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Engaging Educators in the Codesign, Feasibility, and Implementation Quality of Early Years Interventions: The ONE Program

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ABSTRACT— Giving practitioners a voice is essential in developing intervention programs that are adapted to educator and child needs. We aimed to do so by involving educators in the codesign of an intervention supporting early mathematical and executive development, to maximize feasibility and implementation quality. $N = 100$ educators, $N = 24$ Early Years Centers (EYCs), and $N = 16$ education science experts took part. Educators expressed a need for feasible professional development coupled with practical activity suggestions (Phase I). A scientist/educator expert panel developed the intervention (Phase II), further refined via educator input (Phase III) to overcome implementation barriers (e.g., diverse children's needs).

In Phase IV, mixed methods revealed successful solutions (e.g., differentiation guidance) and additional barriers (e.g., diverse staff demands). We demonstrate the value of an iterative codesign process for complex educator-led interventions to produce programs addressing specific needs of educators and children whilst retaining key theoretical principles.

Evidence-based educational intervention programs are increasingly valued by policy-makers as a step toward addressing gaps in educational outcomes (e.g. United Kingdom's House of Commons Science and Technology Committee, 2019) and by cognitive scientists to answer theoretical questions and understand causal relationships (e.g. Chan, Nagashima, & Closser, 2023). Programs that incorporate research evidence, as well as participatory elements, into Professional Development (PD) for educators are often championed for their ecological validity and potential to reach many children at relatively low cost, with effects potentially lasting beyond the intervention period (e.g. Clements, 2007; Clements & Sarama, 2007; Sarama, Clements, Wolfe, & Spitler, 2016; Sims et al., 2021). Evidence indicates PD-based approaches can be effective in changing educator practice (Egert, Dederer, & Fukkink, 2020) and supporting child progress (Brunsek et al., 2020).

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However, successful program implementation depends on numerous factors beyond child-level factors, including educators' perspectives, implementation feasibility, and the adaptation of program features to the specific context (e.g., Hawes, Merkley, Stager, & Ansari, 2021; Sims et al., 2021). A thorough understanding of current practice, systemic barriers faced by educators (e.g., understaffing, long hours, and inadequate pay, Early Years Alliance, 2023), as well as educator involvement in design decisions, may support engagement in programs. Program benefits should clearly outweigh costs for the educators as well as for the children participating (e.g., Egert et al., 2020).

We use the case study of a PD-based mathematics and executive function (EF) preschool program (Orchestrating Numeracy and the Executive, or The 'ONE') to describe the iterative steps taken to move from a theoretical model to a theoretically grounded program that gives educators a voice. This process offers a detailed methodological framework that can be applied to future interventions aiming to improve child outcomes by incorporating codesign and educator involvement as vital elements of the intervention design process.

The ONE Program to Support children's Early Mathematical Skills

Multiple studies point to the importance of early mathematical skills for future academic attainment (Duncan et al., 2007) and the role of Early Years (EY) education in supporting the development of these foundational skills (e.g., Taggart, Sylva, Melhuish, Sammons, & Siraj, 2015). However, 23% of children in England fail to achieve the expected level in mathematics by the end of the first year in primary school (Department for Education, 2024), indicating a need for well-designed EY interventions that prepare children for the mathematical content they will encounter in primary school.

Although specific mathematical knowledge is important for children's later mathematical success, domain-general skills also play an important role. There is considerable evidence linking EF abilities with mathematical performance in preschoolers (Emslander & Scherer, 2022, for a meta-analysis). EFs are a key set of skills used to control and direct our behavior, including *working memory*, which allows us to maintain and manipulate information in our minds; *inhibition*, which helps us to focus on relevant information by overriding automatic responses to stimuli; and *cognitive flexibility*, which allows us to switch between tasks and adjust our behavior according to the demands of the world around us (Miyake et al., 2000). Given the well-established link between EF and mathematical performance, multiple researchers have highlighted the need to combine EF and mathematics, rather than practice them in isolation (e.g., Peng & Swanson, 2022; Scerif et al., 2023). The ONE program combines PD sessions for staff with activities to be played

with children, with the aim of supporting educator and child learning, as well as educator confidence, across EF and foundational areas of mathematics. While PD-based programs supporting mathematics (e.g., Building Blocks Curriculum; Clements & Sarama, 2007) and EFs (e.g., PRSIST, Howard, Vasseleu, Batterham, & Neilsen-Hewett, 2020) have been successfully implemented, the ONE program is the first program to explicitly combine mathematics and EF goals in a UK EY environment. Here we focus on the participatory process of including educators in intervention design.

Moving from Theory to Practice: Central Role of Participatory Iterative Approaches

Educator-led interventions provide greater ecological validity and scalability than highly prescriptive or lab-based interventions (e.g., Clements, 2007). However, with the benefits of educator-led interventions come uncontrollable variables. Where programs have failed to improve child outcomes, it is difficult to establish whether this is because of problematic theoretical assumptions or poor implementation (Mattera, Rojas, Morris, & Bierman, 2021). Poor implementation is less likely when a program is seen as beneficial, instead of solely adding to an already burdensome workload.

Here, we argue that key to intervention feasibility and good implementation is to ground intervention design into participatory and iterative principles (e.g., Clements, 2007), or 'codesign'. This design-based research approach (e.g., Fowler, Cutting, Fiedler, & Leonard, 2023) involves educators throughout the iterative stages of intervention design, including real-world implementation, feedback and evaluation, and refinement of the program, by integrating qualitative and quantitative insights from educators. It has been used to produce early childhood programs in various fields including language development (e.g., Diamond & Powell, 2011), socioemotional teaching practices (e.g., Artman-Meeker et al., 2022), and developing a STEM curriculum (e.g. John, Sibuma, Wunnavu, Anggoro, & Dubosarsky, 2018).

METHODS AND RESULTS: ITERATIVE PROGRAM DESIGN

Our primary goal was to give educators a voice in the process of iterative codesign. In a separate manuscript focused on evaluating intervention efficacy, greater improvements in mathematics and EFs were found particularly for children growing up in socioeconomically disadvantaged circumstances (reported in detail in Scerif et al., 2025). A four-step iterative design process was used, integrating recommendations from a wide range of professionals (Figure 1).

Ethics Statement

This study received ethics approval from the Oxford University Central University Research Ethics Committees

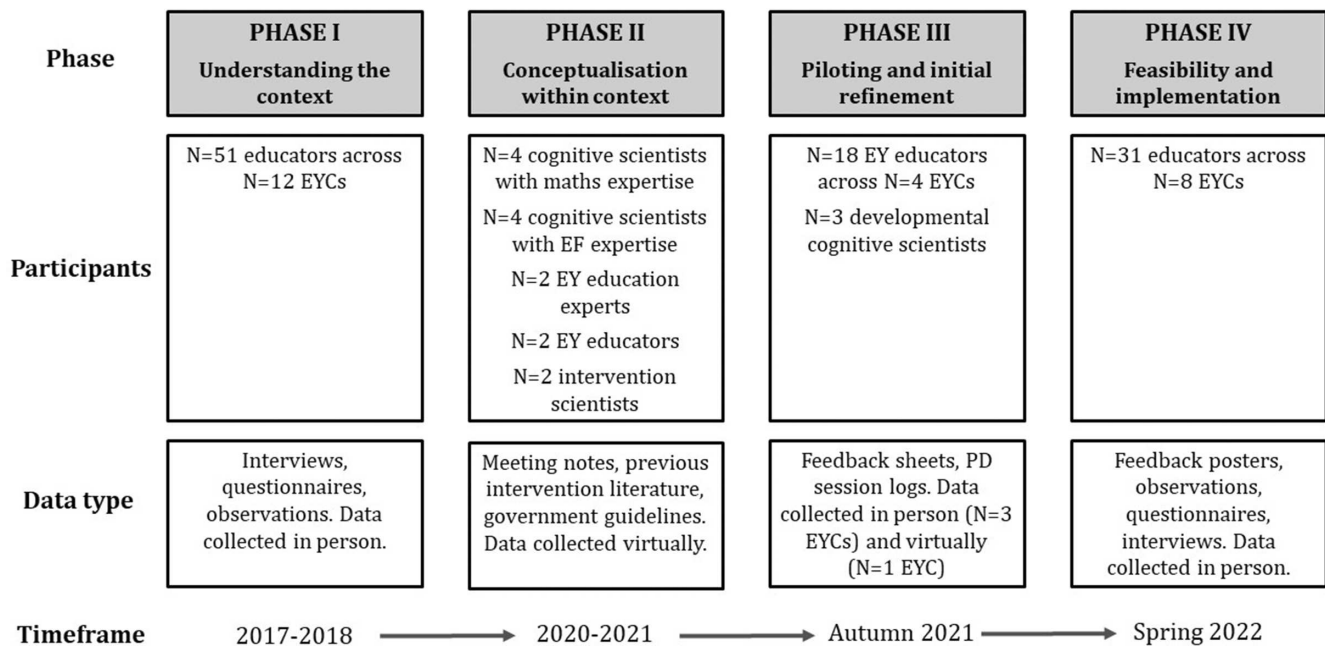


Fig. 1. Summary of phases of refinement, key stakeholders involved, and type of data collected in the development of The ONE program.

(R68839/RE008). Settings and educators provided informed consent to take part.

Setting Characteristics

Across each phase of the design process, efforts were made to select a range of different setting types with which the program would be codeveloped and piloted. For each phase, a new cohort of settings was recruited via phone calls to centers in the local area. Recruitment phone calls were targeted with the aim of capturing variety in terms of size, setting type, and neighborhood deprivation (Table 1). Child characteristics for phases I and IV are available via Coolen et al. (2021) and Scerif et al. (2025).

Phase I: Understanding the Context

Phase I aimed to characterize the context of provision across preschool Early Years Centres (“EYCs” hereafter), identifying current practice strengths and gaps. An additional aim was to understand the priorities, beliefs, and experiences of EY educators to inform sensitive intervention development.

Methods

N = 12 EYCs were recruited via convenience sampling to take part in a larger longitudinal study of preschoolers’ mathematical skills (Coolen et al., 2021). *Questionnaires*—Questionnaires were distributed to all

practitioners at participating settings (*N* = 41 returned). Five support mechanisms were identified before data collection: support with assessing children’s level in mathematics, learning from peers, support with planning, mathematical resources, and training. Educators were asked to indicate the mechanisms currently used and those that they would like better access to in the future. *Group Interviews*—Semi-structured group interviews were conducted in person at each setting (*N* = 51 educators attending, mean group size = 4.25, *SD* = 3.28), with questions related to current practice in mathematics and priorities for future support. *Analysis*—Data were analyzed via a mixed-methods approach, consisting of complementary quantitative and qualitative data. Quantitative questionnaire responses were used to describe practitioner support preferences. This was supplemented by qualitative data from interviews and surveys, analyzed using thematic analysis (Braun & Clarke, 2006). For thematic analysis, broad questions relevant to intervention design were identified prior to analysis (see questions 1–3 below). Specific themes were then derived inductively (i.e., from the data). Following the principles of thematic analysis, it was important to acknowledge the positionality of this researcher, who was a developmental scientist familiar with the aims of the project. The interpretative process itself is inherently dependent on positionality and subjectivity (Braun & Clarke, 2024), but this was moderated by the primary coder discussing emerging themes and subthemes with the research team.

Table 1

Characteristics of Early Years Centers (EYCs) Who Took Part in the Study.

	Phase I	Phase III	Phase IV
Number of EYCs	12	4	8
Number of educators	51	18	31
Mean IDACI decile (SD) ^a (1 = most deprived, 10 = least deprived)	7.25 (2.45)	5.00 (2.55)	5.00 (2.86)
Setting type ^b			
Nursery class in primary school	2	1	2
State-funded nursery school	1	–	2
Private	4	2	4
Voluntary	5	1	–
Educator qualifications ^c			
No EY qualifications	10.0%	–	19.4%
Vocational childcare qualifications	52.0%	–	48.4%
Bachelor's degree or above	22.0%	–	25.8%
Data not available	16.0%	100%	6.5%

^a As a measure of area SES, the Income Deprivation Affecting Children Index (IDACI) was obtained for the postcode of each EYC. This measure ranks all UK postcodes from 1 to 10 based on the proportion of children aged 0–15 living in income-deprived families, with a score of 1 representing the decile with the highest proportion of income-deprived children.

^b Type of setting: in the United Kingdom, settings can be broadly categorized into those that are funded by the local authority (government run) (LA) and private/voluntary/independent (PVI) settings. LA settings include nursery classes within state-funded primary schools and whole settings that are government maintained, whilst PVI settings include workplace childcare, voluntary organizations, and for-profit childcare centers.

^c For more information on UK EY qualifications, please see government guidance (Department for Education, 2025).

Results

Quantitative data. Quantitative questionnaire data (Figure 2) revealed that the majority of educators already had access to resources and peer support. Planning and assessment were less frequently available. Training followed by resources emerged as priorities for future support.

Qualitative data. Below we provide a synopsis of key findings from reflexive thematic analysis of the interview data. Themes, subthemes, and additional quotes are reported in Figure 3 following Braun and Clarke (2006).

Question 1: What practices are currently used to support EY mathematical development? Thematic analysis of interview data revealed a focus on counting, numbers, shapes, and measurement (see Figure 3). Educators viewed mathematics as something that should be integrated across varied contexts such as daily routines and activities in other curricular areas (“Maths is everywhere ... sometimes you don’t think about it.”). Another theme was the differentiation of activities for different children, with educators reporting adapting activities for different needs and interests and using observations to assess differing needs (“Each child is different, so I observe and make plans for activities.”). A variety of techniques were used to deliver mathematical content, including learning through song, offering regular mathematical activities, and using resources to support learning.

Question 2: What do educators identify as gaps in their current practice and/or knowledge? Educator priorities for future support included understanding and following current government guidelines, supporting less motivated children (“Examples of how to support children with little

or no interest in maths”), extending mathematics beyond numbers and counting (“[I] wonder if we could focus more on other areas”), and bringing mathematics into play-based activities (“We need an identification of what maths looks like in play”).

Question 3: What are educator preferences for the format of support? When examining preferences for the format of support, five themes emerged: training, peer-supported learning, use of resources, activity inspiration, and planning. Training was viewed as a key support mechanism, but it was noted that mathematics training was often only made available to one staff member within a setting, meaning that other staff did not directly benefit. However, learning from peers was also seen as beneficial. Resources were viewed as valuable by some educators, but it was noted that no specific resources are needed for mathematics. Another key theme was ideas and inspiration for activities. Thirdly, although few practitioners mentioned support for planning, it was valued by those who reported having such support in place (via dedicated time or planning resources) and identified as a barrier by those who did not.

Phase I Discussion

Overall, Phase I suggests that mathematical learning occurs in informal, play-based contexts, sometimes integrated with other curriculum areas. Counting and numbers are emphasized over other areas of mathematics (e.g., shapes, order, and patterns), indicating that practitioners may need extra support to engage children in some specific curriculum areas. Educators regularly observe children and attempt to

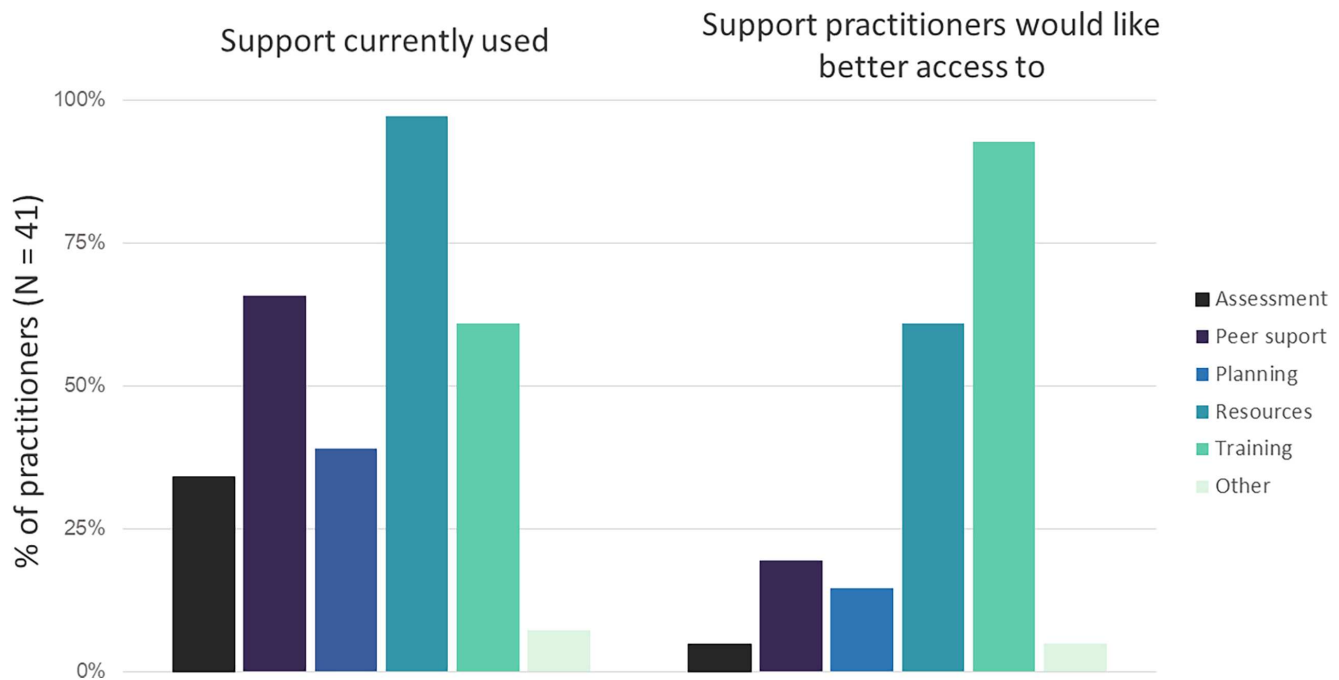


Fig. 2. Phase I quantitative findings (questionnaires): Types of existing support and support needs.

adapt mathematics to children's interests. Qualitative and quantitative data converged on practitioners being eager for additional ideas to incorporate engaging and effective mathematical content into routines, and for additional support with planning and differentiating activities around children's differing goals. Training emerged as the preferred mode of support. We acknowledge that focus on mathematical practice but not EF was a limitation of the interview protocol in Phase I, given the evidence on the mathematics/EF interplay. While terminology that is specific to EF may be a barrier for educators (Gilmore & Cragg, 2014), sensitively phrased questions with a focus on EF in practice would allow for a better understanding of current practice in EF, a refinement introduced in later phases of codesign.

Phase II: Integrating Lessons Learnt from Phase I, Research Evidence, and the National Context to Draft the Intervention

Phase II aimed to combine theoretical aims, findings from Phase I, national governmental educational framework, and prior research to scaffold a workable intervention with guidance and expertise from education and cognitive science professionals.

Methods

First, the core research team integrated Phase I findings with existing research literature to inform a draft framework for the intervention. Next, iterative virtual consultation with a multidisciplinary advisory board (see Figure 1 for range

of professional expertise, including both researchers and educators) informed further development of the program, including intervention materials, with particular attention focused on input from practitioner experts on the advisory board. These consultations resulted in a set of key outputs: the theory of change, the intervention framework, a set of child-focused activities for educators and PD delivery materials, which together formed the backbone of The ONE program.

Results: Initial Program Design

Theory of change development. The existing evidence was summarized via a narrative review and position piece (Scerif et al., 2023). Two target mechanisms, to be tested causally via child-level improvements in mathematics, were identified as core elements of the planned program: increasing children's opportunities to practice EF challenge in the context of well-selected mathematical content, and improving educators' understanding of EY mathematics and EF via PD.

Intervention framework design. Findings from Phase I and a review of existing literature highlighted three priorities for the intervention framework. First, training support (PD) was flagged as a priority for educators (Brunsek et al., 2020). Given the limited time availability of EY educators (Early Years Alliance, 2023), a series of flexible short sessions spaced out with a chance for reflection in between was deemed most appropriate (Muir, Howard, & Kervin, 2023). Second, the theory of change called for PD to support educator knowledge of EFs and their integration into

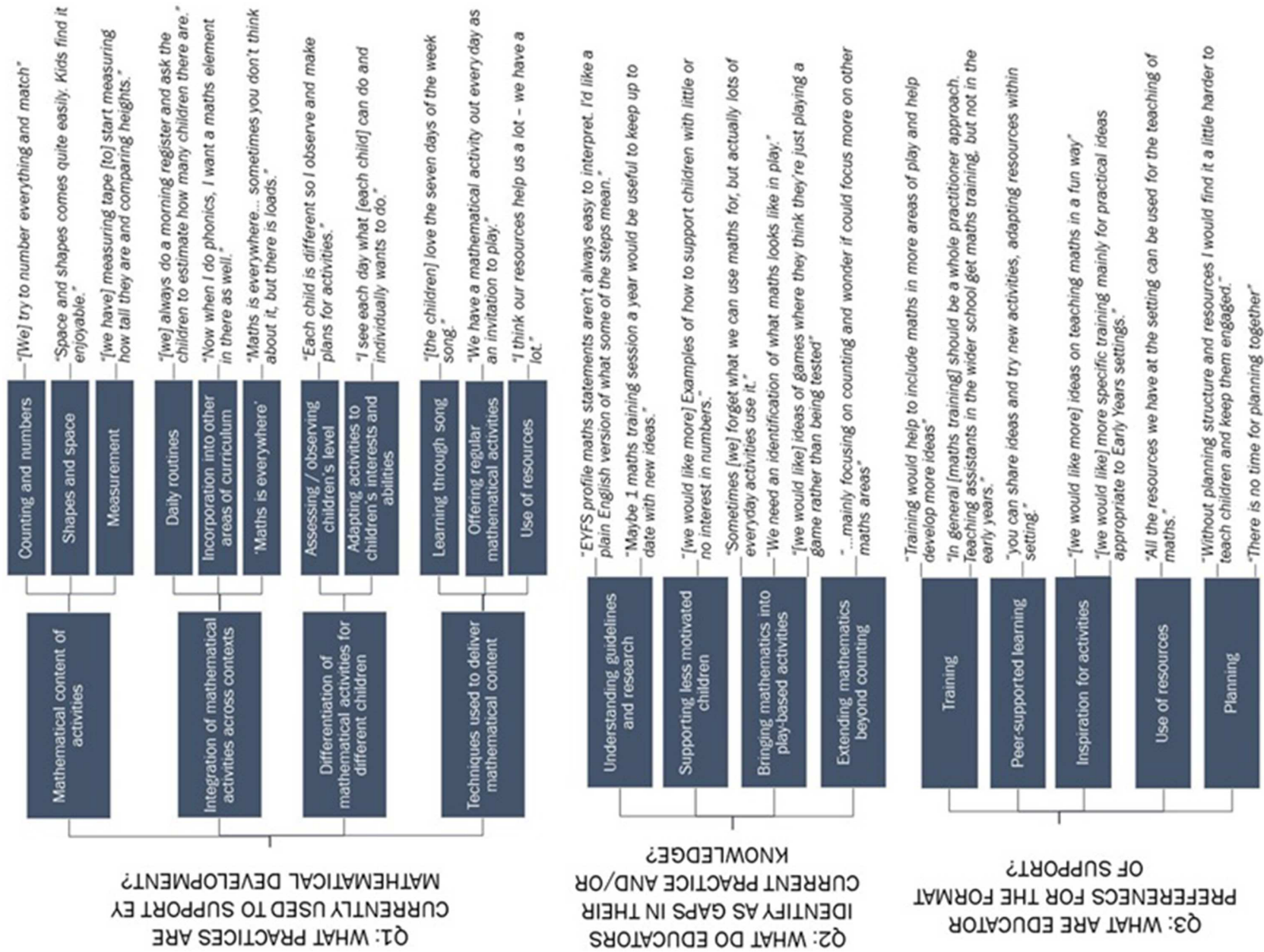


Fig. 3. Phase I qualitative findings (educator interviews): Themes, subthemes, and verbatim evidence.

Table 2

Example of Key Features of Activities Across the Three Areas of Counting and Cardinality, Patterning and Order, and Shapes and Space

<i>Counting and Cardinality: What's the Time Mr. Wolf?</i> <i>A child (Mr Wolf) stands at one end of the playground, facing the other children. The children must walk forward by the number of steps indicated by the 'wolf'. When the 'wolf' says "It's dinner time", the children must all turn and run away.</i>	<i>Patterning and Order: Tower Challenge</i> <i>Children are encouraged to build as many unique towers of four blocks as possible using only two colors of blocks.</i>	<i>Shapes and Space: See it, Build it, Check it</i> <i>The educator creates a pattern using an array of shapes. After discussing the pattern with the children, the educator hides the pattern and asks the children to recreate the pattern from memory.</i>
1. Counting – counting up to the number said by the 'wolf'.	Order – talking about/drawing attention to the order of blocks in the tower.	Shapes – naming shapes and/or talking about the qualities of shapes.
2. Cardinality – practicing one-to-one correspondence by taking steps while counting.	Cardinality – counting the number of blocks in the tower.	Cardinality / subitising – counting or subitising the number of shapes in the pattern.
3. Inhibition – stopping once the appropriate number has been reached.	Number sense – comparing the quantity of different colored blocks in the tower.	Working memory – holding the pattern in mind while building a pattern
4. Working memory – remembering the number that was said by the 'wolf'.	Inhibition – inhibiting the order of blocks in the previous tower.	Cognitive Flexibility – Children are encouraged to use strategies to compare their pattern to the original.
5. Cognitive Flexibility – switching between listening to instructions, walking forward and running away when the 'wolf' shouts "Dinner time!"	Cognitive Flexibility – switching between building, counting and comparing towers.	Inhibition – staying on task and avoiding the temptation to play with the shapes in a different way from intended.

mathematical activities. Prior evidence (e.g., Gilmore & Cragg, 2014) indicated that educators may be unfamiliar with terminology associated with EFs, although we acknowledge that the Phase I protocol did not allow us to test this directly. Therefore, a second framework design decision was for PD to define and provide concrete examples of how EFs play a role in mathematics. A final agreed dimension of the intervention framework was the alignment of program activities with the national regulatory framework (Department for Education, 2020), which emerged as an educator priority at Phase I. The framework currently lacks concrete examples of how educators should work toward these goals for diverse children, so we aimed to support educators to adapt to the high variation in mathematics and EF during the preschool years (e.g. Blakey et al., 2020; James-Brabham et al., 2023).

Child-focused activity development. The theory of change developed called for the integration of EF challenge within the context of mathematics. A review of the literature was conducted to identify child-focused activities that have previously been used to support children's mathematics and/or EF skill development and could be adapted to 3- to 4-year-olds. An initial list of potential activities was adapted from previous interventions that targeted self-regulation (PRISIT, Howard et al., 2020) and mathematics (Hawes et al., 2021; Scalise, Daubert, & Ramani, 2017) in older

children. Relevant activities were modified, resulting in a set of 25 activities. Following the theory of change and government guidelines (Department for Education, 2020), each activity contained mathematical content across one of three areas (Counting and Numbers, Order and Patterning, and Spatial Awareness and Shapes) with embedded executive challenge (Table 2). For example, in "Little Biologists", children are given specific sets of objects to collect (e.g., 3 leaves), thus practicing cardinality skills with the embedded executive challenge of staying on task and maintaining the set of objects in mind. A draft set of activities was shared with the expert panel and revised based on recommendations (e.g., some mathematical goals downscaled to be more age appropriate, based on educators' expertise on the panel). At the same time, an "Adding Challenge" box was added to resource cards to give educators concrete ideas about how to increase executive challenge (e.g., by finding "3 leaves and 1 stick").

Co-designing PD materials. It was deemed important that the activities aligned between research evidence and the English EY curriculum goals and that similarities between the goals of The ONE program and the curriculum were highlighted in PD training. The program of PD was therefore divided into four sessions: (1) Introduction to the program, (2) EFs and their importance for early mathematics, (3) Outline of key mathematical developmental goals during the EY, and (4) The importance and relevance of embedding EFs

in mathematical content and adapting activities for different groups of children. PD included an informal assessment of prior knowledge via mathematics and EF mind maps in PD1, and the use of mind maps again in PD4, to engage in self-reflection. Sessions 2–4 also contained a reflection session for practitioners to discuss the activities completed during the previous week.

Phase II Discussion: Initial Program Design

Numerous consensus decisions regarding the content and design of The ONE were reached during phase II. Combining research evidence, scientists and educators' perspectives into the codesign process was key to striking a balance between key theoretical goals, needs and priorities of educators. Without understanding time and planning constraints that educators work within, the intervention risked asking too much of educators, thus resulting in poor fidelity. Without reviewing government guidelines, the demands of the program could be perceived as contradictory to existing educator goals, again resulting in poor fidelity. On the other hand, the expertise of intervention scientists was key to safeguarding effectiveness. Finally, it was crucial to maintain alignment to the proposed logic model, to maximize the likelihood that changes in behavior could truly be attributed to the theory of change.

Phase III – Working with Educators to Pilot and Further Refine the ONE

The aim of Phase III was to work with practitioners to ensure that the program was considered feasible and beneficial by staff. Key priorities identified with educators included ensuring that activities were appropriate for a range of child ability levels and that PD was engaging, achievable, sustainable, allowed time for reflection, and appropriately detailed without being overcomplex.

Methods

Participants, procedure, and analysis plan. $N = 4$ settings and $N = 18$ educators took part in the pilot stage of the project. Staff members attended four weekly PD sessions (mean number of staff per setting = 3.88, $SD = 1.02$) and were given activities in weekly packs of six or seven activities. $N = 3$ EYCs participated in person and $N = 1$ participated virtually. Educators provided both quantitative and qualitative feedback on each activity. This was supplemented by a detailed discussion of activities at the start of each PD session. Researchers took notes throughout to document content suitability, practitioner engagement, and key issues or queries arising. All practitioners received evaluation forms during the final week of PD, asking them to rate activities on various metrics for administration ease and level of

benefit to staff and children. A mixed-methods approach was employed to extract quantitative information as well as complementary qualitative themes and subthemes across pilot data to inform further program refinement.

Results and Phase III Discussion

Feedback collected from reflection sessions, evaluation forms, and activity feedback posters revealed generally positive attitudes toward the activities (mean activity rating out of 3 = 2.59, $SD = .572$) and PD sessions (mean PD popularity rating out of 5 = 4.5, $SD = .577$). The reflection element of PD sessions was considered particularly successful, both by researchers (“generally great feedback about engaging their different experiences”) and by practitioners (“nice to have the opportunity to stop and reflect on our provision”). Activity cards were popular with practitioners and described as “easy to understand” and useful for “involving new staff members”. Some practitioners reported being “eager to get ideas for activities as we often get stuck thinking of new activities”. Although activities were designed to cover a broad range of different mathematical targets, it was noted that practitioners tended to choose those focusing on cardinality and counting (see Figure 4). Refinements were made to the program before Phase IV to support educators in delivering a broad mathematics curriculum.

Phase IV: Feasibility and Implementation Quality of the ONE Program

Codesign is essential to reduce barriers to feasibility, but it is not without limitations. Crucially, while it is important that educators deem programs ‘fit for purpose’, this must not undermine the core theoretical principles underpinning the specific program. Dowling and Barry (2020) propose a multidimensional mixed-methods approach to characterizing implementation differences across settings. We embraced this approach via acceptability and feasibility indices from interviews, as well as measures of adherence and fidelity to theoretical principles underpinning the intervention.

Methods

Participants. Sixteen EYCs were recruited for an evaluation trial of The ONE via a combination of convenience sampling and targeted sampling of centers in areas of deprivation. One setting withdrew prior to data collection, resulting in a total of 15 settings for which data were collected. A coinvestigator who was blind to setting identity assigned them to either the intervention group (eight settings) or a business-as-usual group (7 settings) based on setting size and type. $N = 31$ educators contributed to this phase of codesign.

Procedure. The eight intervention settings were asked to carry out the full 12 weeks of intervention, including



Fig. 4. Phase III: Proportion of activities in each mathematical category chosen across pilot settings.

8 weeks of independent activity completion without direct supervision from the research team. This was a difference from the pilot phase (Phase III), in which activities were only carried out during the first 4 weeks, as the primary goal of Phase III was to codesign PD and gather initial feedback on the activity pack, rather than test the feasibility of delivery over the full program, a central goal of Phase IV. Multiple tools were used to provide qualitative, quantitative, and combined indices of feasibility, acceptability, adherence, and implementation quality: practitioner feedback posters (measuring adherence by asking practitioners to record the number of activities completed per week), practitioner evaluation forms (measuring the success of PD training and of activities), an activity observation (measuring fidelity to EF/mathematics goals of the activity, quality of delivery, and ability to adapt activities appropriately for the children present), and an interview with one volunteering practitioner, held in person (measuring program acceptability and barriers) (further details in SOM).

Analysis Plan

Adherence to intervention delivery was measured using the percentage of activities completed over 12 weeks out of a maximum of three per week, as reported by practitioners in the posters and feedback sheets. Attendance at PD sessions was also recorded.

For **implementation quality**, we employed a mixed-methods approach:

Quantitative data. To quantify implementation quality, indicators were selected from the adherence posters, observations, teacher evaluations, and interviews to represent the dimensions of implementation: Dosage, Fidelity, Quality of

Delivery, and Participant Responsiveness (following Dowling & Barry, 2020).

Qualitative data. Qualitative themes were extracted from interview data, using reflexive thematic analysis (Braun & Clarke, 2006) with an inductive approach, with the aim of describing the successes and failures of the program and potential future steps. All coding was carried out by a trained researcher who was highly familiar with the aims of the intervention, acknowledging her positionality, while reviewing themes and subthemes with the research team. Codes were assigned to text within each interview, and these codes were grouped together to form themes and subthemes.

Results

Adherence. At least two members of staff attended PD sessions in all 4 weeks of the program across all eight settings (see Table 3). The percentage of activities completed out of a possible three activities per week was calculated across all settings. Five of the eight settings had high activity completion rates, with more than 80% of activities completed across the 12 weeks of the program and additional activities played in some weeks. Two settings had acceptable activity completion rates (72.2% and 63.9%). One setting had a low activity completion rate (25.0%).

Implementation Quality

Quantitative data. An average of the four-dimension scores (dosage, fidelity, quality of delivery, and participant responsiveness) was calculated, providing a total score for implementation quality of The ONE. These scores were then grouped, resulting in three groups: high ($N = 4$), moderately high ($N = 2$), and low ($N = 2$). No centers fell into a “moderately low” bin (Table 4).

Table 3
Adherence to the Intervention Across Settings

Setting	Activities completed	Additional activities	Number of PD sessions attended	Average (SD) number of staff at each session
A	100%	3	100%	3.00 (0)
B	100%	9	100%	2.00 (0)
C	100%	5	100%	2.50 (0.500)
D	97.2%	4	100%	5.00 (0)
E	86.1%	4	100%	5.00 (0)
F	72.2%	0	100%	5.75 (0.433)
G	63.9%	0	100%	5.75 (0.829)
H	25.0%	0	100%	2.00 (0)

Table 4
Mean and Range Scores for Each Implementation Quality Dimension, Split by Overall Group

Dimension	High Group (N = 4)	Moderately High Group (N = 2)	Low Group (N = 2)	Total (N = 8)
Total dosage score	95.8% (86.1%–100%)	68.1% (63.9%–72.2%)	62.5% (25.0%–100%)	80.6% (25.0%–100%)
Total fidelity score	94.4% (81.1%–100%)	97.3% (96.4%–98.2%)	27.5% (17.1%–37.9%)	78.4% (17.1%–100%)
Total quality of delivery score of the one	97.5% (95.5%–99.1%)	96.5% (93.8%–99.1%)	51.8% (35.7%–67.9%)	85.8% (35.7%–99.1%)
Total participant responsiveness score	99.3% (98.2%–100%)	96.5% (93.8%–99.1%)	48.7% (29.0%–68.3%)	87.2% (67.4%–100%)
Total implementation quality score of the one	96.5% (94.2%–98.4%)	85.3% (84.6%–85.9%)	48.7% (29.0%–68.3%)	83.0% (39.0%–98.4%)

Qualitative data. Reflexive thematic analysis resulted in the following major themes from interviews: benefits of the program, barriers to taking part, more successful and less successful activities, and suggestions for the future (see Figure 5). Subthemes are also presented in Figure 5, and centered around positive benefits for staff and children, systemic barriers (staff turnover, lack of planning time), and worries about the suitability of some activities to children with SEND or other differences.

Phase IV Discussion

Educators reported many aspects of the program as successful: gains in confidence, knowledge and inspiration at the staff level, and many of the activities were reported as being fun and engaging for the children. All 4 weeks of PD delivery were attended by at least two members of staff across all eight settings, with no settings dropping out during the delivery period, indicating that 4 weeks of short, in-person PD sessions could feasibly be integrated into their schedule. However, reflections on any barriers to feasibility, adherence, and implementation quality led to suggestions for a future series of final iterative refinements to the program. In response to the feedback that some children found the mathematical content difficult, a *Differentiation Ideas* box was added to each activity card for future implementation, informed by team members with a background in education

and including suggestions for making the level of challenge more accessible (for example, using manipulatives instead of number cards). The idea of executive *challenge* within maths was core to the intervention, so it was important that the differentiation box provided practical ideas on how to reframe and adapt challenge, rather than removing difficulty altogether. PD slides were also adapted to remind practitioners to continuously increase the level of executive challenge in line with the child's level of comfort and familiarity with the activity, again to remove researchers' implicit assumptions that educators knew how to implement core elements of activities.

DISCUSSION

The current manuscript describes the multiphase process of developing, evaluating, and refining a PD-based mathematics and EF intervention for preschoolers, incorporating feedback from educators across multiple iterative stages, thereby giving educators a voice at all stages of the process, in line with participatory (e.g., Clements, 2007) and research-design approaches (Fowler et al., 2023) to developing mathematics education programs. At the content level, mathematics and EF are high-priority areas for educators (Costa, Outhwaite, & Van Herwegen, 2023; Gilmore & Cragg, 2014) and researchers alike (Hodgen et al., 2020;

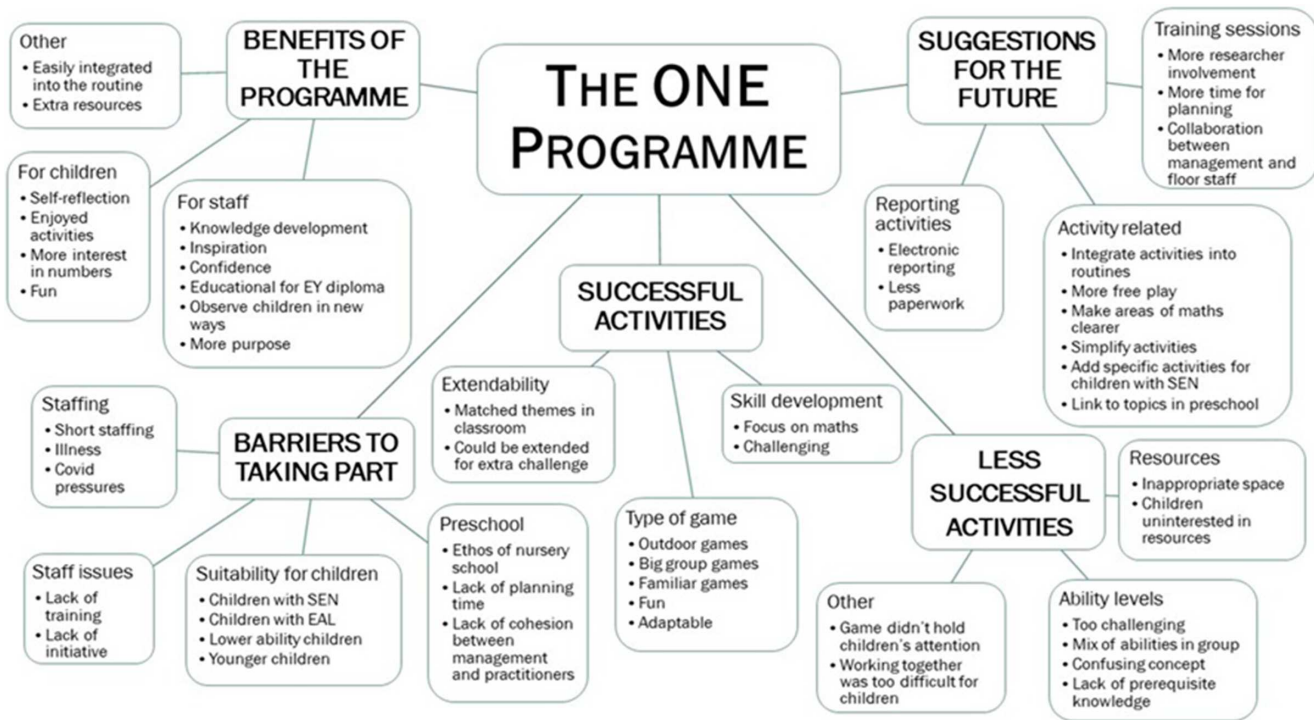


Fig. 5. Phase IV: Themes and subthemes emerging from interviews with practitioners.

Mattera et al., 2021). Bringing together educators and researchers is key to designing interventions that target EF and mathematics in ways that are acceptable, feasible, but also high in theoretical robustness and implementation quality.

Our central aim was iterative codevelopment to maximize feasibility and facilitate high implementation quality. Following recommendations in EY intervention development (e.g., Artman-Meeker et al., 2022; Clements, 2007; Diamond & Powell, 2011), each of the multiple phases of intervention development offered insights from educators, converging across qualitative and quantitative indices. During Phase I, observations, interviews, and questionnaires with practitioners allowed the team to understand “business-as-usual” practice in EY settings and the constraints faced by educators (e.g. lack of planning time in settings), as well as their priorities for future support (e.g. training in maths; supporting diverse children). The focus on mathematics alone was a limitation of the interview protocol, redressed later. During Phase II of the program, an expert panel of researchers and educators collaborated to lay the foundations of The ONE program, whilst considering prior research and the national EY context. Importantly, this board encompassed researchers as well as educators with first-hand experience of EY environments. Piloting PD with a small but representative sample of educators during Phase III allowed educators to have input on refinements to PD and activities

before implementing the program on a larger scale. Phase IV of the intervention design process was carried out alongside an evaluation of the efficacy of The ONE program (Scerif et al., 2025). Child-level outcomes provide important insights on the overall efficacy of an intervention, but in a complex, real-world environment such as an EYC, quantitative and qualitative data collected from educators through multiple sources were key to providing an in-depth understanding of the areas of the program that were successful and those that would benefit from refinement. Qualitative and quantitative data converged in highlighting addressable program-specific barriers (e.g. activity content too challenging for some children) and systemic barriers that are outside of the scope of the program (e.g. chronic staff shortages).

CONCLUSIONS: RECOMMENDATIONS FOR RESEARCH/PRACTICE INTEGRATION AND POLICY

The findings of educational intervention programs are often inconsistent, with a tendency for smaller effect sizes or failures to replicate when the program is implemented at scale (Perry, Morris, & Lea, 2022; Sims et al., 2021). The scientific community must learn from the successes and failures of other researchers, which requires adequately detailed implementation reporting via qualitative and quantitative data from educators involved in intervention codesign, as illustrated here.

Many of the barriers to taking part experienced by practitioners who contributed to this study were systemic and outside of the scope of the research team to resolve, such as low staffing levels, low preexisting staff qualifications, and a high proportion of children with additional needs. More funding, staff support, and infrastructure at the policy level are needed to resolve these issues. However, instead of dismissing these barriers as being unsolvable, we underscore the need for intervention programs to be supportive in the context of these wider constraints by, for example, reducing the time and resource burden of any program, providing easily obtained resources for practitioners, and providing activity differentiation options for children. Educator/researcher/policy partnerships could reduce systemic barriers by integrating programs into existing staff training structures and providing additional resources for high-need settings.

We describe the multiphase development process of a complex EY program, to help inform future PD initiatives for early years educators. Here, feedback from educators informed program refinement, to meet educator needs while retaining key theoretical underpinnings. Implementation quality measures indicated high intervention acceptability across some settings, whilst other settings struggled to meet dosage and/or fidelity measures, indicating a combination of systemic barriers that policy-makers must address and program-specific barriers that must be addressed by the program team. Future randomised controlled trials must investigate multiple factors contributing to differences in implementation quality across diverse settings. We present an approach to creating and refining a feasible program that remains consistent with core theoretical elements of interventions, but also centers educator experience and is adaptable to a diverse range of children and educational contexts.

AUTHOR CONTRIBUTIONS

Rosemary O'Connor is a *former early years English language teacher*, who now delivers professional development to early years educators, and is a researcher in early years education. Data curation; Investigation; Methodology; Project Administration; Supervision; Writing – Original Draft Preparation; Writing – Review & Editing. Sylvia U. Gattas is a *researcher* with a focus on bridging the science and practice gap. Conceptualization; Data curation; Investigation; Methodology; Project Administration; Writing – Original Draft Preparation; Writing – Review and Editing. Emma Blakey is a *researcher* with a focus on executive functions and diversity. Conceptualization; Methodology; Writing – Review and Editing. Carmel Brough is a *researcher* with a focus on the neural correlates of attention and executive functions. Data curation; Investigation; Writing – Review and Editing.

Keely Cook is an *educator* and Early Years Foundation Stage leader. Conceptualization; Methodology; Writing – Review and Editing. Zachary Hawes is a previous *educator* and now a *researcher* in mathematical education. Conceptualization; Funding Acquisition; Methodology; Writing – Review and Editing. Steven J. Howard is a *researcher* with a focus on executive functions and measurement. Conceptualization; Funding Acquisition; Methodology; Writing – Review and Editing. Caroline Korell is a previous *early years educator* and now delivers as well as manages *professional development* to educators in early years. Data curation; Investigation; Writing – Review & Editing. Toni Loveridge is a previous *early years educator* and now delivers *professional development*. Data curation; Investigation; Writing – Review & Editing. Rebecca Merkley is a *researcher* in early years mathematical cognition and education. Conceptualization; Funding Acquisition; Methodology; Writing – Review and Editing. Fionnuala O'Reilly is a *researcher* and an early years trial expert. Conceptualization; Methodology; Writing – Review and Editing. Victoria Simms is a *researcher* with a focus on early years mathematical learning. Conceptualization; Methodology; Writing – Review and Editing. Megan von Spreckelsen was a *researcher* and is now a practicing *educational psychologist*. Data curation; Formal Analysis; Investigation; Methodology; Project Administration; Writing – Review and Editing. Kathy Sylva is a *researcher* in early years education. Conceptualization; Methodology; Writing – Review and Editing. Gaia Scerif is a *researcher* with a focus on executive functions and diversity. Conceptualization; Data curation; Funding Acquisition; Investigation; Methodology; Project Administration; Supervision; Writing – Original Draft Preparation; Writing – Review and Editing.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Phase II Logic Model: Key inputs, outputs, and outcomes.

Table S1. Summary of UK government guidelines on mathematical learning at age 3–4, and their mapping to The ONE activities.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

This study received ethics approval from the Central University Research Ethics Committees of the University of Oxford (REC references: R48431/RE003; R85139/RE007). Settings and educators provided informed consent to taking part. Additional information on all phases of the study is available for interested reviewers in the Supplementary Online Materials and at the DOI on Open Science Framework [<https://osf.io/8y5u6/files/osfstorage>].

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Open Science Framework at https://osf.io/sekug/?view_only=640d4817bfb74ca6936d22e6a41e58c3.

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