative evaluation would include baseline and delayed follow-up measures of mathematical reasoning, modelling and concept transfer, with attention to school clustering, prior achievement and participation patterns. Where random allocation is not feasible, a carefully matched comparison group and transparent analysis of baseline differences would be preferable to a simple before–after comparison. Qualitative video or observation data, student work, interviews and teacher planning records would help explain not only whether outcomes changed, but how mathematical ideas were generated. Accessibility, student interest and

mathematical performance should be reported separately rather than merged into an undifferentiated "success" measure.

Because the doctoral theme extends across educational levels, common theoretical principles should be combined with age-appropriate measures. For preschool children the emphasis may be language, pattern recognition and spatial reasoning; in primary and lower secondary education, representations and quantitative problem-solving; in upper secondary education, modelling, functions, uncertainty and argumentation; and in higher education, mathematical investigation and instructional design. Evidence across levels should not be pooled without demonstrating that tasks and measures are comparable. Ethics approval where applicable, consent, appropriate safeguards for minors and GDPR-compliant handling of observations and images would be required before any field research begins.

10. Discussion

The literature supports a careful synthesis of educational opportunity and institutional conditions. RME explains why meaningful contexts and learners' mathematical activity matter; mathematics-trail research shows ways in which authentic objects can support problem-solving, while also revealing limitations in reasoning and feedback; informal learning research provides evidence of potential effects on engagement and attitudes but cautions against broad generalisation; and leadership research highlights the organisational work required to sustain partnerships (Gravemeijer, 2020; Jablonski, 2024; Xia et al., 2025; Meerts-Brandsma et al., 2026). The proposed contribution is the integration of these strands around public-space curriculum development.

Several tensions must be acknowledged. Physical authenticity can increase contextual meaning but also introduce irrelevant complexity, weather disruption or inaccessible routes. Digital support can expand interaction but create device inequities and shallow answer checking. Participation can support collective ownership but make accountability ambiguous unless roles are specified. Permanent installations can increase visibility and repeated access, yet mobile mathematical trails may be cheaper and easier to revise. Each tension is a design decision to be evaluated in context, not resolved by asserting the superiority of one format.

In the Greek context, an implementation strategy could begin with existing municipal parks, school surroundings, cultural sites or open university campuses before undertaking major construction. This strategy would permit educational authorities and partners to develop evidence on actual curricular use and inclusion needs. Any proposal for permanent installations or formal curriculum changes should be pursued through the competent public bodies and current regulatory procedures, rather than inferred from the scholarly framework itself.

11. Conclusions and Practical Implications

Mathematics beyond the classroom can be understood as a deliberate extension of the mathematical learning environment, not as a replacement for systematic school teaching. Science and mathematics theme parks and ordinary public spaces can provide situations that invite estimation, measurement, modelling, representation and argumentation. Their promise is most coherent when interpreted through RME, which links meaningful phenomena to progressive mathematisation and teacher-guided generalisation. The reviewed evidence gives grounds for thoughtful pilots, not a definitive claim that constructing a park will, by itself, improve students' mathematical achievement.

The role of educational administration is therefore constitutive rather than peripheral. Leaders can coordinate partnerships, secure access, create professional learning time, clarify responsibilities, establish accessible and sustainable procedures, and connect field experiences to formal curriculum goals. For policy and practice, the priority should be to design modest, high-quality, adaptable interventions; evaluate mathematical learning rather than visitor satisfaction alone; and scale only those activities whose educational value and feasibility are adequately demonstrated. In this approach, public space becomes a shared setting for mathematically informed participation and a potentially enduring resource for schools and communities.

12. Limitations

The article offers a conceptual, purposive synthesis rather than a comprehensive systematic review or a completed empirical study. Evidence from science centres and general STEM activities is relevant but not interchangeable with mathematics-specific outcome research. Studies differ in their age groups, tasks, outcome measures and educational systems; transfer to Greek municipalities and schools must be tested rather than assumed. The PUBLIC–RME framework is an original proposal that has not yet undergone independent validation. Further study is required to estimate effects on mathematical learning, establish implementation costs and determine which governance arrangements are sustainable and equitable.

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