Rudd, JR, Crotti, M, Fitton-Davies, K, O'Callaghan, L, Bardid, F, Utesh, T, Roberts, S, Boddy, LM, Walsh, BA, Cronin, CJ, Knowles, ZR, Watson, PM, Button, C, Lubans, D, Pesce, C, Buszard, T, Foulkes, JD and Foweather, L

Skill Acquisition Methods fostering Physical Literacy in Early-Physical Education (SAMPLE-PE) in 5-6 year old children: Rationale and study protocol for a cluster randomised controlled trial

Skill Acquisition Methods fostering Physical Literacy in Early-Physical Education (SAMPLE-PE) in 5-6 year old children: Rationale and study protocol for a cluster randomised controlled trial

Authors: Rudd, J.* [1,2], Crotti, M.[1,3], Fitton-Davies, K. [1,3], O'Callaghan, L.[1,3], Bardid, F.[4,5], Utesch, T.[6], Roberts, S.[1], Boddy, L.M.[3], Walsh, B[1], Cronin, C.J.[1], Knowles, Z. [3], Watson, P.M. [3], Button, C.[7], Lubans, D. R.[8], Pesce, C.[9], Buszard, T.[2], Foulkes, J.D.[1], Foweather, L. [3]

Affiliations:

1. Department of Sport Studies, Leisure and Nutrition, Liverpool John Moores University, IM Marsh, Barkhill Road, Liverpool, United Kingdom L176BD J.R.Rudd@ljmu.ac.uk, M.Crotti@2016.ljmu.ac.uk, K.FittonDavies@2017.ljmu.ac.uk, L.A.OCallaghan@2017.ljmu.ac.uk, S.Roberts2@ljmu.ac.uk, B.Walsh@ljmu.ac.uk, C.J.Cronin@ljmu.ac.uk, J.D.Foulkes@ljmu.ac.uk
2. Institute for Health and Sport (IHES), Footscray Park Campus, Victoria University, Melbourne, Victoria 3011, Australia. Tim.buszard@vu.edu.au
3. Physical Activity Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, 62 Great Crosshall Street, Liverpool, United Kingdom, L32AT L.Foweather@ljmu.ac.uk, L.M.Boddy@ljmu.ac.uk, Z.R.Knowles@ljmu.ac.uk, P.M.Watson@ljmu.ac.uk
4. School of Education, University of Strathclyde, Glasgow, United Kingdom farid.bardid@strath.ac.uk
5. Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium

6. Institute for Sport and Exercise Sciences, University of Münster, Einsteinstraße 22, 148149 Münster, Germany, till.utesch@uni-muenster.de
7. School of Physical Education, Sport and Exercise Sciences, University of Otago, Dunedin, Otago, New Zealand. chris.button@otago.ac.nz
8. Priority Research Centre in Physical Activity and Nutrition, School of Education, University of Newcastle, Callaghan, NSW 2308, Australia david.lubans@newcastle.edu.au
9. Department of Movement, Human and Health Sciences, University of Rome "Foro Italico", Rome, Italy caterina.pesce@uniroma4.it

Corresponding author

James Rudd J.R.Rudd@ljmu.ac.uk

Abstract

Background

There is a need for interdisciplinary research to better understand how pedagogical approaches in primary physical education (PE) can support young children to develop key aspects of physical literacy (physical, affective, cognitive), as well as to create stronger pedagogical models that will inform educators' decision making around learning design and help foster physical literacy in young children. The *Skill Acquisition Methods fostering Physical Literacy in Early-Physical Education (SAMPLE-PE)* study aims to examine the efficacy of two different pedagogical models for PE, underpinned by theories of motor learning, to foster physical literacy, especially for children living in disadvantaged areas.

Methods

SAMPLE-PE will be evaluated through a cluster-randomised controlled trial targeting 5-6 year old children from schools located in areas of high deprivation in Merseyside, North-West England. Schools will be randomly allocated to one of three conditions: *Linear Pedagogy*, *Nonlinear Pedagogy* or Control. Nonlinear and Linear Pedagogy intervention primary schools will receive a PE curriculum delivered by trained coaches over 15 weeks, while control schools will follow their usual practice. Data will be collected at baseline (T0), immediately post-intervention (T1) and six months after the intervention has finished (T2). Children’s motor competence is the primary outcome in this trial. Secondary outcomes include physical activity, perceived competence, motivation, executive functions, and self-regulation. An extensive process evaluation will also examine implementation factors such as intervention context, reach, dose, fidelity and acceptability.

Discussion

This study will support the development of new, integrative, and interdisciplinary knowledge of how to operationalise physical literacy into PE practice, and aims to enhance the provision of high-quality learning experiences for children participating in PE. Further, SAMPLE-PE aims to provide robust scientific evidence of the efficacy of theoretically-informed PE pedagogy to improve children’s physical literacy.

Trial registration

Retrospectively registered on 5th September 2018 at ClinicalTrials.gov, a resource provided by the U.S. National Library of Medicine (Identifier: NCT03551366).

Keywords: physical education, intervention, motor learning, pedagogy, children, motor competence, physical literacy, cluster-randomised controlled, mixed methods, motor learning

4

Background

Physical Literacy

Physical literacy can be understood as the embodied relationship between a child's physical competence (motor and fitness), motivation, confidence (affective), knowledge and understanding (cognitive), and also their environment, which shapes movement skills and ongoing physical activity (1,2). There is a need for interdisciplinary studies into physical literacy leading to a better understanding of pedagogical practices that can foster physical literacy in early primary school. It is widely accepted that early quality physical education (PE) experiences are crucial for laying a strong foundation to support children on their physical literacy journey (1,3).

Physical Education

It is therefore a concern that across the world PE has become marginalised within the primary school timetable. Core subjects such as numeracy and literacy (4,5) are typically prioritised at PE's cost, primarily because government policy has introduced national standardised tests in these subjects (6–8). The emphasis on numeracy and literacy has arguably weakened the perceived educational value of PE and prompted many to consider it an "oxymoron" (9–12). The downgrading of PE within teacher education (13–15) has resulted in 78% of English primary schools (from a sample of 642 primary schools) employing sports coaches in the absence of qualified teachers to teach PE during curriculum time (10). As a result of its diminished status as a core primary school subject, many children only receive one hour of PE per week, while lessons delivered suffer from a lack of critical planning with little focus on pedagogy (16–18).

Supporting Physical Literacy through Physical Education

Across the globe, primary school PE curriculums and standards reference support of the whole child, including physical, affective, cognitive and social development (19–21), and advocate the importance of physical literacy (22–25). Although physical literacy is considered a holisitic concept with relevance through the life course, the early to middle childhood period is particularly important for nurturing the acquisition of foundational movement skills (e.g., striking, kicking) and abilities (e.g., agility, balance, coordination) (1,26,27), collectively known as movement competence. Research in the fields of human movement sciences define these constituents of movement under the umbrella term of "motor competence". Motor competence exists across a spectrum of human movement and is dependent upon an individual's capacity to control, coordinate and perform motor skills efficiently (motor proficiency), as well as to adapt, attune and combine motor skills, creating novel functional solutions (motor creativity) across a broad range of physical activity contexts (28–30). Supporting motor competence is considered central to fostering meaningful experiences in PE (31), therefore "nurturing the physical literacy journey" (32).

Importance of Motor Competence for Fostering Physical Literacy

Low levels of motor competence have been reported among primary school-aged children in western countries (33–35). In particular, children from areas of high deprivation have less developed motor skills than their peers from more affluent areas due to fewer opportunities to take part in physical activity or a lack of safe outdoor spaces (34,35). Low levels of motor competence among children from deprived areas is a concern because children with higher levels of motor competence have higher cardiorespiratory fitness, and are less likely to be overweight or obese, compared to children who perform these skills poorly (36–38). From an affective perspective, children with high motor competence have been found to have higher perceived competence (39–41), which is important because children who feel confident whilst participating in PE are more likely to enjoy involvement, and consequently feel intrinsically motivated to continue effort and participation in all forms of physical activity. From a cognitive perspective, the ability to perform complex motor skills is positively associated with higher-order cognitive skills, i.e., executive functions: working memory, inhibitory control and cognitive flexibility (42,43), that allow children to manage their thoughts, actions and emotions in order to accomplish everyday tasks, and also to plan, organise and manage their time effectively. Therefore, poor motor coordination development may have wide-reaching adverse effects on perceptual, cognitive, and social development (44). It has also been suggested that the development of complex motor skills through well-designed PE lessons can act as a 'carrier' of higher-order cognitive skill learning beyond those achieved through traditional classroom-based activities (45). From a behavioural perspective, children with higher levels of motor competence are more likely to be physically active during childhood, which in turn tracks into adolescence (46–49). Whilst these articles highlight the potential physical, affective, cognitive and behavioural benefits of high motor competence, much of the research to date is cross-sectional or longitudinal (46,50,51). There is a need for more experimental research within PE to provide robust evidence for motor competence influencing these elements of physical literacy (1,3,52).

Use of Pedagogy in Motor Competence Interventions

In order for children to develop high motor competence, it is important that they can access a PE curriculum with a strong theoretical basis, delivered by skilled practitioners, using systematic, progressive and developmentally-appropriate approaches to learning (20,53). There have been a number of PE-based curriculum intervention studies which have focused on early primary school children's development of motor competence through the acquisition of foundational movement skills, such as object-control (e.g., catching, throwing, kicking) and locomotor (e.g., running, hopping, jumping) skills (see 39,49–51). While, in general, these interventions were successful, there is no clear indication in terms of the pedagogy, curriculum, teaching behaviours and instructional strategies of which are most effective at developing motor competence (31,50,54,55). Research in motor learning and control has advanced knowledge about the physical, perceptual and cognitive processes involved in the acquisition of motor competence and has highlighted how to design optimal learning environments. It therefore offers an excellent opportunity to develop a strong theoretical underpinning for primary school PE (57,58).

Motor learning literature underpinning effective learning design and pedagogy

Linear Pedagogy

Typically, pedagogical approaches and assessment methods utilised within PE curriculums align with cognitive and linear approaches to motor learning in accordance with Information Processing Theory (18,58,59). Lesson design structure and teaching methods hold with the premise that learning (skills) is a gradual linear process where the development of a skill progresses through three observable stages of learning (such as cognitive, associative and autonomous) characterised by a reduction in cognitive processing when performing the skill

(60). One example of a popular Linear Pedagogy approach is the Direct Instruction Model for teaching in PE (61). The main aim of this linear pedagogical model is to create highly structured, constrained environments that first develop 'technical proficiency' before being applied within a game or performance setting (62). For example, initially learning a foundational skill in isolation (closed environments) before the introduction of rules and game play situations (open environments) (63). Linear pedagogy includes both prescriptive (e.g., following technical demonstrations and instructions from the teacher) and repetitive actions (e.g., replication of the optimal technique), where variability is reduced until a performer can execute a motor skill efficiently and reliably (58). Feedback is largely a one-way process: the teacher tells the child what they are doing incorrectly and proposes a different (and often better) way to move.

To fully appreciate the potential of Linear Pedagogy to foster physical literacy in children, it is important to consider the individual learning experience. The utilisation of this pedagogical approach will have implications for children's perceptions of competence and motivation for PE, which can be understood through the framework of Self-Determination Theory (SDT:(64)). SDT distinguishes between autonomous (self-determined) and controlled motivation based on the reasons that move an individual towards a particular behaviour, and is framed in a way that social and environmental factors are seen to facilitate or undermine autonomous motivation (64). SDT is underpinned by the concept of supporting and satisfying three basic psychological needs: *competence* which refers to experiencing satisfaction in demonstrating capabilities in optimal developmentally-based challenges, *autonomy* where the individual perceives their actions to be volitional, and *relatedness* which is the need to seek out connected relationships with others (64). Linear pedagogies emphasise a development of motor proficiency in one optimal technique may result in fast learning, leading to early feelings of success that should increase perceptions of competence (65), contributing to higher levels of motivation in the lesson, as well as PE and physical activity more broadly (62). Autonomy may be supported by the teacher or coach providing clear explanations of why children are being asked to complete certain activities, though a child's freedom to explore and express different movements may be limited. Relatedness can be supported through positive communication between the teacher or coach and the children. From a cognitive perspective, it is suggested that pedagogies that follow a linear progression of skill learning may support the natural scaffolding of the executive functions of inhibitory control and working memory, providing the architecture for cognitive flexibility to be built upon (42,66,67). This is due to the learning design of Linear Pedagogy first constraining children to practice skills in isolated environments before moving into a game or performance situation that will require cognitive flexibility.

Evidence suggest that PE interventions aligned to the Direct Instruction Model and/or reflecting linear methods of skill learning are an effective teaching strategy for supporting young children to develop motor skill proficiency (50,54,55). However, some of this evidence can be interpreted as low-quality, while many studies lack long-term follow-up (54,55), which is important in order to establish whether beneficial intervention effects are maintained. Further, while studies have documented increases in motor skill proficiency, there is a lack of evidence for motor creativity outcomes, and limited evidence of concomitant increases in affective and cognitive domains, as well as physical activity behaviour (48,50,55). Further research investigating the benefits of pedagogical approaches that emphasise linear progressions of skill learning on supporting children's physical literacy is therefore warranted.

Nonlinear Pedagogy

The theory of Ecological Dynamics, offers a Nonlinear perspective on the learning and development of movement (68). Ecological Dynamics is the combination of two theories: Ecological Psychology (69) and Dynamical Systems Theory (70). Ecological Psychology (69) postulates a constant reciprocal relationship between an individual and their environment as they move through it. One important implication is that a PE teacher or coach should pay as much attention to the environment and the context of their PE lesson as they do to the children participating within it. Dynamical Systems Theory (70) emphasises the need to understand that each complex system, such as the human body, has many interacting and related parts, and that these interrelating parts constrain movement actions. When combined to form Ecological Dynamics, learners are regarded as complex adaptive systems who are presented with opportunities for action (affordances) from their environment. The concept of affordances highlights the interaction between the environmental features and functional capabilities of the individual child. Children are able to identify affordances within their environment based on their level of skill development (i.e., coordination, control and skill) (71). Goal-directed movements are the product of the interaction between personal, environmental and task constraints (72,73). From an Ecological Dynamics perspective, motor learning is not simply a matter of processing information and accruing representations (as is the case in cognitive theories), but is the constant active, perceptual engagement of the learner and context (74).

The theoretical scaffold of Ecological Dynamics informed the development of Nonlinear Pedagogy (57). In Nonlinear Pedagogy, the teacher's role is to design learning experiences in which the child's capability and environmental opportunities are closely aligned, creating opportunities for goal-directed movement (i.e., affordances). One way for the teacher to create affordances and channel the child's motor competence development is through manipulation of task and environmental constraints (e.g., space, equipment, rules). The manipulation of task constraints aims to promote an external focus of attention within the child, leading to coordination and control processes of a motor competence being delegated to a lower level of the central nervous system where skills are learnt implicitly (75). The child is left free to experiment by performing, adapting and creating movement solutions that best answer their individual needs within a given context. Traits of nonlinear pedagogy can be observed in pedagogical models such as 'Teaching Games for Understanding' and teaching styles such as inquiry-led, co-operative and discovery learning, and could therefore be considered an approach which addresses children's development of physical, cognitive and affective learning domains (61,76,77), therefore supporting physical literacy. However, to deliver Nonlinear Pedagogy effectively, the teacher/practitioner needs to possess an in-depth pedagogic knowledge of movement to identify constraints that can create teachable or coachable moments to improve motor competence (78,79). A Nonlinear pedagogical approach to learning in PE also has implications for a child's affective and cognitive development, and physical activity behaviour. Similar to *linear* pedagogies, the development of motor competence (motor proficiency and motor creativity) should increase perceptions of competence, contributing to higher levels of motivation in the lesson, as well as PE and physical activity more broadly (80). Nonlinear pedagogy will also have implications for children's autonomous motivation for PE, which again can be understood through the framework of SDT (64). Nonlinear pedagogy provides the child with choice and freedom to move in different ways within their PE lessons, which could enhance their enjoyment and perceptions of autonomy. Further, the focus on finding different movement solutions to achieve a goal may see a shift in how the child views competence, away from an 'ideal' movement performance towards functional, creative movements (81–83). The respect the teacher or coach gives to the child's ability to explore, learn and problem solve may also enhance the child's feelings of relatedness. A Nonlinear Pedagogy may have a more favourable impact on the development of executive functions as it will create conditions that continuously challenge executive function processes and can offer learning tasks that elicit children's commitment and emotional investment delivered in instructional environments with supportive instructors (84). From a behavioural perspective, it is suggested that the long-term effect of this pedagogy is that children will acquire a wide range of functional movement solutions that are both adaptable and attuned across a variety of physical activity environments (85,86). The child is able to identify affordances (opportunities for action and participation) in physical activity regardless of whether they are in a PE lesson, in the playground or outside of the school environment.

While the potential holistic benefits of Nonlinear Pedagogy for primary school PE have been widely discussed (85,86), to date there is little evidence investigating this approach in supporting physical literacy in primary school children and within PE (50). Studies which have employed PE interventions with characteristics of Nonlinear Pedagogy have demonstrated improvements in motor proficiency among primary school children, relative to control conditions following usual PE practice (66,87). Miller et al. (87) also demonstrated increased pedometer steps (physical activity behaviour) in PE following the intervention but found no difference between intervention and control groups in perceived athletic competence, while Pesce et al. (66) reported increases in object control skills and inhibitory control but not working memory aspects of cognitive development. Taken together, while to date there is limited evidence of the successful utilisation Nonlinear Pedagogy in primary PE, this approach does hold promise in developing motor competence and fostering physical literacy and physical activity, and, as such, further research is required.

Aims of the Current Study

The purpose of the Skill Acquisition Methods fostering Physical Literacy in Early-Physical Education (SAMPLE-PE) study, is therefore to assess the efficacy of utilising *Linear* and *Nonlinear* pedagogy within PE to promote motor competence (proficiency and creativity) and wider physical literacy in 5-6 year old children from deprived areas in a major city in north-west England. Specifically, the main objectives of the study are to assess the efficacy of PE pedagogies (*Linear* or *Nonlinear*) delivered over 15 weeks, compared to standard PE practice, on 5- and 6- year-old children's motor competence (physical domain), perceived motor competence (affective), self-determined motivation (affective), executive function (cognitive), self-regulation (cognitive-affective), and physical activity (behavioural). A further objective of the study is to explore the potential mediating mechanisms for any intervention effects, and in particular whether increases in motor proficiency and/or motor creativity mediate differential effects of Linear and Nonlinear Pedagogy across other elements of physical literacy.

Hypotheses

Based on previous literature (50,55), we expect that children who participate in the *Linear* and *Nonlinear* Pedagogy interventions will demonstrate greater improvements in motor competence (motor proficiency and motor creativity) compared to children following standard PE practice. It is also expected that children in the Nonlinear Pedagogy intervention will demonstrate greater motor creativity but lower technical motor proficiency than children in the Linear Pedagogy group (88). Furthermore, children in Linear and Nonlinear Pedagogy interventions will show greater gains across physical literacy elements (affective [perceived competence and motivation], cognitive [executive functions] and behavioural [physical activity]) than children in usual PE practice. Finally, it is also expected that the Nonlinear Pedagogy intervention will see greater improvements in children's affective (motivation) and cognitive development (core executive functions: cognitive flexibility, working memory and inhibitory control) than the Linear Pedagogy intervention (81,89,90). The net effect of the Nonlinear pedagogy principles will provide the children with autonomy and encourage them to regulate their own behaviours and experiment to find solutions that best answer their own individual needs within the given context. This pedagogy promotes purposeful decision-making, a strong sense of self-regulation and creative movement behaviours supporting the holistic development of Physical Literacy.

We also hypothesize that the differential outcomes of different PE pedagogies in the motor domain will not be merely paralleled by outcomes in non-motor domains, but that the multiple outcomes will be interconnected by mediating paths providing a better understanding of a child's physical literacy journey. Within the framework of mediating mechanisms of physical activity effects on cognitive and affective development (91), enrichment in PE has been found to lead to cognitive benefits that are specifically mediated by gains in motor competence (92). Furthermore, the emerging role of perceived motor competence as a mediator between actual motor competence and physical activity behaviours (51,93) suggests that different PE pedagogies might lead to different outcomes ongoing physical activity behaviours through a mediational chain of gains in actual and perceived motor competence.

Methods

Design

A cluster randomized controlled trial (RCT) will be conducted to evaluate the efficacy of the SAMPLE-PE pedagogy interventions that aim to improve motor competence and other key aspects of children's holistic development in year 1 children (5-6 years) in twelve government-funded primary schools. The trial has received institutional research ethics committee approval (Reference 17/SPS/031), and is registered (ClinicalTrials.gov identifier: NCT03551366). A schematic overview of the intervention and evaluation components is shown in Figure 1, while the flow diagram of schools through the study is shown in Figure 2. The UK school academic calendar spans September to the middle of July. Data collection will occur over 14 months with measurements at baseline (T0, January-February 2018) and post-intervention (T1, June-July 2018), whilst children are in year 1 of primary school, with a follow-up planned for six months after the intervention has finished (T2, January-February 2019; year 2 of primary school; one year post-baseline assessments). The design, conduct and reporting of this cluster RCT will adhere to the Consolidated Standards of Reporting Trials (CONSORT) guidelines for group trials and the Standard Protocol Items: Recommendations for Interventions (SPIRIT) checklist.

<<FIGURE 1 AND FIGURE 2 NEAR HERE>>

Sample size and statistical power

Based on previous studies (55), we anticipate a small to medium effect size of d=0.4 for changes in motor competence. In accordance with CONSORT guidelines, our power calculations were adjusted for the clustering of effects at the class level. Adjusting for clustering at class level, we used a correction factor of $[1+(m-1)\times ICC]$, with participants m per class and the intraclass correlation ICC coefficient. Assuming an average class size of about 20 participants and an ICC for motor competence of 0.16 (based on TGMD-2 data of 8 classes from 7-8 year-olds,(94)), the correction factor is 4.04 (i.e., $1+(20-1)\times0.16$)(95). The power calculation to detect within-between interactions for three groups and across three time points with 80% power, α levels set at $p<0.05$ and $r = .5$ is suggested a minimal sample size of 54 children. The final power calculation including the correction factor indicated sample size of 218 children. Allowing for 20% dropout at each time points, the aim of this study will be to have a sample of at least 314 children.

Settings and participants

Eligible government-funded primary schools located within a large city in North West England will be invited to participate in the study via email and telephone. Eligible schools are required to be located within an area ranked within the most deprived tertile for the English population, as measured by the 2015 English Indices of Deprivation index (96). Representatives from eligible schools will subsequently be invited to an information meeting with the research team, where they will be given an in-depth overview of the project. Signed consent will be obtained from headteachers for recruitment, data collection and potential delivery of PE by the research team. Eligible children from year 1 classes will then be invited to participate in the study via a parent/carer and child invitation pack, including information sheets, consent forms, parent and child characteristics questionnaire, child medical information form, and child assent form. Children that are not able to participate in

PE (e.g. due to medical conditions) or those with profound learning disabilities and formally recognised special educational needs (e.g., behavioural issues, speech and language impairment) will be excluded from assessments and data analysis. Children that do not return parent consent forms will be exempt from the research, but able to participate in PE lessons.

Blinding and randomisation

For practical reasons, it will not be possible to blind the researchers, teachers, and coaches to group allocation. Following collection of headteacher consent, randomisation will take place at the school (cluster) level. Schools will then be matched based on the number of students enrolled and level of deprivation identified using the school postcode (96). Following this, schools will be randomly allocated to an intervention condition or control group using a computer-based random number producing algorithm by an independent researcher not associated with the study. This method ensures that schools had an equal chance of allocation to each group.

Intervention

Overview

SAMPLE-PE aims to explore the efficacy of two PE pedagogies (Nonlinear Pedagogy and Linear Pedagogy), delivered through 2 x 60 minute weekly PE lessons as part of a 15-week PE curriculum in primary schools situated in areas of high deprivation. Randomisation will be carried out at the school level with each of school being assigned to one of three conditions: Nonlinear Pedagogy PE intervention, Linear Pedagogy PE intervention or control group (standard PE curriculum). All groups will have the same dose (i.e., 2 x 60 minute weekly PE lessons, for 15 weeks).

The SAMPLE-PE intervention curriculum for both the Linear Pedagogy and Nonlinear Pedagogy arms will consists of three, five-week phases of lesson delivery (15 weeks in total), commencing two weeks after baseline assessments. The first phase focuses on dance, the second on gymnastics and the final phase on ball sports. Each phase has its own scheme of work, which includes five lesson objectives, each taught over a two lesson period, and delivered in school during existing PE curriculum time. The lesson objectives are aligned to the aims of the English national curriculum (19) and are identical in both Linear and Nonlinear Pedagogy schemes of work, but the remaining content was differentiated by pedagogical approach in an effort to support the development of the lesson plans (described in detail below). Lessons will be delivered twice a week by trained coaches, with each lesson lasting 60 minutes in total, with 45 minutes of on-task teaching time, culminating in a total of thirty PE lessons.

Training coaches for intervention delivery

The current study is an efficacy trial and, given that generalist primary school teachers lack the confidence and competence to effectively deliver PE (97), coaches will be recruited to deliver the Linear and Nonlinear Pedagogy PE interventions. This approach also corresponds with usual practice in primary PE in England, as the majority of primary schools currently employ sports coaches to deliver PE (10). Sport coaches will be recruited through advertisements aimed at postgraduate and undergradate students undertaking Sports Coaching or PE courses or via the university's in-house sports coaching provider. Applicants will be shortlisted if they have a level 2 coaching qualification in any sport and at least one-year’s coaching and/or teaching experience in an early primary school PE setting. Coaches who meet the essential criteria and will then be invited to attend a bespoke five-week training programme. This training aims to develop the coaches' knowledge and skills to deliver either a Linear (operatinally through Direct Instruction Model) or Nonlinear Pedagogy SAMPLE-PE curriculum.

Prior to the start of the training programme, coaches will be asked to design and deliver a coaching session to year 1 children, which will be video recorded by the research team. The video recordings of the session will subsequently be analysed by two members of the research team with expertise in both pedagogical approaches. This exercise will enable the research team to determine whether each coach's style of delivery is consistent with direct instruction-based teaching characteristics of Linear Pedagogy or more consistent with inquiry-based and problem solving teaching characteristics of Nonlinear Pedagogy. Coaches will then be allocated to either a Linear or Nonlinear five-week pedagogy training programme based upon their observed teaching style. This programme will comprise of three hours training each week delivered by the research team within a local primary school. Each training session will include a 90 minute classroom theory session on either Linear or Nonlinear Pedagogy, with pedagogical content knowledge relating to dance, gymnastics and ball sports, and a 90 minute practical session of PE delivery to year 1 and 2 primary school children. The practical sessions will consist of a 45-minute model lesson delivered in the pedagogical style by a member of the research team who has recognised expertise in PE teaching (98) , followed by the coaches implementing their own lessons in accordance with the respective pedagogy.

All coaches will be provided with a scheme of work, lesson plans and a pedagogical framework (Table 1) for each PE subject (dance, gymnastics and ball sports), a resource pack covering key elements of their respective pedagogical approach and copies of recorded theory and practical lessons were put online as coaches' resources. Coaches will be asked to complete a self-reflection either via diary or audio recording (99) each week concerning their implementation of the respective SAMPLE-PE pedagogy principles. This self-reflection will form the basis of discussions in weekly meetings with a member of the research team, alongside any changes necessary to the next week's lesson plans. Coaches will also have the opportunity to access telephone support and a critical friend from the research team throughout the intervention delivery schedule.

[INSERT TABLE 1 NEAR HERE]

Linear Pedagogy

The SAMPLE-PE Linear Pedagogy intervention postulates that motor learning is a process that unfolds in identifiable linear phases (100). The Direct Instruction Model pedagogical approach will be used by coaches to create a PE environment where the learner first replicates the coaches' technique as well as scaffolding activities, starting with low enviromental varability as skill improves the learner will be placed into incrementally more variable and dynamic environments. To support the coaches' learning design and delivery they were trained to utilise three models: Fitts and Posner's stages of learning (60), Gentile's taxonomy (101) of motor skills, and the challenge point framework (102). Coaches were trained to identify children in each of Fitts's and Posner's three stages of learning (cognitive, associative or autonomous) and then, prior to the start of the PE lesson, to use this knowledge to modify lesson activities using Gentile's taxonomy. The 16 categories of the taxonomy lead coaches through a logical sequence of potential progressions and forces the coach to consider two main perspectives -

the environmental context in which the skill takes place and the function that the motor skill must fulfil. Using Gentile's taxonomy, a coach can manipulate the skill to its simplist form in which the child has a stable base without any object manipulation and in an environment free from distraction. If the coach believes that a child or class of children have higher competence they can use Gentilie's taxonomy to create a skill context that is far more challenging, i.e., body in motion, manipulation of an object, and environmental factors dictating motor skill responses (101).

To support children's individual needs during the lesson, coaches utilise the challenge point framework (102), which indicates that there is an optimal level of challenge for children to maximise learning in a given activity. Each lesson activity represents different challenges for children at different phases of learning a motor skill. The level of difficulty will be dependent upon a number of key variables: the skill level of the performer, the complexity of the activity, and the environment in which the activity is taking place. The more difficult the activity, the greater the learning potential, though this is related to an increase in task difficulty, and as such, the performance of the learner is expected to decrease. Thus, learning is maximised in PE when a child is optimally challenged. This framework supports coaches to critically assess if learning is taking place and consider how they can support a child to maximise learning.

The Linear Pedagogy curriculum was guided by four principles. The first principle is that there is a correct optimal movement pattern for each foundational movement skill. This is based on the idea that is there is a movement trace that acts as a reference of correctness to guide a child's movement. In Linear Pedagogy, the coach relies heavily on demonstrations of an optimal movement pattern as this offers a unique opportunity for learners to gather information about appropriate coordination patterns and task requirements which can benefit performance (103,104). The second key principle is that motor skills are broken down or simplified into key components of a skill for learning, as performing an optimal movement pattern is often beyond the reach of children who are in the early stage of learnig a skill . The third key principle is that movement variability is viewed as noise in the system, which the child has to reduce in their quest towards mastery of a skill. The coach overcomes this by repetitive practice of the skills, which gradually reduces the amount of variability in the system, and the result is an efficient, reliable and accurate movement skill performance. The fourth principle is the focus of attention when performing a motor skill. The majority of research in this area highlights that promotion of an 'external focus' generally results in more effective performance and learning of a motor skill (105). However, individuals in the cognitive phase of motor skill learning have been found to benefit from an internal focus of attention, e.g., a focus on the foot contact if dribbling a football (106). Therefore, the SAMPLE-PE Linear Pedagogy curriculum coaches will be trained to create an internal focus of attention for children identified as in the cognitive phase of skill development (i.e., children with low motor competence), while for children progressing beyond this stage (i.e., children with higher movement competence), coaches focused on an external attention of focus.

To help to apply the Linear Pedagogical principles into direct instructional pedagogy, coaches will be trained to use the 'DIFFerentiation' framework (see Table 1) to support common behaviours coaches use when teaching PE, demonstration, instruction, frequency and feedback (DIFF). For a complete example, of a Linear Pedagogy lesson plan for the log roll , (Supplementary material 1).

Nonlinear Pedagogy

Ecological dynamics considers individuals (or at a higher level of analysis, a class of children) to be complex and adaptive systems. If this theoretical premise is accepted there is, from a learning design perspective, considerable uncertainty as to how any particular PE lesson will unfold, and consequently lesson plans should act as a guide, rather than being adhered to strictly at the cost of learning opportunities. Coaches therefore need to adopt a frontloaded approach, whereby they consider in advance how any changes within the PE lesson may alter the learning of each child. While this may seem like an impossible task, there are some consistent variables across schools (e.g., class sizes, lesson duration, national PE curriculum objectives). Moreover, within the classroom there will be common constraints acting upon children such as their age, socio-economic demographic, and the school environment, which either facilitate or hinder motor learning. The research team and coaches will work together to identify common constraints for year 1 children, creating an expected range of variation that the coach could plan for and exploit during their PE lessons, allowing them to design more individualised and meaningful movement experiences for their children. It is important to highlight that this approach recognises that it is impossible to repeat a movement identically from one attempt to the next (71). Thus, accepting variability in movement is central and the coaches' role is to encourage participants to adapt their movements and continue to improve their technique .

In order to help the coaches deliver the Nonlinear Pedagogy curriculum, they were trained to utilise two models: Newell's (71) model of motor learning, and the Space, Task, Equipment and People (STEP) framework (107). Newell's (71) model of motor learning is based on Ecological Dynamics and was used to teach coaches that high motor competence is represented by a child's ability to be creative and adaptable whilst still succeeding in their performance of motor skills. SAMPLE-PE Nonlinear Pedagogy coaches were trained to identify motor competence levels of children within the PE class, and subsequently individualise the PE activity towards a child's particular level of competence by changing one or more task constraints. The STEP framework (107) was used to support coaches with manipulating task constraints to individualise the PE activity towards a child's particular level of competence in order to increase or reduce the likelihood of affordances, with the aim of enabling children to effectively solve movement problems. The coach could reduce or increase the playing Space, alter the rules of the Task, use different sized Equipment and/or change the number of People playing the game. For example, if a group of children have been identified as being highly competent in a throwing and catching game, using the STEP framework, the coach can increase the space between teams, reduce the size of the ball, or introduce defenders, thereby altering the difficulty level of the task. The coaches were also trained to allow children the time and freedom to explore their own creative solutions to movement problems, rather than attempting to correct and remove this variation in performance.

Alongside these models, the Nonlinear Pedagogy curriculum is underpinned by five core principles. The first of these principles is a representative learning design. Arguably, a common representative learning design for young children within a PE setting is fun (31,108). In gymnastics, dance and ball skills Nonlinear Pedagogy PE lessons, music and A3 colour posters will be used to help foster all aspects of a representative learning design. Another important aspect of a representative learning design is that it highlights the importance of skill transfer between multiple settings. For this to occur, it is important that there is a behavioural correspondence between learning and the child's other performance environments, such as the playground, afterschool clubs and sport clubs (e.g., a gymnastics club). Therefore, for each gymnastics lesson within the Nonlinear Pedagogy curriculum, all equipment was set out prior to the lesson starting and remained out throughout the duration of each lesson. This is similar to a gymnastics club where equipment is always available instead of being brought out one piece at a time, or for the last part of the lesson, as was the case in the linear curriculum. This creates a similar environment between the PE lesson and the gymnastics club allowing an easier transfer of skill between the two.

The second principle asserts that movement-perception coupling must be maintained when performing skills. This means that skills are practiced in their entirety rather than broken down into component parts. Movement creates information that we perceive and in turn supports further movement in a cyclical process; hence, breaking the skill into components or decontextualising the skill impedes movement-perception coupling. For this reason, movement-perception coupling is seen as a micro (skill level) equivalent of the macro (environment) representative learning design. From a macro perspective, the movement-perception coupling is maintained within gymnastics lessons by having all equipment present throughout the duration of each lesson. This encourages children to become more spatially and socially aware over time, as with continued exposure they learn how to move around the equipment safely and sensibly. At the level of the microstructure of practice, the coach does not prescribe the type of motor skill that the child should learn. Instead, the coach promotes creativity and exploration through the use of scenarios and/or mini-games, that encourage children to explore and experiment with a broad range of motor skills, meaning movements are learnt in context, and the coach does not isolate skills or develop them by separating into components. Developing analogies and questions upon a common theme encourages problem solving from the child rather than the teacher telling the child exactly what to do.

The third underpinning principle of Nonlinear Pedagogy is an external focus of attention within the child, which is considered necessary to support the acquisition of both creative and functional motor skills. Profeta and Turvey (75) suggest that movement coordination and control is delegated to the lower levels of the central nervous system where movement is less conscious. An external focus of attention allows for self-organisation of movement patterns to meet the goal of the task, whilst an internal focus of attention promotes a conscious process which is believed to lead to an undesirable breakdown of movements (57,109). To develop functional and adaptive movements, coaches were trained to create mini-games within the lessons, and to utilise and build upon teaching methods such as analogies and questions. These type of activities create an external focus of attention. At the heart of the activity is problem solving that requires functional movements solutions.

The fourth principle is the application of constraints coaching. Constraints are boundaries or features that encourage the development of motor competence. There are three types of constraint: individual, environmental and task (66). The coaches are able to make decisions on what task constraints to manipulate based upon their observations of children's interactions with their environment and using their knowledge of Newell's stages of learning and the STEP framework (66, 108).

The fifth principle is infusing perturbations within the learning process. This means that if the coach observes a child demonstrating a stable and functional motor skill, the coach will act to destabilise the skill by altering task constraints, or changing the task goal. In the snake game used in the gymnastics rolling lesson, the coach will use STEP to create instability in movement by giving children different types of equipment (i.e., different size, shape, weight) to transport across the mat. Changing task constraints will result in new affordances. The coach might also create different types of affordances by manipulating other task constraints depending upon how the child succeeds at the game. These manipulations will be at the coaches' discretion, however it is important that the coach understands that it is acceptable for different children to display different movement solutions to the same task and that regression in skill is inevitable when altering constraints (such as equipment). The coach must also keep in mind that as long as the skill is functional and achieves the outcome of the lesson then it is to be accepted.

To support our coaches to integrate the key principles of nonlinear pedagogy, the coaches were taught to use the DIFFerentiation framework to support the development of motor competence (see Table 1). The Nonlinear Pedagogy PE curriculum was successfully trialled with year 1 children across three primary schools in summer 2016 and was found to be feasible and acceptable to children, teachers and schools (Foulkes et al., in preparation). For an example, of a Nonlinear Pedagogy lesson plan see supplementary material 2.

Control (n = 6 schools)

Control schools will be asked to continue with their usual PE curriculum provision, and timetable and deliver 2 x 60 minute PE lessons per week for 15 weeks. The control schools follow current national curriculum aims for PE in Key Stage 1 (early primary), which state that: *'Pupils should develop fundamental movement skills, become increasingly competent and confident and access a broad range of opportunities to extend their agility, balance and coordination, individually and with others. They should be able to engage in competitive (both against self and against others) and co-operative physical activities, in a range of increasingly challenging situations.'* (19). Information pertaining to the PE curriculum being delivered in control schools will be collected as part of a process evaluation (described later in secondary outcomes).

Outcomes

Trained research assistants will undertake data collection at participating schools across three time-points (see Figure 1). Demographic characteristics including child's age, gender, ethnicity, and home postcode will be collected at baseline through parent consent forms. A number of primary and secondary outcomes are measured through the study.

Primary Outcome

Motor competence

Motor competence will be assessed through a battery of assessments to examine both technical motor proficency and motor creativity across different domains (locomotor, object-control and stability skills). All motor competence assessments will take place during school hours within the school hall or playground and video-recorded for later analysis. Trained research assistants who have established acceptable agreement (80%) in terms of intra-rater and inter-rater reliability with pre-coded videos, will complete analysis of video recordings.

Technical Motor proficiency will be assessed using the Test of Gross Motor Development-3 (TGMD-3 (110,111)), the Test of Stability Skills (112). Specifically, six locomotor (run, gallop, hop, skip, horizontal jump, slide) and seven object-control (two-hand strike, one-hand strike, one-hand dribble, two-hand catch, kick, overhand throw, underhand throw) skills will be assessed using the TGMD-3. Proficiency at stability skills will be assessed using the three tasks (log roll, rock, back support) from within the Test of Stability Skills (112).

The psychometric quality of these assessments has been well established (110,112). Participants will receive a verbal explanation and single demonstration from the assessor and are then given one practice attempt before undertaking two trials of each skill.

Motor creativity will be assessed using the Divergent Movement Ability Assessment (113), which requires children to complete three stations, a stability skill station, a locomotor skill station and object control skill station. In the stability station, children are asked to make as many shapes on or around the bench as they can. In the locomotor station, children are challenged to find as many different ways to move around the obstacle course as possible. Finally, in the object-control skill station, children will be asked to play with a large ball in a designated area, showing all the different skills and ways that they can play with the ball. For every station, children will complete two 90 second trials, during which, every 30 seconds the child will get a predefined prompt from the research assistant to support and encourage the child.

Secondary Outcomes

Physical activity

Participants will be asked to wear a monitor (accelerometer; ActiGraph GT9X, ActiGraph, Pensacloa, FL) on their non-dominant wrist continuously for seven days to measure physical activity at each time point. Participants will be asked to wear their monitors at all times, and to remove them only for water-based activities. Accelerometers will be initialised at a sampling frequency of 30hz. During the monitoring period, children's parents are asked to keep a diary in order to record any times when the monitor is taken off, any activities completed whilst the monitor is removed (e.g. swimming, bathing), and the time the monitor is put back on. A member of the research team will return to the school at the end of the seven-day period to collect the monitors and diaries. Accelerometry data will be used to examine within school, leisure (after-school and weekend), and habitual (total) physical activity levels. Children will be included in the analyses if they have worn the monitor for at least 10 hours per day over three days, including one weekend day. Time spent in sedentary, light, moderate and vigorous activity will be determined using age- and- population-specific raw acceleration cut-points for the wrist-worn ActiGraph, developed through an ongoing research study (114).

Perceived competence

Perceived physical competence (higher order construct) will be assessed using the corresponding subscale within The Pictorial Scale of Perceived Competence and Social Acceptance for Young Children (65). The Physical Competence subscale includes items 3, 7, 11, 15, 19, and 23 from the Pictorial Scale. Each item is scored on a 4-point scale, where 4 represents the highest degree of perceived competence. The subscale score is computed by adding values of child responses and ranges from 6 to 24.

Perceived Skill Competence (lower order construct) will be assessed by the Pictorial Scale of Perceived Movement Skill Competence for Young Children (115). The Scale consists of thirteen items with two subscales of six items each representing "Locomotor Skill Perceived Competence" and "Object-Control Skill Perceived Competence", respectively. Each item is scored on a 4-point scale, where 4 represents the highest degree of perceived competence. Subscale scores are computed by adding values of child responses and range from 6 to 24 (higher values indicate higher perceived competence). All 13 items are summed to generate the Perceived Movement Skill Competence scale score, which ranges from 13 to 52 (higher values indicate higher perceived competence). The Pictorial Scale of Perceived Movement Skill Competence for Young Children is a valid and reliable instrument to assess perceived motor competence in young children (115).

Motivation and Psychological Needs Satisfaction

Self-determined motivation and psychological needs satisfaction are difficult to assess in young children as traditional self-report measures are not appropriate (116). Therefore, following Noonan et al. (117) and Parker, MacPhail, and O'Sullivan (118), we have developed a child friendly and age-appropriate 'draw, write, show and tell' activity to assess self-determined motivation for PE (119). All children in each year 1 class will be asked to draw a picture of "what they like about PE" on one side of a piece of A4 paper and conversely "what they don't like about PE" on the other. A sub-sample of participants will then be chosen randomly (~n=5 per class) to participate in 1:1 ' draw, write, show and tell' activities with a researcher. This random sample will be selected from a pool of research children whom the class teacher has identified as wishing to talk to researchers, and with a sufficient level of English verbal skills to be able to have a conversation with an adult. The 1:1 activities will take place in a quiet open space outside of the classroom (e.g., school library) where the researcher can be overlooked but not overheard and the conversation between the child and researcher will be recorded using a Dictaphone. The 1:1 activities will commence with an icebreaker activity to relax and build rapport between the researcher and child (a PE themed pair-matching card game). The researcher will then ask the child to describe their drawing(s) and ask questions in order to ascertain information about the picture stimulated from its content. This will be followed by a series of activities including the use of resource cards to explore needs satisfaction during PE lessons in relation to (i) relatedness, (ii) competence, and (iii) autonomy. The final activity will involve each child being presented with a picture that represents each level of regulation along the self-determined motivation continuum (64) that is coupled with a stem (e.g., '*I do PE because it is fun'*). Each stem will be read aloud to the child and clarification given if needed. The child will then be asked to pick their favourite reasons for taking part in PE, which they are subsequently asked to rank (first being most important to them, last being least important). Each 1:1 session will last around 15-20 minutes. Audio recordings will be subsequently analysed using a combination of quantitative content analysis and qualitative thematic analysis.

Executive functions

Under the guidance of a trained member of the research team (1:1), in a quiet space outside the classroom (e.g. the library), individual children will be asked to work through three age-appropriate activities from the National Institute for Health (NIH) Toolbox (120) to assess each aspect of executive function. The NIH Toolbox is a comprehensive set of neuro-behavioural measurements that quickly assess cognitive, emotional, sensory, and motor functions from the convenience of an iPad. Each child will complete three cognitive activities lasting 15 minutes in total: inhibitory control is assessed through The Flanker Test (3 mins), cognitive flexibility through the dimension card sort (4 mins), and working memory via a list sorting task (7 mins). The NIH toolbox has well established validity and reliability for use with children aged 3-15 years (121).

Self-regulation

Children’s self-regulation will be assessed using the Strength and Difficulties Questionnaire (SDQ; (122,123)), which will be completed by class teachers for each participating child at each time point. The SDQ is a brief behavioural screening questionnaire consisting of 25 items within 5 subscales (emotional, conduct, hyperactivity, peer and prosocial), and has demonstrated good reliability and validity across several studies (124). There are five items on each subscale with each item scored 0, 1 or 2. Scores therefore range from 0-10 for each subscale, with 10 indicating higher levels of difficulties (emotional, conduct, hyperactivity, peer subscales) or strengths (prosocial subscale) and 0 indicating lower levels. A total difficulties score is also generated by summing scores from all the scales except the prosocial scale, with scores ranging from 0 (low) to 40 (high).

Each child's self-regulation will also be assessed by researchers using the Response to Challenge Scale (RCS: (125,126)). The RCS is an observer-rated measure of children’s responses to challenges in an obstacle course. The course is designed to vary demand and challenge and takes 10-15 minutes to complete in a school hall/outside school playground. The trained observer rates children on 16 items comprising bipolar adjectives (e.g., Vulnerable—Invincible), which are rated on 7-point scales (scored 1-7). Negatively worded items are reversed prior to aggregation, so that possible scores on all items ranged from 1 to 7, with higher scores indicating greater self-regulation. Items are summed to assess self-regulation within three subscales: "Cognitive" (6 items, scoring range from 6 to 42), "Affective" (7 items, scoring range from 7 to 49) and "Physical/Motor" (3 items, scoring range from 3 to 21).

Anthropometrics

Children's height, sitting height, waist and body mass will be measured with an accuracy of 0.1cm and 0.1kg, respectively. Height and sitting height will be assessed with a portable stadiometer (Leicester Height Measure, SECA, Birmingham, UK) and body mass will be assessed using digital scales (Tanita WB100-MA, Tanita Europe, The Netherlands). Waist circumference will be measured around the navel region. Measurements will be taken without shoes and whilst wearing light clothing. Height and weight values will be used to examine weight status through the International Obesity Task Forces's age and sex adjusted body mass index (BMI) growth-reference (127).

Process evaluation

Informed by existing frameworks (128,129), a pragmatic process evaluation design will examine intervention *context* (contextual and environmental aspects within study schools), *reach* (the proportion and demographics of the target audience who received the intervention), *dose* (the amount of intervention delivered and how the participants responded), *fidelity* (whether the intervention was delivered as intended), and *acceptability*. This approach is in keeping with UK Medical Research Council guidance for process evaluation that advocates exploring context, implementation, impact and outcomes (130), and as such involves a wide range of process evaluation methods.

Reach will be assessed using school administrative data on child demographics and school registers. Teachers (control schools) and SAMPLE-PE coaches (intervention schools) will be asked to log the number of PE lessons implemented at each school, and the duration of each PE lesson in minutes to determine *Dose delivered*. Direct observations of PE lessons by researchers and coaches' logs will be used to examine *fidelity* and participant responsiveness

(*Dose received*). Specifically, in each intervention and a subsample of control schools, three lessons from each class (one in every five-week phase of delivery) will be audio- and video-recorded, using a wireless microphone and video camera (situated to capture the whole class and deliverer). Video footage will be captured for approximately 50 lessons, which will subsequently be analysed by trained researchers to assess whether the intervention was delivered as intended (*fidelity*) using developed observation checklists for *Nonlinear* and *Linear* pedagogies, respectively. Intervention fidelity will be confirmed if (i) the Nonlinear pedagogy intervention schools' PE lessons show greater implementation of *Nonlinear* pedagogical principles than *Linear* and control schools PE lessons, and (ii) the reverse is true for Linear pedagogy intervention schools' PE lessons. Video recordings of PE lessons will also be retrospectively coded using established observation checklists to examine SAMPLE-PE coach (intervention schools) and teacher (control schools) behaviours in relation to promoting children's moderate-to-vigorous physical activity (SOFIT+: (131,132) and supporting or thwarting children's psychological needs for relatedness, competence and autonomy (133). Researchers will also record the number of children participating in lessons, and the number of staff present and collect data on the themes and types of activities undertaken within the control group's PE lessons.

Participant responsiveness refers to how responsive participants are to an intervention (134). For the purposes of this process evaluation, we will examine participant responsiveness in terms of children's self-determined motivation and physical activity levels within the observed PE lessons. These variables were chosen as process outcomes to check children's engagement and enjoyment in the PE lessons. Psychological need satisfaction and enjoyment of the PE lesson from a child perspective will be assessed at the end of each observed PE lesson

(15 lessons at each three time points) to examine participant responsiveness in terms of self-determined motivation. Immediately following the lesson, all research children (those within both experimental arms and three control schools) will complete brief measures of relatedness, autonomy and competence need satisfaction on a 1:1 basis with trained researchers. For relatedness, we will look to explore the quantity of social interactions. In line with Sebanc (135), children will be asked by a member of the research team to identify which children within their class they worked with during that lesson from a school class photo list. For competence, children will be asked *how good were you at things during that PE lesson?* This will be measured on a 1-5 star rating scale: 1 being not very good and 5 being very good. For autonomy, children will be asked *did you get to do any choosing during that PE lesson?* The answer format is on a two-layer response where they first choose either 'yes' or 'no.' Depending on their initial response, they will be asked if this is 'sometimes yes' or always yes', or 'sometimes no' or 'always no.' For enjoyment, as children leave the PE lesson, they will be asked to tap on 1 of 3 posters situated on a wall by the exit door displaying an emoji face depicted either as boring, ok or fun. Children's actions will be video recorded by a research assistant. A sub-sample of children (50% of the research participants in each class) will be randomly-selected to wear an Actigraph GT9X+ accelerometer (Actigraph, Pensacloa, FL) on their non-dominant wrist within each PE lesson observation in order to assess *participant responsiveness* in terms of physical activity levels. The time that the teacher commences and ends the lesson will be recorded by a research assistant, and used to calculate the proportion of time children spent in moderate-to-vigorous physical activity.

A qualitative methodology, will be utilised to explore the experiences and perceptions of key stakeholders within intervention schools with regards to *context*, *fidelity*, *implementation*, *impact*, and *acceptability* and *sustainability*. Utilising the interpretivist paradigm, it is recognised that human action and interaction such as PE lessons, is experienced subjectively evaluated through individual meaning making (136). Thus, the effectiveness of an intervention, such as SAMPLE-PE, is inherently linked to the experiences and perceptions of key stakeholders such as teachers. Collecting and analysing these perceptions, through interpretivist qualitative methods is, therefore, an essential part of a process evaluation (137). To that end, qualitative methods are an appropriate methodology to gather data (138).

Through interviews participants will explore: 1) the *fidelity* of the intervention; 2) *implementation* and *impact*; and 3) *acceptability* and *sustainability* of *Linear* and Nonlinear pedagogy intervention curriculums. The sample is purposive in that individuals with the experience of intervention will be recruited. It is also iterative, because as the intervention proceeds, the sample size may increase to include other stakeholders, e.g. teaching assistants. Importantly, the process evaluation not only gathers the experiences and perceptions of stakeholders such as teachers, but a process evaluation can also describe the context in which interventions were experienced. This will be captured through structured interviews with head teachers of intervention schools who are well placed to describe the school as a whole. These interviews will explore school policy, funding, support, equipment, time allocation for PE, and potential for scale-up of the interventions, as well as any other aspects of the complex school environment that may have influenced the intervention and outcomes.

To collect interview data, a combination of skype, face-to-face and email interviews will be utilised. More specifically, participants will be offered the opportunity to share their experiences and perceptions in the format that best enables them to do so. This choice enables participants to exercise their autonomy (139). Structured interview schedules have been developed (supplementary material 3) in order to focus attention on the context, fidelity, implementation, impact, acceptability and sustainability of the intervention across both *Linear* and Nonlinear Pedagogy schools. The use of a structured interview schedule will ensure that interviews will be conducted in a consistent manner regardless of medium, e.g. face-to-face or email. The structured format of the interview schedule will also ensure that any researcher bias is 'managed' in order to maintain equipoise as far as possible (140). Interviews will be transcribed and analysed using thematic analysis (141). To ensure rigour during the data collection and analysis processes, co-researchers will act as critical friends (138). This will involve reviewing the structured interview schedule to identify leading questions, and reviewing coding and themes to ensure verisimilitude with the data.

Data Analysis

Linear-mixed models will be conducted to examine the effects of the SAMPLE-PE intervention on the main outcomes of the study (i.e., motor competence development) to determine short-term (post-intervention) and medium-term (at follow-up) effects of the PE curricula. Separate analyses will be conducted for each outcome measure. Mixed models are used to account for the nested structure of the data. The significance level will be set $p \leq .05$ for all statistical analyses. Regression coefficients for the group variables (with a "0" and "1" dummy coding) will reflect average differences in the outcome variables over time. Potential effects of confounding factors such as sex and age will be examined in the hierarchical linear regression analyses. Mediation analyses will be conducted to examine hypothesised mediating pathways through actual and perceived motor competence, and physical activity behaviour. Attrition analyses comparing children who completed the study and those who dropped out will also be performed. Analyses will be conducted using R and follow an intention-to-treat approach.

Discussion

The Skill Acquisition Methods fostering Physical Literacy in Early-Physical Education (SAMPLE-PE) study aims to examine the efficacy of two different pedagogical approaches to PE Linear or Nonlinear), upon children living in deprived areas. Each approach is informed by motor learning using theories to support learning design and enhance physical literacy as well as providing important insights into the inter-connected nature of physical, affective and cognitive domains. To deliver these pedagogical models effectively, the coaches will need to possess an in-depth knowledge of the respective pedagogy and learning design principles to improve motor competence (79,80). Coaches will receive a comprehensive and extensive training programme from the research team to enable them to deliver the SAMPLE-PE intervention curriculums. A potential limitation to the evaluation is that we do not have the capacity to examine the fidelity of the training, though we will measure the coaches' ability to deliver the interventions in accordance with the corresponding pedagogy via direct observation of sample of PE lessons.

The findings of this study should further develop pedagogical practice, inform learning design within PE, throw new light on how to enhance children's development of movement competence and, more broadly, lead to a better understanding of how to foster physical literacy in the children who need it most. As such, the study could have significant implications for the primary school PE curriculum and for career professional development and training offered to sports coaches and specialist/generalist primary school teachers. Furthermore, the comprehensive mixed methods process evaluation and use of robust outcome measures should provide novel, inter-disciplinary insight into movement competence as a driver of perceived competence, motivation, cognition and physical activity, and extend current knowledge about the effectiveness of PE interventions. The study has therefore the potential to raise standards and the value of PE, and progress to a scaled-up, effectiveness trial involving classroom teachers in the future.

References

1. Whitehead ME. Physical literacy; throughout the lifecourse. - ProQuest [Internet]. Oxford: Routledge; 2010. 230 p. Available from: http://search.proquest.com.proxy.bib.uottawa.ca/docview/733799374?OpenUrlRefId=info:xri/sid:primo&accountid=14701
2. Cairney J, Dudley D, Kwan M, Bulten R, Kriellaars D. Physical Literacy, Physical Activity and Health: Toward an Evidence-Informed Conceptual Model. Sports Med. 2019 Mar;49(3):371–83.
3. Dudley DA. A Conceptual Model of Observed Physical Literacy. Phys Educ [Internet]. 2015;72(504):236–60. Available from: http://js.sagamorepub.com/pe/article/view/6020
4. Bailey R. Sport, physical education and educational worth. Educ Rev [Internet]. 2018 Jan 1;70(1):51–66. Available from: https://doi.org/10.1080/00131911.2018.1403208
5. Marshall J, Hardman K. The State and Status of Physical Education in Schools in International Context. Eur Phys Educ Rev [Internet]. 2000 Oct 1;6(3):203–29. Available from: https://doi.org/10.1177/1356336X000063001
6. OECD. Programme for International Student Assessment [Internet]. 2018 [cited 2018

Oct 10]. Available from: www.OECD.org/pisa/

7. Roberts N. The School Curriculum and SATs in England: Reforms since 2010 [Internet]. London; 2016. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN06798

8. Ward G, Quennerstedt M. Curiosity killed by SATs: an investigation of mathematics lessons within an English primary school. Educ 3-13 [Internet]. 2018 Jan 23;1–16. Available from: https://doi.org/10.1080/03004279.2018.1429479

9. Reid A. Physical Education, Cognition and Agency. Educ Philos Theory [Internet]. 2013 Sep 1;45(9):921–33. Available from: https://doi.org/10.1080/00131857.2013.785357

10. Griggs G. Spending the Primary Physical Education and Sport Premium: a West Midlands case study. Educ 3-13 [Internet]. 2016 Sep 2;44(5):547–55. Available from: https://doi.org/10.1080/03004279.2016.1169485

11. Petrie K, lisahunter. Primary teachers, policy and physical education. Eur Phys Educ Rev [Internet]. 2011 Oct 1;17(3):325–39. Available from: https://doi.org/10.1177/1356336X11416729

12. Whipp PR, Hutton H, Grove JR, Jackson B. Outsourcing physical education in primary schools: Evaluating the impact of externally provided programmes on generalist teachers. Asia-Pacific J Heal Sport Phys Educ [Internet]. 2011 Jun 1;2(2):67–77. Available from: https://doi.org/10.1080/18377122.2011.9730352

13. Harris J, Cale L, Musson H. The predicament of primary physical education: A consequence of “insufficient” ITT and “ineffective” CPD? Phys Educ Sport Pedagog [Internet]. 2012 Sep 1;17(4):367–81. Available from:

https://doi.org/10.1080/17408989.2011.582489

14. Lucas B, Claxton G, Spencer E. Progression in Student Creativity in Schools [Internet]. London; 2013. Available from: http://www.oecd.org/education/ceri/5k4dp59msdwk.pdf

15. EACEA. Education and Training in Europe 2020. Responses from the EU Member States [Internet]. 2013. Available from: https://eacea.ec.europa.eu/national-policies/eurydice/home_en

16. Harris J. The Case for Physical Education becoming a Core Subject in the National Curriculum [Internet]. 2018. Available from: http://www.afpe.org.uk/physical-education/wp-content/uploads/PE-Core-Subject-Paper-20-3-18.pdf

17. Kirk D. Sport education, critical pedagogy, and learning theory: Toward an intrinsic justifi cation for physical education and youth sport. Quest [Internet]. 2006 May 1;58(2):255–64. Available from: https://doi.org/10.1080/00336297.2006.10491882

18. Kirk D. What Is the Future for Physical Education. In: Cape S, Whitehead M, editors. Debates in physical education. London: Routledge; 2012. p. 220–31.

19. Department for Education. The National Curriculum Key Stages 1 and 2. 2013.

20. UNESCO. Quality Physical Education [Internet]. Paris; 2015. Available from: http://unesdoc.unesco.org/images/0023/002311/231101E.pdf

21. Australian Curriculum Assessment and Reporting Authority. The Shape of the Ausralian Curriculum: Health and Physical Education. Canberra; 2012.

22. Play for Life. Canada's Physical Literacy Consensus Statement [Internet]. Sport for Life. 2015 [cited 2018 Dec 14]. Available from: http://physicalliteracy.ca/physical-literacy/consensus-statement/

23. ShapeAmerica. Grade-level outcomes for K-12 physical education. Reston, VA. 2013.

24. Keegan R, Barnett L, Dudley D. The Australian Physical Literacy Standard. Canberra; 2017.

25. Sport Enland. Primary School Physical Literacy Framework [Internet]. 2013 [cited 2018 Dec 14]. Available from: https://www.sportengland.org/news-and-features/news/2013/november/15/primary-school-physical-literacy-framework/

26. Giblin S, Collins D, Button C. Physical Literacy: Importance, Assessment and Future Directions. Sport Med [Internet]. 2014 Sep;44(9):1177–84. Available from: https://doi.org/10.1007/s40279-014-0205-7

27. Hulteen RM, Morgan PJ, Barnett LM, Stodden DF, Lubans DR. Development of foundational movement skills: A conceptual model for physical activity across the lifespan. Sport Med. 2018;48(7):1533–40.

28. Bardid F, Utesch T. Motor Competence. In: Hackfort D, Schinke R, Strauss B, editors. Dictionary of Sport Psychology [Internet]. 1st Editio. Elsevier; Available from: https://www.elsevier.com/books/dictionary-of-sport-psychology/hackfort/978-0-12-813150-3

29. Orth D, van der Kamp J, Memmert D, Savelsbergh GJP. Creative Motor Actions As Emerging from Movement Variability [Internet]. Vol. 8, Frontiers in Psychology . 2017. p. 1903. Available from: https://www.frontiersin.org/article/10.3389/fpsyg.2017.01903

30. Ng, Jonathan Leo, Button, Chris. Reconsidering the fundamental movement skills construct: Implications for assessment. Mov Sport Sci/Sci Mot [Internet]. 2019; Available from: https://doi.org/10.1051/sm/2018025

31. Beni S, Fletcher T, Ní Chróinín D. Meaningful Experiences in Physical Education and Youth Sport: A Review of the Literature. Quest [Internet]. 2017 Jul 3;69(3):291–312. Available from: https://doi.org/10.1080/00336297.2016.1224192

32. Roberts WM, Newcombe DJ, Davids K. Application of a constraints-led approach to pedagogy in schools: embarking on a journey to nurture physical literacy in primary physical education. Phys Educ Sport Pedagog [Internet]. 2018 Dec 6;1–14. Available from: https://doi.org/10.1080/17408989.2018.1552675

33. Bardid F, Rudd JR, Lenoir M, Polman R, Barnett LM. Cross-cultural comparison of motor competence in children from Australia and Belgium. Front Psychol [Internet]. 2015;6:964. Available from: http://journal.frontiersin.org/Article/10.3389/fpsyg.2015.00964/abstract

34. Foulkes JD, Knowles Z, Fairclough SJ, Stratton G, O’Dwyer M, Ridgers ND, et al. Fundamental Movement Skills of Preschool Children in Northwest England. Percept Mot Skills [Internet]. 2015 Aug 1;121(1):260–83. Available from: http://journals.sagepub.com/doi/10.2466/10.25.PMS.121c14x0

35. Morley D, Till K, Ogilvie P, Turner G. Influence of gender and socioeconomic status on the motor proficiency of children in the UK. Hum Mov Sci [Internet]. 2015;44:150–6. Available from: http://www.sciencedirect.com/science/article/pii/S0167945715300312

36. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents: Review of associated health benefits. Sport Med. 2010 Dec;40(12):1019–35.

37. D’Hondt E, Deforche B, Gentier I, Verstuyf J, Vaeyens R, De Bourdeaudhuij I, et al.

A longitudinal study of gross motor coordination and weight status in children. Obesity (Silver Spring). 2014 Jun;22(6):1505–11.

38. McWhannell N, Foweather L, Graves EL, Henaghan LJ, Ridgers DN, Stratton G. From Surveillance to Intervention: Overview and Baseline Findings for the Active City of Liverpool Active Schools and SportsLinx (A-CLASS) Project. Vol. 15, International Journal of Environmental Research and Public Health . 2018.

39. Duncan MJ, Jones V, O'Brien W, Barnett LM, Eyre ELJ. Self-Perceived and Actual Motor Competence in Young British Children. Percept Mot Skills. 2018 Apr;125(2):251–64.

40. Barnett LM, Morgan PJ, Van Beurden E, Ball K, Lubans DR. A reverse pathway? Actual and perceived skill proficiency and physical activity. Med Sci Sports Exerc. 2011 May;43(5):898–904.

41. Liong GHE, Ridgers ND, Barnett LM. Associations between skill perceptions and young children's actual fundamental movement skills. Percept Mot Skills. 2015 Apr;120(2):591–603.

42. van der Fels IMJ, te Wierike SCM, Hartman E, Elferink-Gemser MT, Smith J, Visscher C. The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. J Sci Med Sport [Internet]. 2015;18(6):697–703. Available from: http://www.sciencedirect.com/science/article/pii/S1440244014001777

43. Oppici L, Rudd J, Buszard T, Spittle S. Efficacy of a 7-week dance (RCT) PE curriculum with different teaching pedagogies and levels of cognitive challenge to improve working memory capacity and motor competence in 8-10 years old children.

Psychol Sport Exerc.

44. Leonard HC, Hill EL. Review: The impact of motor development on typical and atypical social cognition and language: a systematic review. Child Adolesc Ment Health [Internet]. 2014 Feb 8;19(3):163–70. Available from: https://doi.org/10.1111/camh.12055

45. Paas F, Sweller J. An Evolutionary Upgrade of Cognitive Load Theory: Using the Human Motor System and Collaboration to Support the Learning of Complex Cognitive Tasks. Educ Psychol Rev [Internet]. 2012;24(1):27–45. Available from: https://doi.org/10.1007/s10648-011-9179-2

46. Holfelder B, Schott N. Relationship of fundamental movement skills and physical activity in children and adolescents: A systematic review. Psychol Sport Exerc [Internet]. 2014;15(4):382–91. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84898933670&partnerID=40&md5=39b8d88a28e27a58d1429a093bc0704a

47. Cohen KE, Morgan PJ, Plotnikoff RC, Barnett LM, Lubans DR. Improvements in fundamental movement skill competency mediate the effect of the SCORES intervention on physical activity and cardiorespiratory fitness in children. J Sports Sci. 2015;33(18):1908–18.

48. Lai SK, Costigan SA, Morgan PJ, Lubans DR, Stodden DF, Salmon J, et al. Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. Sports Med. 2014 Jan;44(1):67–79.

49. Foweather L, Knowles Z, Ridgers ND, O'Dwyer M V, Foulkes JD, Stratton G. Fundamental movement skills in relation to weekday and weekend physical activity in preschool children. J Sci Med Sport [Internet]. 2015 Nov 1;18(6):691–6. Available from: http://dx.doi.org/10.1016/j.jsams.2014.09.014

50. Tompsett C, Sanders R, Taylor C, Cobley S. Pedagogical Approaches to and Effects of Fundamental Movement Skill Interventions on Health Outcomes: A Systematic Review. Sport Med. 2017 Sep;47(9):1795–819.

51. Robinson LE, Stodden DF, Barnett LM, Lopes VP, Logan SW, Rodrigues LP, et al. Motor Competence and its Effect on Positive Developmental Trajectories of Health. Sport Med. 2015;45(9):1273–84.

52. Bailey R. Physical education and sport in schools: a review of benefits and outcomes. J Sch Health. 2006 Oct;76(8):397–401.

53. EUPEA. DECLARATION OF MADRID / AMSTERDAM [Internet]. 2009. Available from: http://www.apep.lu/old/docs/EUPEA/DeclMadridAmsterdam.pdf

54. Wick K, Leeger-Aschmann CS, Monn ND, Radtke T, Ott L V, Rebholz CE, et al. Interventions to Promote Fundamental Movement Skills in Childcare and Kindergarten: A Systematic Review and Meta-Analysis. Sports Med. 2017 Oct;47(10):2045–68.

55. Morgan PJ, Barnett LM, Cliff DP, Okely AD, Scott HA, Cohen KE, et al. Fundamental Movement Skill Interventions in Youth: A Systematic Review and Meta-analysis. Pediatrics [Internet]. 2013 Oct 28;132(5):e1361–83. Available from: http://pediatrics.aappublications.org/cgi/doi/10.1542/peds.2013-1167

56. Cohen KE, Morgan PJ, Plotnikoff RC, Callister R, Lubans DR. Physical activity and

skills intervention: SCORES cluster randomized controlled trial. Med Sci Sports Exerc. 2015 Apr;47(4):765–74.

57. Chow JY, Davids K, Button C, Renshaw I. Nonlinear Pedagogy in Skill Acquisition: An Introduction. Abingdon: Routledge; 2016.

58. Schmidt R, Lee T, Winstein C, Wulf G, Zelaznik H. Motor Control and Learning. Human kinetics; 2018.

59. Ennis C. Handbook of Physical Education Pedagogies [Internet]. Ennis C, editor. Routledge; 2018. Available from: https://www.routledge.com/Routledge-Handbook-of-Physical-Education-Pedagogies/Ennis-Armour-Chen-Garn-Mauerberg-deCastro-Penney-Silverman-Solmon-Tinning/p/book/9781138820999

60. Fitts P, Posner M. Human performance. [Internet]. Human performance. Oxford, England: Brooks/Cole; 1967. Available from: http://psycnet.apa.org/record/1967-35040-000

61. Metzler M. Instructional Models in Physical Education. New York: Routledge; 2011.

62. Oslin J, Mitchell S. Game-Centered Approaches to Teaching Physical Education. In: Kirk D, Macdonald D, O'sullivan M, editors. Handbook of Physical Education [Internet]. SAGE Publications; 2006. Available from: http://sk.sagepub.com/reference/hdbk_physed

63. Blomqvist M, Luhtanen P, Laakso 1 L. Comparison of Two Types of Instruction in Badminton. Eur J Phys Educ [Internet]. 2001 Jan 1;6(2):139–55. Available from: https://doi.org/10.1080/1740898010060206

64. Ryan RM, Deci EL. Intrinsic and extrinsic motivations: Classic definitions and new directions. Contemp Educ Psychol. 2000;25(1):54–67.

65. Harter S, Pike R. The pictorial scale of perceived competence and social acceptance for young children. Child Dev. 1984;1969–82.

66. Pesce C, Croce R, Ben-Soussan TD, Vazou S, McCullick B, Tomporowski PD, et al. Variability of practice as an interface between motor and cognitive development. Int J Sport Exerc Psychol [Internet]. 2016 Aug 19;1–20. Available from: https://doi.org/10.1080/1612197X.2016.1223421

67. Deák GO, Wiseheart M. Cognitive flexibility in young children: General or task-specific capacity? J Exp Child Psychol. 2015;138:31–53.

68. Chow JY, Davids K, Button C, Shuttleworth R, Renshaw I, Araújo D. The Role of Nonlinear Pedagogy in Physical Education. Rev Educ Res [Internet]. 2007 Sep 1;77(3):251–78. Available from: https://doi.org/10.3102/003465430305615

69. Gibson J. The ecological approach to visual perception. Boston: Houghton Mifflin; 1979.

70. Bernstein NA. The co-ordination and regulation of movements. Oxford: Pergamon; 1967.

71. Newell K. Constraints in the Development of Coordination. In: Wade MG, Whiting HT., editors. Motor Development in Children: Aspects of Coordination and Control [Internet]. Martinus Nijhoff: Dordrecht; 1986. Available from: http://dx.doi.org/10.1007/978-94-009-4460-2_19

72. Chow JY, Davids K, Hristovski R, Araújo D, Passos P. Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. New Ideas Psychol. 2011;29(2):189–200.

73. Jenkins S. Dynamics of Skill Acquisition: A Constraints-Led Approach. Vol. 3,

International Journal of Sports Science and Coaching. Champaign, IL: Human Kinetics; 2009. 147-151 p.

74. Bailey R, Pickard A. Body learning: Examining the processes of skill learning in dance. Sport Educ Soc [Internet]. 2010 Aug 1;15(3):367–82. Available from: https://doi.org/10.1080/13573322.2010.493317

75. Profeta VLS, Turvey MT. Bernstein’s levels of movement construction: A contemporary perspective. Hum Mov Sci. 2018 Feb;57:111–33.

76. Tan CWK, Chow JY, Davids K. “How does TGfU work?”: Examining the relationship between learning design in TGfU and a nonlinear pedagogy. Phys Educ Sport Pedagog [Internet]. 2012 Sep 1;17(4):331–48. Available from: https://doi.org/10.1080/17408989.2011.582486

77. Mosston M, Ashworth S. Teaching Physical Education. Spectr Inst Teach Learn. 2008;378.

78. Chow JY. Nonlinear Learning Underpinning Pedagogy: Evidence, Challenges, and Implications. Quest [Internet]. 2013 Oct 1;65(4):469–84. Available from: https://doi.org/10.1080/00336297.2013.807746

79. Greenwood D, Davids K, Renshaw I. How Elite Coaches’ Experiential Knowledge Might Enhance Empirical Research on Sport Performance: A Response to Commentary. Int J Sports Sci Coach [Internet]. 2012 Jun 1;7(2):427–9. Available from: http://journals.sagepub.com/doi/10.1260/1747-9541.7.2.427

80. Harter S. Effectance motivation reconsidered. Toward a developmental model. Hum Dev. 1978;21(1):34–64.

81. Lee MCY, Chow JY, Button C, Tan CWK. Nonlinear Pedagogy and its role in

encouraging twenty-first century competencies through physical education: a Singapore experience. Asia Pacific J Educ [Internet]. 2017 Oct 2;37(4):483–99. Available from: https://doi.org/10.1080/02188791.2017.1386089

82. Ryan RM, Deci L E. Self-determination theory: basic psychological needs in motivation. New York: Guildford Press; 2017.

83. Moy B, Renshaw I, Davids K. The impact of nonlinear pedagogy on physical education teacher education students’ intrinsic motivation. Phys Educ Sport Pedagog [Internet]. 2016 Sep 2;21(5):517–38. Available from: https://doi.org/10.1080/17408989.2015.1072506

84. Diamond A, Ling DS. Aerobic-Exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. Dev Cogn Neurosci. 2019 Jun;37:100572.

85. Chow JY, Atencio M. Complex and nonlinear pedagogy and the implications for physical education. Sport Educ Soc [Internet]. 2014 Nov 17;19(8):1034–54. Available from: https://doi.org/10.1080/13573322.2012.728528

86. Renshaw I, Chow JY, Davids K, Hammond J. A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? Phys Educ Sport Pedagog [Internet]. 2010 Apr 1;15(2):117–37. Available from: https://doi.org/10.1080/17408980902791586

87. Miller A, Christensen E, Eather N, Gray S, Sproule J, Keay J, et al. Can physical education and physical activity outcomes be developed simultaneously using a game-centered approach? Eur Phys Educ Rev [Internet]. 2015 Jul 13;22(1):113–33. Available from: https://doi.org/10.1177/1356336X15594548

88. Lee MCY, Chow JY, Komar J, Tan CWK, Button C. Nonlinear pedagogy: An effective approach to cater for individual differences in learning a sports skill. PLoS One [Internet]. 2014 Aug 20;9(8):e104744. Available from: https://doi.org/10.1371/journal.pone.0104744

89. Alvarez-Bueno C, Pesce C, Cavero-Redondo I, Sanchez-Lopez M, Martinez-Hortelano JA, Martinez-Vizcaino V. The Effect of Physical Activity Interventions on Children's Cognition and Metacognition: A Systematic Review and Meta-Analysis. J Am Acad Child Adolesc Psychiatry. 2017 Sep;56(9):729–38.

90. Vazou S, Pesce C, Lakes K, Smiley-Oyen A. More than one road leads to Rome: A narrative review and meta-analysis of physical activity intervention effects on cognition in youth. Int J Sport Exerc Psychol [Internet]. 2016 Sep 17;1–26. Available from: https://doi.org/10.1080/1612197X.2016.1223423

91. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, et al. Physical Activity for Cognitive and Mental Health in Youth: A Systematic Review of Mechanisms. Pediatrics. 2016 Sep;138(3).

92. Pesce C, Masci I, Marchetti R, Vazou S, Sääkslahti A, Tomporowski PD. Deliberate Play and Preparation Jointly Benefit Motor and Cognitive Development: Mediated and Moderated Effects. Front Psychol [Internet]. 2016 Mar 11;7:349. Available from: https://www.ncbi.nlm.nih.gov/pubmed/27014155

93. Stodden DF, Goodway JD, Langendorfer SJ, Roberton MA, Rudisill ME, Garcia C, et al. A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. Quest [Internet]. 2008 May 1;60(2):290–306. Available from:

http://www.tandfonline.com/doi/abs/10.1080/00336297.2008.10483582

94. Rudd JR, Barnett LM, Farrow D, Berry J, Borkoles E, Polman R. Effectiveness of a 16 week gymnastics curriculum at developing movement competence in children. J Sci Med Sport. 2017;20(2):164–9.

95. Lubans DR, Smith JJ, Peralta LR, Plotnikoff RC, Okely AD, Salmon J, et al. A school-based intervention incorporating smartphone technology to improve health-related fitness among adolescents: rationale and study protocol for the NEAT and ATLAS 2.0 cluster randomised controlled trial and dissemination study. BMJ Open [Internet]. 2016 Jun 1;6(6). Available from: http://bmjopen.bmj.com/content/6/6/e010448.abstract

96. Gov.UK. English Indices of Deprivation [Internet]. Ministy of Housing, Communities & Local Government. 2015 [cited 2018 Oct 10]. Available from: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015

97. Morgan PJ, Hansen V. Classroom Teachers' Perceptions of the Impact of Barriers to Teaching Physical Education on the Quality of Physical Education Programs. Res Q Exerc Sport [Internet]. 2008 Dec 1;79(4):506–16. Available from: https://doi.org/10.1080/02701367.2008.10599517

98. Roberts SJ, Rudd. J, Reeves M. Efficacy of using nonlinear pedagogy to support attacking players' individual learning objectives in elite-youth football: A randomised cross-over trial. J Sports Sci. 2019;

99. Gibbs. Learning by Doing: A guide to teaching and learning methods. Oxford, England: Polytechnic; 1988.

100. Schmidt R, Wrisberg C. Motor Learning and Performance: A situational-based

Learning Approach. 4th ed. Champaign, IL: Human Kinetics; 2008.

101. Gentile AM. Skill acquisition: Action, movement, and neuromotor processes. In: Carr J., Shepard J., editors. Movement science: Foundations for physical therapy in rehabilitation. Rockville, MD: Aspen; 2000. p. 111–87.

102. Guadagnoll MA, Lee TD. Challenge Point: A Framework for Conceptualizing the Effects of Various Practice Conditions in Motor Learning. J Mot Behav [Internet]. 2004 Jul 1;36(2):212–24. Available from: https://doi.org/10.3200/JMBR.36.2.212-224

103. Hayes SJ, Ashford D, Bennett SJ. Goal-directed imitation: The means to an end. Acta Psychol (Amst) [Internet]. 2008;127(2):407–15. Available from: http://www.sciencedirect.com/science/article/pii/S0001691807000790

104. Sweeting T, Rink JE. Effects of Direct Instruction and Environmentally Designed Instruction on the Process and Product Characteristics of a Fundamental Skill. J Teach Phys Educ [Internet]. 1999 Jan 1;18(2):216–33. Available from: https://doi.org/10.1123/jtpe.18.2.216

105. Wulf G. Attentional focus and motor learning: A review of 15 years. Int Rev Sport Exerc Psychol [Internet]. 2013 Sep 1;6(1):77–104. Available from: https://doi.org/10.1080/1750984X.2012.723728

106. Beilock SL, Carr TH, MacMahon C, Starkes JL. When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. J Exp Psychol Appl. 2002 Mar;8(1):6–16.

107. Trust YS. YST TOP PE [Internet]. 2018 [cited 2018 Oct 10]. Available from: https://www.youthsporttrust.org/TOPPE

108. Headrick J, Renshaw I, Davids K, Pinder RA, Araújo D. The dynamics of expertise acquisition in sport: The role of affective learning design. Psychol Sport Exerc. 2015;16:83–90.

109. Wulf G. Attention and Motor Skill Learning. Vol. 2, International Journal of Sports Science and Coaching. Champaign, IL: Human Kinetics; 2007. 329-334 p.

110. Ulrich DA. The Test of Gross Motor Development - 3 (TGMD-3): Administration, scoring, and international norms. Spor Bilim Derg Hacettepe J Sport Sci [Internet]. 2013;24(24):27–33. Available from: http://dergipark.ulakbim.gov.tr/sbd/article/viewFile/5000092253/5000085728#page=35

111. Webster EK, Ulrich DA. Evaluation of the psychometric properties of the Test of Gross Motor Development—third edition. J Mot Learn Dev. 2017;5(1):45–58.

112. Rudd JR, Barnett LM, Butson ML, Farrow D, Berry J, Polman RCJ. Fundamental movement skills are more than run, throw and catch: The role of stability skills. PLoS One. 2015;10(10).

113. Cleland FE, Gallahue DL. Young children's divergent movement ability. Percept Mot Skills. 1993 Oct;77(2):535–44.

114. Crotti M, Foweather L, Rudd. J, Schwarz S, Hurter L, Utesch T, et al. Calibration of wrist-worn accelerometers raw acceleration thresholds for the assessment of physical activity in 5-8 year old children. Unpublished.

115. Barnett LM, Ridgers ND, Zask A, Salmon J. Face validity and reliability of a pictorial instrument for assessing fundamental movement skill perceived competence in young children. J Sci Med Sport. 2015;18(1):98–102.

116. Sebire SJ, Jago R, Fox KR, Edwards MJ, Thompson JL. Testing a self-determination theory model of children's physical activity motivation: a cross-sectional study. Int J Behav Nutr Phys Act [Internet]. 2013 Sep;10(1):111. Available from: https://doi.org/10.1186/1479-5868-10-111

117. Noonan RJ, Boddy LM, Fairclough SJ, Knowles ZR. Write, draw, show, and tell: a child-centred dual methodology to explore perceptions of out-of-school physical activity. BMC Public Health. 2016 Apr;16:326.

118. Parker M, MacPhail A, O'Sullivan M, Ní Chróinín D, McEvoy E. 'Drawing' conclusions: Irish primary school children's understanding of physical education and physical activity opportunities outside of school. Eur Phys Educ Rev [Internet]. 2017 Apr 12;24(4):449–66. Available from: https://doi.org/10.1177/1356336X16683898

119. Fitton-Davies K, Rudd J, Watson P., Bardid F, Knowles Z, Roberts S, et al. A qualitative method to explore young children's motivation for physical education using self-determination theory. Unpublished.

120. Gershon RC, Cella D, Fox NA, Havlik RJ, Hendrie HC, Wagster M V. Assessment of neurological and behavioural function: the NIH Toolbox. Lancet Neurol [Internet]. 2010 Feb 1;9(2):138–9. Available from: https://doi.org/10.1016/S1474-4422(09)70335-7

121. Weintraub S, Dikmen SS, Heaton RK, Tulsky DS, Zelazo PD, Bauer PJ, et al. Cognition assessment using the NIH Toolbox. Neurology. 2013 Mar;80(11 Suppl 3):S54-64.

122. Goodman R. The Strengths and Difficulties Questionnaire: A Research Note. J Child Psychol Psychiatry [Internet]. 2006 Dec 7;38(5):581–6. Available from:

https://doi.org/10.1111/j.1469-7610.1997.tb01545.x

123. Stone LL, Otten R, Engels RCME, Vermulst AA, Janssens JMAM. Psychometric Properties of the Parent and Teacher Versions of the Strengths and Difficulties Questionnaire for 4- to 12-Year-Olds: A Review. Clin Child Fam Psychol Rev [Internet]. 2010 Sep 30;13(3):254–74. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2919684/

124. Essau CA, Olaya B, Anastassiou-Hadjicharalambous X, Pauli G, Gilvarry C, Bray D, et al. Psychometric properties of the Strength and Difficulties Questionnaire from five European countries. Int J Methods Psychiatr Res. 2012 Sep;21(3):232–45.

125. Lakes KD. The Response to Challenge Scale (RCS): The Development and Construct Validity of an Observer-Rated Measure of Children's Self-Regulation. Int J Educ Psychol Assess [Internet]. 2012 Apr;10(1):83–96. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4349369/

126. Lakes KD. Measuring self-regulation in a physically active context: Psychometric analyses of scores derived from an observer-rated measure of self-regulation. Ment Health Phys Act [Internet]. 2013 Oct;8(3):189–96. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4348026/

127. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ. 2000 May;320(7244):1240–3.

128. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. Am J Public Health. 1999 Sep;89(9):1322–7.

129. Linnan L, Steckler A. Process evaluation for public health interventions and research. Jossey-Bass San Francisco; 2002.

130. Moore GF, Audrey S, Barker M, Bond L, Bonell C, Hardeman W, et al. Process evaluation of complex interventions: Medical Research Council guidance. bmj. 2015;350:h1258.

131. Weaver RG, Webster CA, Erwin H, Beighle A, Beets MW, Choukroun H, et al. Modifying the System for Observing Fitness Instruction Time to Measure Teacher Practices Related to Physical Activity Promotion: SOFIT+. Meas Phys Educ Exerc Sci [Internet]. 2016 Apr 2;20(2):121–30. Available from: https://doi.org/10.1080/1091367X.2016.1159208

132. Fairclough SJ, Weaver RG, Johnson S, Rawlinson J. Validation of an observation tool to assess physical activity-promoting physical education lessons in high schools: SOFIT. J Sci Med Sport. 2018 May;21(5):495–500.

133. Haerens L, Aelterman N, Van den Berghe L, De Meyer J, Soenens B, Vansteenkiste M. Observing Physical Education Teachers' Need-Supportive Interactions in Classroom Settings. J Sport Exerc Psychol [Internet]. 2013 Feb 1;35(1):3–17. Available from: https://doi.org/10.1123/jsep.35.1.3

134. Durlak JA, DuPre EP. Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. Am J Community Psychol. 2008 Jun;41(3–4):327–50.

135. Sebanc AM. The Friendship Features of Preschool Children: Links with Prosocial Behavior and Aggression. Soc Dev [Internet]. 2003 Apr 28;12(2):249–68. Available from: https://doi.org/10.1111/1467-9507.00232

136. McKenzie GW, Powell J, Usher R. Understanding social research: Perspectives on methodology and practice. Psychology Press; 1997.

137. Cheng KKF, Metcalfe A. Qualitative Methods and Process Evaluation in Clinical Trials Context: Where to Head to? Int J Qual Methods [Internet]. 2018 Apr 30;17(1):1609406918774212. Available from: https://doi.org/10.1177/1609406918774212

138. Smith B, McGannon KR. Developing rigor in qualitative research: problems and opportunities within sport and exercise psychology. Int Rev Sport Exerc Psychol [Internet]. 2018 Jan 1;11(1):101–21. Available from: https://doi.org/10.1080/1750984X.2017.1317357

139. Orb A, Eisenhauer L, Wynaden D. Ethics in Qualitative Research. J Nurs Scholarsh [Internet]. 2004 Apr 23;33(1):93–6. Available from: https://doi.org/10.1111/j.1547-5069.2001.00093.x

140. Eborall HC, Dallosso HM, Daly H, Martin-Stacey L, Heller SR. The face of equipoise--delivering a structured education programme within a randomized controlled trial: qualitative study. Trials. 2014 Jan;15:15.

141. Clarke V, Braun V. Teaching thematic analysis: Over- coming challenges and developing strategies for effective learning. Psychologist [Internet]. 2013;26(2):120–3. Available from: http://eprints.uwe.ac.uk/21155

List of abbreviations

EUPEA: European Physical Education Association

NIH: National Institute for Health

OECD: Organisation for Economic Co-operation and Development

PE: Physical Education

RCS: Response to Challenge Scale

SAMPLE-PE: Skill Acquisition Methods fostering Physical Literacy in Early - Physical Education

SDQ: Strengths and Difficulties Questionnaire

STEP: Space, Task, Equipment, People

RCT: Randomised Controlled Trial

TGMD-3: Test of Gross Motor Development Third Edition

UNESCO: United Nations Educational, Scientific and Cultural Organisation

Declarations

Ethics approval and consent to participate

This study was approved by Liverpool John Moores University Research Ethics Committee (ref: 17/SPS/017). All study participants are required to provide written informed consent. Parental and legal consent will be obtained for all children participating in the study.

Consent for publication

Not applicable.

Availability of data and materials

The two principle investigators (JR and LF) will have access to the final trial dataset

The datasets used and/or analysed during the current study will be available from the principal investigators (JR, LF) on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was funded by Liverpool John Moores University. The funding commissioners were not involved in the design of the study and will not be involved in data collection and analysis, interpretation of data, or in writing the manuscript.

Authors' contributions

JR and LF conceived the study. All authors (JR, LF, MC, KFD, LOC, FB. TU, SR, LB, BW, CC, ZK, PW, CB, DL, CP, TB, JF) were involved in the design of the study protocol and assisted with the drafting and revising of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

We would like to thank Tom Eisenhuth, Rachael Grace, Sebastian Schwarz and Aina Cid Centelles, Michelle Gorlani for support with data collection procedures.

Table 1: DIFFerentiation Framework used to support coaches teaching behaviours

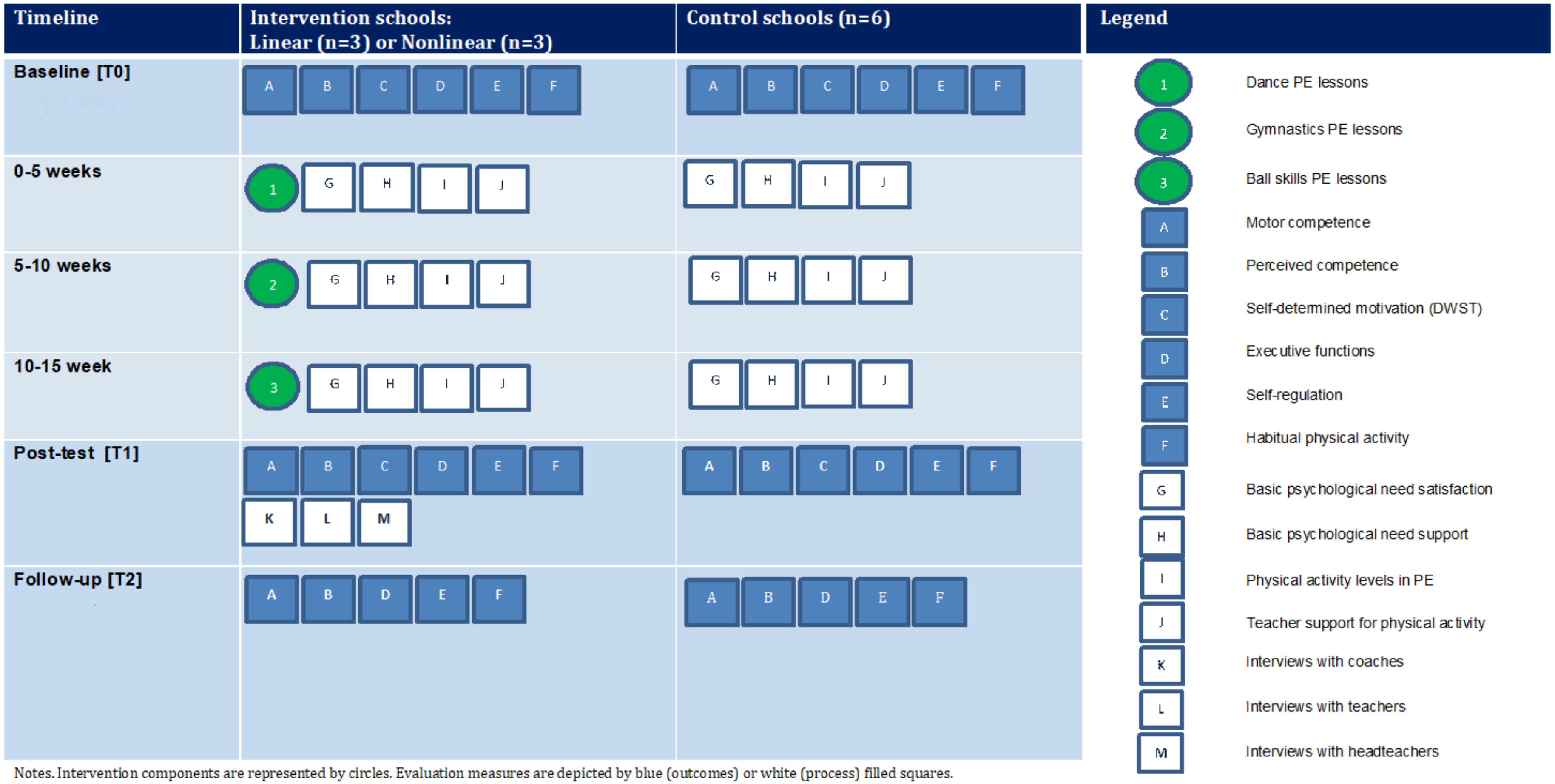
Figure 1: Schematic overview of SAMPLE-PE study design and evaluation components

Figure 2: SPIRIT participant timeline

Linear Pedagogy			Non- Linear Pedagogy		
General Assumptions (‘DIFFerentitaion’)	**High Motor Competence Children**	**Low Motor Competence Children**	**General Assumptions (‘DIFFerentitaion’)**	**High Motor Competence Children**	**Low Motor Competence Children**
Demonstration **Isolated demonstrations of a motor skill by an adult or competent child is to be promoted as it offers a unique opportunity for learners to gather information about appropriate coordination patterns which could benefit performance.** (145)	Demonstration provided after practice of a task lead to stronger retention of learning than demonstration prior practice (147). (refer to frequency to see how often this should be used as a coaches tool)	Demonstration of a skill by an individual presenting high proficiency is beneficial for motor learning. (148)	**Demonstration** **Adult demonstration is avoided as NLP encourages more than one optimal way to move in a functional manner** (150)	No demonstration is given as NLP suggests that it is more or less redundant as they are at the level where further demonstration will no longer provide them with useful information. (60)	A few highly competent children to demonstrate the movement in context so that the observing moderate to low competent children can see what they could do within their own movement. (60)
Instruction **The use of instruction should have both an internal (skill focus) and external focus of attention is allowed.** (107,111)	Verbal instructions should focus on movement outcomes rather than on the movements required by the task. (151) Verbal instructions could be used to focus on specific performance goals e.g. speed-accuracy. (152)	A skill focus instruction is encourage to support early acquisition of the skill as it has been found to be more effective in skill execution. (107) Verbal cues should be provided to learners along with a demonstration to support visual information. (153)	**Instruction** **The use of instruction is not encouraged if it is needed it should be short and not be prescriptive. Instead coaches were encouraged create games, scenarios and to manipulate task constraints to promote skills being learnt implicitly.**	Use of questioning and external focus as it allows children to problem solve towards a movement solution. (60) Coach use STEP framework to manipulate task constraints	If the child has no previous experience of the motor skill, the use of analogies can help as it chunks a large amount of information together that frees up mental capacity providing an external focus of attention. (60)
Feedback and Frequency **Feedback is a powerful tool in the coaches toolbox and should be used at the coaches discretion based on their judgement of a child’s motor competence.**	Feedback should be provided only when error are large enough to warrant attention. (154)	Providing verbal feedback after each trial or as much as possible during early stages of acquisition is a priority (155)	**Feedback and Frequency** **Feedback should focus on children finding different movement solutions. Feedback is kept to a minimum and only used when children get stuck or**	Augmented feedback should only be given if they miss the mark. If they achieve the desired outcome, feedback is not necessary. (157)	Feedback should never be corrective. The coaches feedback should be minimal and if used should promote an external focus of attention. As with instructions

Feedback can either take the shape of knowledge of results or knowledge of performance (154, 155,156).		Practitioner should identify the component of the skills that needs to be learned, determine which is most critical for learning and prioritise feedback about the critical component of the task though this should not happen after every trial. (156)	**to create instability in movement pattern.**	Instead coaches should utilise STEP framework to manipulate task constraints	analogies can be useful to support learning. Coaches can also utilise STEP framework to manipulate task constraints (60).

Figure 1: Schematic overview of SAMPLE-PE study design and evaluation components



Notes. Intervention components are represented by circles. Evaluation measures are depicted by blue (outcomes) or white (process) filled squares. Different components are labelled with different numbers or letters (see Legend). Process evaluation measures G-J are completed for 1 lesson per five week PE lesson block within all intervention schools and 3/6 control schools. PE = Physical Education, DWST = Draw, write, show and tell method.

Figure 2: SPIRIT participant timeline